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Integrated Policy Strategies and Regional Policy Coordination for Resilient, Green and Transformative Development: Supporting Selected Asian BRI Partner Countries to Achieve 2030 Sustainable Development Agenda

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Micro-sectoral study on Plastics: Greening Challenges and Environmental Impact

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Introduction

Plastics industry is a large manufacturing industry comprising more than 11,000 processing units across the country. Though plastic is either bio-based or synthetic, the manufacturing sector in Pakistan largely comprises of synthetic plastic producers. Plastic being a cheap raw material, lightweight and pliable is widely used across various sectors, packaging materials. , household items, construction materials, and other commercial use items. The various types of plastic as per the polymer type are mentioned in table 1. The environmental impact of each plastic varies across the life-cycle. Hence, this sectoral analysis of the greening status of plastic processing in Pakistan prioritizes three major categories Polyethylene Terephthalate (PET), Polystyrene (PS) and Polyvinyl Chloride (PVC). The plastic kitchenware is taken up in a separate study under this project due differential use and manufacturing processes.

2. Current Situation and Trend

As per a study by the WWF Pakistan, Pakistan has the second largest domestic market for Plastics after India with a growth rate of 15% per annum (WWF-Pakistan). The total production capacity of Pakistan's plastic industry exceeds 745,000 (PBIT). However, the producers of raw material for plastic are only four and situated in Karachi. As per sectoral study of PACRA on Plastic Packaging industry 2022, the market is highly oligopolistic with low competition (PACRA, 2022). Nevertheless, the market also comprises many small and medium manufacturers both formal and informal.

The plastic industry contributes 15% to Pakistan's GDP and it is essential because of its linking to other sectors like the automobile industry, agriculture and telecommunications sectors etc. Plastic industry employs more than a million individuals directly and 200,000 people indirectly (Tufail, 2023). Pakistan earned US$386 million with the export of plastic July-May (2021-22)

The plastic raw-material falls in the larger cluster of petro-chemical industry, in which the domestically produced plastic raw materials are PVC, PS, Polyester, Purified Terephthalic Acid (PTA) and Polyethylene Terephthalate PET resins.

The plastic waste comprises 9% of the 49.6Mt of solid waste produced every year (Naeem, 2024). Plastics per capita consumption is 6.5kg and the plastic demand is growing by 15% per year (Dawn, 2025; Pakistan National Action Partnership). Many plastic manufacturers resist the idea of going green or opening to environmental accountability.

Table 1. Types of Plastic

Plastic major types	Types of plastic	Common use
Thermoplastic (melted and reshaped)	Polyethylene Terephthalate (PET)	Beverage bottles, food containers
	High-Density Polyethylene (HDPE)	Packaging, milk jugs, detergent bottles, and pipes
	Polyvinyl Chloride (PVC)	Pipes, window frames, and medical equipment.

	Low-Density Polyethylene (LDPE)	Plastic bags and squeeze bottles.
	Polypropylene (PP)	Food containers, automotive parts, and textiles
	Polystyrene (PS)	Disposable cups, plates, and packaging materials such as foam
Thermosetting Plastic (cannot be remelted or reshaped)	Epoxy resin	Adhesives, coatings
	Phenolic Resins	Electrical insulators, cookware handles
	Melamine	Plates, cups, and laminates

As the main raw materials used in the plastic are derived from petroleum, usually imported from Saudi Arabia, Kuwait and UAE, the prices can vary significantly and can affect production and profitability. One of the main challenges that the plastic industry faces is that the molds, dyes and other raw materials have to be sourced from other countries and there aren't many initiatives for training skilled labor to produce raw materials locally.

Recent plastic manufacturing activities are concerning because finished plastic products are being produced from plastic waste imported from other countries.

Local manufacturers use these unchecked scraps to produce plastic goods, frequently in violation of both Pakistan Import Policy Order (25th September, 2020), and the Basel Convention and Pakistan as well as the National Hazardous Waste Management Policy, 2022.

The **import policy order (2020)** restricts the import of "Waste, parings and scrap of Plastics". However, it provides exemption for industrial consumption on the condition of Environmental approval of the recycling facility by the respective EPA. These regulatory measures need to transform in time with the finalization of the Global Plastic Pollution Treaty. These plastic scraps and leftovers, still being imported contain harmful toxins and chemicals and bacterial matter which are extremely dangerous.

The distribution of plastic manufacturing units across provinces shows that 56% of the units are in Punjab and 39% in Sindh (See fig 1). KP and Balochistan have significantly smaller shares with Balochistan having the smallest proportion of 3%. Given the larger share, the regulatory policy in Punjab and Sindh needs to develop effective implementation mechanism for environmental compliance of industry.

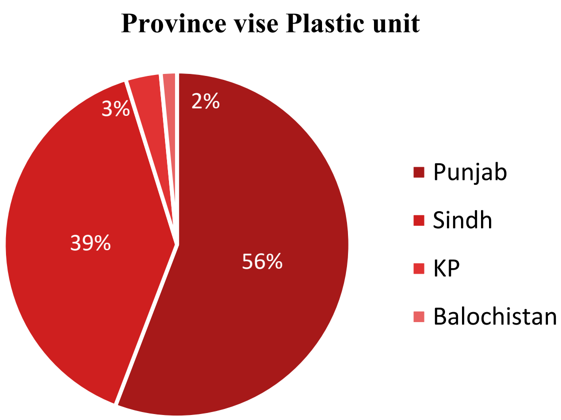

Figure 1. Source: PBS

Table 1. World Bank report on Marine Plastic Pollution in South Asia 2024

Import and exports of plastic waste by country in South Asia (2021) (Metric Tons/ per year)

Country	Imports	Exports
Afghanistan	633	43
Bangladesh	6,492	18,513
Bhutan	71	0
India	95,562	7,223
Maldives	21	224
Nepal	44	23
Pakistan	31,937	3,537
Sri-Lanka	1,590	123
Total	136,350	29,686

2.1. Environmental Impact of Plastic Waste in Pakistan

Only 3% of all plastic waste is recycled in Pakistan as the country has limited recycling capacity. The country wastes 3.3 million tons of plastic and uses 55 billion single use plastic bags in a year (Mukheed & Alisha, 2020). According to the UNEP, in 2020, Pakistan produced 12.17 million tons of plastic waste, which is expected to rise to 22.04 million tons by 2050. Plastic production in the country also releases a lot of greenhouse gases (GHGs), and this will increase from 0.8 billion tons in 2020 to 1.46 billion tons by 2050 (Tamoor et al., 2022). According to the PBS report on the Compendium on Environmental Statistics of Pakistan 2020, plastic waste in various cities of Punjab is mentioned in Table 3 below.

Table 3.

LAHORE	**RAWALPINDI**	**GUJRANWALA**
12347	4488	5340

Figure 2. below shows the plastic waste generated by polymers globally. Polypropylene (PP) generates the most plastic waste followed by other polymers, fibres, LDPE, HDPE, and PET, PVC, PS, and smaller contributors like PUR, ABS and Bioplastics account for less waste.

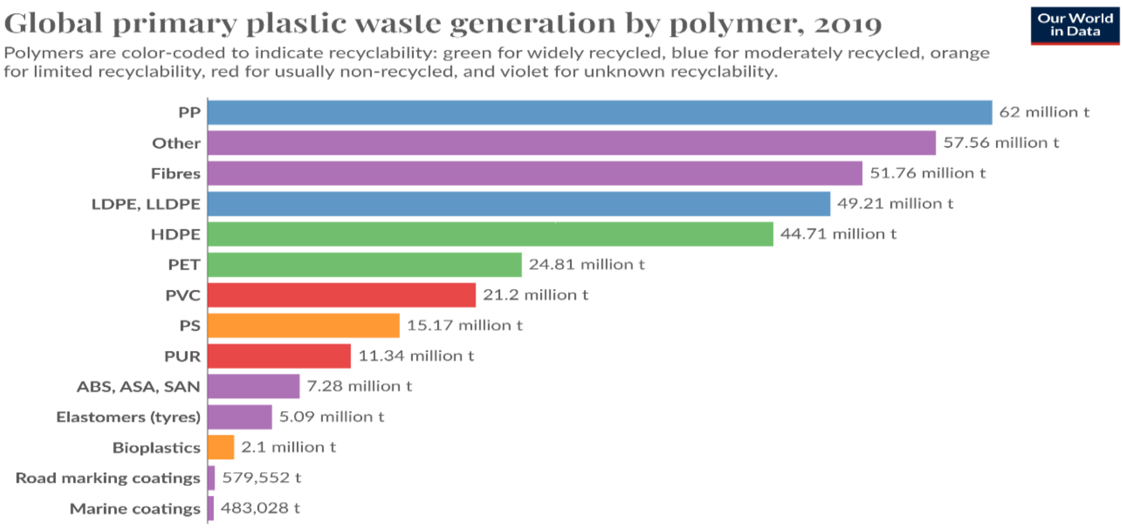

Figure 2.

Source Our World Data (The figure also highlights the recyclability of plastics in color format which shows: in that green for widely recycled (e.g., PET, HDPE), blue for limited recycling, orange for minimally recycled (e.g., PS), and red for non-recycled (e.g., PVC).

2.2. Plastic Waste Damage Soil Quality and Plant Growth

Plastics are widely used in agriculture due to their specific properties. PVC is used in drip irrigation pipes for its durability and chemical resistance, PET is commonly found in the agricultural sector in the form of plastic bottles and polystyrene is utilized for storage and fruit protection and when these plastics in agriculture sector break down into microplastics they enter into the soil and food chain and harming its quality by reducing nutrients and plant growth (Sa'adu & Farsang, 2023).

2.3. Challenges and Limitations of Plastic Recycling

Recycling plastic is not easy. Recycling plastic involves many steps from the use of dyes, fillers, and additives. The US and European countries imprint plastic recycling symbols on the bottoms of the materials and the recycling factories sort the materials by these symbols. Once the materials are cleaned, they are melted and converted into pellets from which different products are prepared. This process may contain flaws and problems. The dyes may be contaminated. The toxicities coming along with mixing medical plastics with others can be shifted to the recycled products. The main problem with the recycling is that it does not reduce the need for virgin plastic. There needs to be mandatory cap on production of virgin plastics. Moreover, the technological fixes such as chemical recycling may not offer solutions of plastic pollution, as their environmental impact is still not properly underscored.

Upscaling plastic collection for reuse and recycling critical to reduce plastic pollution. To enhance the recycling rate of the plastic packaging, eco-friendly design standard need to be adopted.

The recycling still reduces the use of natural resources such as timber. According to World Economic Forum, in the US, 40 million of plastic waste is generated and only 5 to 6% of the plastic is recycled. There are many items which are not recycled or not considered recyclable such as children's toys, straws, and smaller pieces of plastics such as stickers, tapes, and wraps, packages, pouches, and toffee wraps are generally left out of recycling.

In fact, most of what is termed recycled or recycling is not both. Most of the plastic is downcycled. The used plastic is downgraded to a lower quality. In fact, it is difficult to determine the footprint of the recycling efforts in both informal and formal sectors. As a result, it is difficult to ascertain the effectiveness of recycling.

3. Policy landscape

The policies and regulatory measures on controlling and reducing policy pollution vary across the country. The stringent regulatory measures recently introduced in Federal government and Punjab are positive developments. However, the persistent issue of enforcement as observed in other sectors plagues the control of environmental pollution in plastic sector as well. A thorough anlaysis of legislative and regulatory measures against plastic pollution is presented in table 4.

Table 4

Legislation	Type	Strength	Weakness
Federal Legislation			
Single-use Plastics (Prohibition) Regulations, 2023	Regulation for banning Single Use Plastic (Polythene Bags, Cutlery, Crockery, Straws) Phasing out Single Use Beverage Containers (Covers PET and PS products)	Applying Extended Producer Responsibility (EPR) Principle on producer, importer and beverage manufacturer of single use plastic with the responsibility to formulate a plan for waste collection and recycling Penalties prescribed for Producer, Importer, retailer and consumer	The enforcement arm of the Federal Agency EPA, is weak in enforcing the legislation. The regulation does not provide specific actions for enforcement in coordination with local authorities such as police, CDA etc. Phasing out of cutlery and crockery requires putting liability on restaurant owners as well who have not been included in this regulation. The regulation is not clear on packaging material as it exempts “industrial packaging”
Provincial Legislations			
Plastic Management Strategy, Punjab 2023	Strategy for “transforming the way plastic products are designed, produced, used, upcycled, & recycled through leapfrogging towards a	Provides a phased action plan from 2023-2030 Upholds EPR and Circular Economy principles Proposes Environmental tax on the Producer of Single use plastic	The highly ambitious strategy though takes up Technological Innovation and Recycling Infrastructure and institutional Capacity Building as principles, but the targets mentioned in the action plan are less

	circular plastic economy" (Covers PET and PS products)	100% increase in duty on import of Plastic waste	concrete except Integrated Plastic Material Recovery Facilities (MRFs)
Punjab Single-Use Plastic Production and Consumption Act 2023	Regulation	Registration of Producer, collector, distributor, recycler of single use plastic Applies EPR principle Enforces 75 micron thickness on plastic bags Establishment of District Plastic Management Committees under the Provincial EPA	The transition of industry from producing single use plastic to sustainable alternative is not adequately addressed in the regulation, which can create challenges in its enforcement
Punjab Packaging Material Regulation 2018	Regulations	Foamed polystyrene (including; Expanded Polystyrene (EPS), Expressed Polystyrene (XPS) and Oriented Polystyrene (OPS)) is banned for any usage as food packaging	
Sindh prohibition of non-biodegradable plastic products (Manufacturing, Sale and Usage) 2014	Regulation banning non-biodegradable plastic bags & packaging (Covers only PE bags)	The legislation imposes penalties which may be effective in reducing use of plastic bags	Mandates use of xo-biodegradable plastic products, which do not completely bio-degrade Leaves other plastic products such as PET cutlery and PS crockery out of the legislation The legislation does bot porpoise any measures for reuse, recycle and circular economy approaches
Khyber Pakhtunkhwah prohibition of non-biodegradable plastic products (Manufacturing,	Regulation banning non-biodegradable plastic bags & packaging	The legislation imposes penalties which may be effective in reducing use of plastic bags	Mandates use of xo-biodegradable plastic products, which do not completely bio-degrade Leaves other plastic products such as PET

Sale and Usage) 2014	(Covers only PE bags)		cutlery and PS crockery out of the legislation The legislation does bot porpoise any measures for reuse, recycle and circular economy approaches

Year	Policies and legislation
1997	Pakistan Environmental Protection Act
2003	Hazardous Substances Rules
2005	National Environmental Policy
2005	Guidelines for Solid Waste Management
2005	Hospital Waste Management Rules (repealed 2022)
2012	National Climate Change Policy
2012	Guidelines for Processing and Using Refuse Derived Fuel (RDF) in Cement Industry
2013	Prohibition of Non-degradable Plastic Products (Manufacturing, Sale and Usage) Regulations
2015	Amendments to Prohibition of Non-Degradable Plastic Products (Manufacturing, Sale, Usage) Regulations of 2013
2019	Pakistan Environmental Protection Agency Ban on (Manufacturing, Import, Sale, Purchase, Storage, and Usage) Polythene Bags Regulations
2021	National Climate Change Policy (Updated)
2022	Hospital Waste Management Rules
2022	National Hazardous Waste Management Policy
2023	Single-use Plastics (Prohibition) Regulations

Figure 2. Source: World Bank Report

4. Diagnostic Analysis of sub-sectors: PET, PS and PVC

4.1. Polyethylene Terephthalate (PET)

Polyethylene Terephthalate (PET) belongs to the family of polyesters and is the most common thermoplastic polymer. PET is mainly used food packaging such as juices and water bottles, as it is considered safe to use for food.. Polyester is also derived from PET production process.

According to WWF-Pakistan 2020, 70% of PET resin is produced domestically while the rest is imported. The local import of PET resin has been increasing over the years, at the CAGR 52% from 2018-2022 (PACRA 2022). The major PET manufacturer in Pakistan is Gatron and Novatex that produces more than 345,000 Mt per annum of PET resin and 2.5 billion PET bottles.

4.1.1. Green status analysis of PET Manufacturing industry

PET resins are produced through polymerization of Purified terephthalic acid (PTA) using mono-Ethylene Glycol (MEG). PTA is both domestically produced and imported in Pakistan.

Table 5. PET Bottle Manufacturing Process

Step	Process	Input	Environmental Concern	Output
1.	**Polymerization**	PTA & MEG Heat 290° C	Virgin Plastic GHG Emissions	PET Resin
2.	**Polycondensation**	Heat 300° C	High energy use	PET Pellets
3.	**Drying of PET**	Heat 180° C Dry heat	High energy use	Pre-dried PET Pellets
4.	**Injection Molding Process (Plasticizing pellets)**	Heat 280 ° C Pre-dried Pellet Water (closed-loop cooling)	High energy use VOC Emissions GHG Emissions	PET Preform
5.	**Stretch Blow Molding Process (Stretching to shape)**	Heat 180 ° C Cold and compressed air PET Preform	High energy use VOC Emissions	PET Bottle

This involves esterification reaction where PTA and MEG react under heat, then, a polycondensation process occurs in which it undergoes condensation in a vacuum at a high temperature that is 290°C to 300°C. The PET is in the form of a thick viscous liquid at this stage, and cooled down to form **PET resin pellets**. In order to produce 1 ton of PET, 0.85-0.86 tons of PTA and 0.33-0.34 tons of Mono-Ethylene Glycol are required (TDAP, 2021). The drying process requires a temperature of 150-180°C.

The PET bottle manufacturing companies use both pellets produced domestically, and imported. The PET pellets whether domestically produced or imported are transformed into **PET Preform** through *injection molding technique*. This process involves high use of energy and GHG emissions as resins are melted to form test tube shapes (PET preforms). Majority of the processing units employ the injection molding technique in this cluster. A disadvantage of this technique is that it mostly follows a linear approach by using virgin plastic resins instead of utilizing circular approach utilizing recycling techniques, as using recycled pellets requires intensive drying. The recycled plastic pellets contain more moisture than virgin plastics, hence, manufactures are more inclined towards virgin plastic. Blow molding process involves stretching and heating the preforms to shape into a bottle. This process requires high energy and water consumption (Ullah et al., 2016).

4.1.1.1. Emissions from manufacturing process

In the production of PET resin greenhouse gas is emitted in all the stages from extracting raw material to factory gate. The emissions from the production of PET resin mostly come during methods like extrusion, stretch blow molding and polyester fiber production. According to the international study the total life cycle of PET releases 534.6 Mt of CO2 globally, while a large amount of these emissions come during the production of PET resin which is 46.1%, then from manufacturing of PET which is 44.7% and less amount of emission emit during end life treatment of PET. The emissions released during the manufacturing of PET products are majorly emitted during the production of PET fibers responsible for 60.5% of emission from total manufacturing emissions followed by PET bottles contributing 34.8% and PET fibers 3.5% (Duan et al., 2024).

4.1.1.2. Effect on environment and health

PET is not biodegradable. According to 2020 WWF-Pakistan report on PET bottles in Pakistan, overall 22,332,636 kg of PET waste was generated by all 10 cities studied, out of which Karachi had the highest waste i.e. 5,551,992 kg per month and Muree has the lowest that is 86,315 kg. Furthermore, they found that 65% of the total waste ended in beaches and this waste includes PET bottles, packages, plastic bags and other items. Waste disposal contributes to emitting 9.2% of greenhouse gas in the total PET life cycle. Out of which combustion of PET releases 40.5 Mt and the sorting process releases 25.0 Mt of CO2 (Duan et al., 2024).

After degradation, the micro and nano plastic move into air, soil and water bodies. These particles may cause allergies, asthma, digestive problems and chronic lung diseases. Although PET is considered safe to use in food packaging, the chemical called antimony is released into water bottles when the water is stored for a long time period. Also, at 60°C, antimony levels cross the safety limits. Moreover, clear bottle has a lower level of antimony than colored bottles.

The chemicals used in the production of PET fibers and the energy used during the manufacturing of PET bottles are responsible for global warming and are toxic to human health. Lung disease which is known as hypersensitivity pneumonitis (HP) is found in the workers who work in the production of PET bottles. The medical reports of the workers tell that lung issue was caused by the chemical that is used in PET production specifically terephthalic acid and dimethyl terephthalate (Sartorelli., 2020).

4.1.1.3. Recycling challenges

According to Plastic Prohibition Regulation 2023 for Islamabad Capital Territory, this regulation established a timeline for restricting single-use plastic to reduce and ban the use of single-use plastic. Under this regulation, the production, import, and use of single-use plastic beverage containers which are made from entirely new plastic are banned. This regulation applies to manufacturers and producers of these beverages. However, the implementation of this regulation is very weak as PET bottles are produced and used in the country in large amounts and it is not documented and traceable that how many manufactures are sourcing PET pellets from recycled sources. Similarly, the Punjab Food Authority (PFA) put a ban on the reuse of PET bottles in 2017. They directed the restaurants and hotels to discard plastic bottles or make holes in them after use. This prevents to reuse of these PET bottles and discards them which then go for recycling. However, the implementation is understood to be week.

Still it is found that many informal **recycling units** operate with the country with a lot of greening challenges particularly with regards to **high water consumption and workers safety**. There is complete negligence towards health and safety of workers, who are exposed to micro-plastic inhalation and noise pollution above permissible limits. The lack of standardization in recycling of plastic is also resulting in unchecked consumption of water which is mostly not re-used in same plant and dispose in the nearest sewage system (Hashmi, et. al 2023). This also leads to water pollution in nearby area.

4.1.2. Policy Recommendation

- **Recycling:** PET in the form of bottles can undergo recycling a maximum of 10 times in order to make a new product. Moreover, the recycling of PET is more effective as it reduces environmental impact and energy consumption instead of making new PET plastic. The recycling of PET helps to prevent the emission of 16.3 Mt of CO2 which is released from making new PVC material (Duan et al., 2024).

• **Alternative fuel:** Many manufacturing industries in Pakistan use PET waste in making new products. One of the studies uses food waste and PET plastic bottles to make energy sources. They mixed 60% of PET and 40% of food waste and produced refuse paper fuel (RPF) which has the same energy as coal. By doing this not only energy is produced but we can also prevent PET waste from going into landfills. (Qureshi et al., 2020).

• Renewable energy use in manufacturing: In order to prevent the emission of GHG during PET production there is the need to implement strong policies and adopt technologies like carbon capture and renewable energy. For that, there is a need to replace fossil fuels with biomass which can help in reducing emissions. Total global production of bio-based plastic reached 2.05Mt in 2017 and it is estimated that it grows 20% in the next five years. However, switching to renewable energy is cheaper than producing bio-based plastic. Even If we still use fossil fuels and use 100% renewable energy the emission rate is cut in half.

• **Reducing Carbon emissions:** Similarly, there is a need to adopt carbon capture filters another Pakistani study recommended to use of Carbon Capture and Storage (CCS) technology to reduce CO2 emissions from power plants and industries. CCS is the best technology to capture CO2 but it is very costly and the study also suggested using Carbon Capture and Utilization (CCU) method (Hussain et al.,2019).

• **Bio-plastics:** In the long term, there is a need to encourage businesses to invest more in bioplastic by introducing carbon taxes on new PET production and complementary support polices for transition to bio plastic.

• **Formalize recycling of plastic bottles:** In Pakistan small businesses and informal workers like waste pickers play a major role in collecting and recycling PET plastic, therefor there is a need to include these informal waste pickers in the formal recycling system which helps the country's waste to be reused properly. Moreover, it can also help in reducing child labor in the country.

4.2. Polystyrene (PS)

Polystyrene is thermoplastic which means it softens when heated and it is a synthetic polymer made from styrene monomer. Polystyrene is usually used in the production of consumer products. It is widely used for packaging and is also used in the production of various household appliances like refrigerators, air conditioners, ovens and microwaves, automotive parts and electronics. There are different types of polystyrene as per various applications (See table 6).

Table 6. Types of PS

Types of PS	***Property***	***Used***
Expanded polystyrene (EPS)	Lightweight and Insulating	Packaging materials, insulation panels and disposable food containers.
Extruded polystyrene (XPS)	Rigid foam insulation	Applications specifically for building construction such as insulation on roofs, walls and foundations.
High Impact Polystyrene (HIPS)	Modified form of polystyrene	Applications such as in the production of toys, appliances, and automotive parts.

General Purpose Polystyrene (GPPS)	Clear, rigid and brittle form of polystyrene	Applications such as food packaging and disposable containers.
Syndiotactic Polystyrene (SPS)	Crystalline form of polystyrene	High performance applications such as automotive components and electronic housings.

As mentioned above, that the main raw material of PS is styrene monomer. The yearly import of Styrene increased from 2019 to 2022 (see figure 4). Pakistan Petrochemical Industries (Pvt) Ltd produces 100,000 units of General Purpose Polystyrene (GPPS), High Impact Polystyrene (HIPS) and Expanded Polystyrene (EPS) (PBIT, 2020).

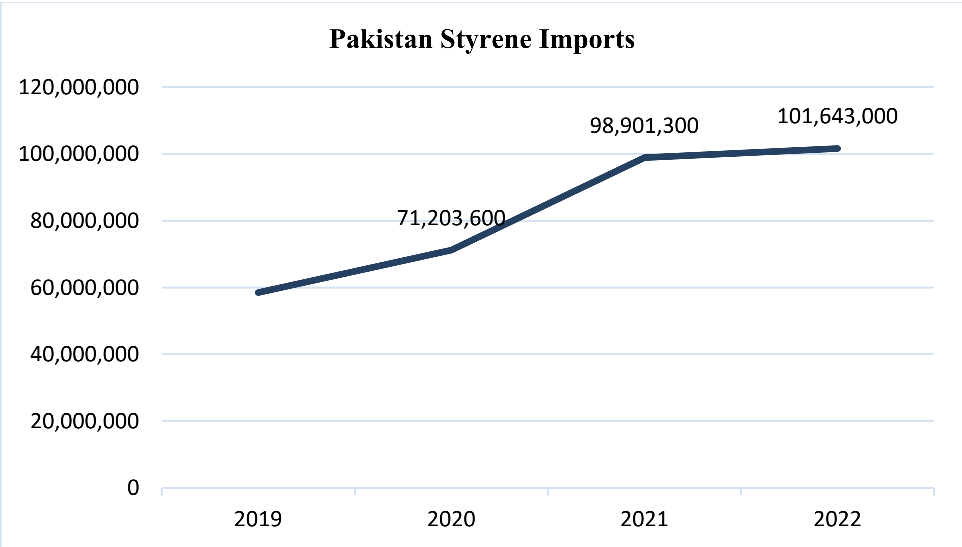

Figure 4

4.2.1 Green Status analysis

The Styrene monomers undergo the polymerization process which involves many techniques but free radical polymerization is mostly used worldwide. Pakistan's petrochemical refining industry produces Polystyrene (PS), but its production is insufficient to meet local demand and hence, imported in large quantitates. In this process, benzoyl peroxide as a radical initiator is used for the radial process. Benzoyl peroxide is unstable and breaks when heated at 80-90 °C which slits into oxygen-oxygen bonds into radicals. When a molecule with a double bond is present then a radical can attach to it. Through this, a new radial is created which reacts with more molecules which cause the chain to grow and this process keeps going until two radicals join together or one radical takes a hydrogen atom from another molecule.

After obtaining the polystyrene in its raw form, it further undergoes various processes according to its use in application. In order to make PS sheets and pellets, the polystyrene resin is melted and then the shapes of pellets and sheets are formed after they pass through the extruder. In order to make products like food packaging, electronics parts, or other household items, it goes through an injection molding process in order to give particular shapes.

4.2.1.1. Emissions and pollution during manufacturing

The building blocks of polystyrene are styrene, benzene and ethylene. All the three are considered as carcinogens and cause other health issues. The hazards come from monomer styrene, additives and plasticizers. The harmful nature of polystyrene depends on the weakness in production. According to Toxics Release Inventory data in 2022, a styrene facility releases 32 million pounds of styrene, 3.2 million pounds of benzene and 2.1 million pounds of ethylbenzene into the air.

During PS manufacturing if the polymerization process is not completed then free styrene may remain as a residual chemical in the PS product and due to this it can leach out into the food stored in the containers or into the environment. During the production of polystyrene, all three raw materials are released into the air.

Also, during the molding and extrusion of polystyrene, the material needs to be heated at high temperatures which can release unreacted styrene monomer. The release of styrene monomers into the environment during the polymerization and melting process is harmful and toxic. Polystyrene is a good heat conductor; pure Polystyrene does not degrade at a temperature below 200°C but tiny particles of styrene during heating can be found in the air. However, if it is heated at a temperature above than 330°C it breaks down completely and releases styrene (Kik et al., 2020).

The prolonged and high concentrations of these toxic substances may pose a serious health threat to workers. The study found that workers with high exposure to styrene had high chances of chronic cough, phlegm, wheezing and breathlessness and also slightly affected their lung function (Zulu & Naidoo, 2022). Another study while assessing the health risks of styrene among workers in Iran, found that most of the workers were exposed to styrene above the safety limit and had a high chance of developing cancer due to exposure, like the workers using injection devices and shift managers were found to have a higher risk. (Mohammadyan et al., 2019).

4.2.1.2. Effect on environment and health

Polystyrene is not biodegradable, it may degrade through photo-degradation which requires prolonged exposure of sunlight and mechanical degradation in which it breaks down into smaller pieces through physical force like wind or waves, which then become micro-plastic.

Polystyrene especially when used in foam packaging (EPS) it is lightweight and easily carried by wind or water and poses a significant threat to marine life as it is not biodegradable (Febriansya et al., 2024). Recently Pakistani study investigated the effect of polystyrene nanoparticles on aquatic animals and found that the nanoparticles of PS affect the fish body functions, disturb their immune system, metabolism, and even their genes (Zaman et al., 2024).

Moreover, styrene is also associated with lymphoma, leukemia, and respiratory problems and also causes vision and hearing issues. According to the World Health Organization's International Agency for Research on Cancer, styrene is considered a possible human carcinogen. When hot food or drinks are served in polystyrene foam cups or plates or when microwaved at high temperatures they decompose and enter into our food. This harmful chemical also enters our drinking water from landfills as it soaks into water bodies. Also, researchers found that through food packaging there is the migration of chemicals from plastic into food.

4.2.1.3. Recycling challenges

A significant challenge for recycling plastic, lies in the fact that recycling plastic is 10-47% more costly compared to virgin plastics to due to subsidies on global petrochemical industries (Xu et a;., 2024).

Table 2

PLASTIC	TRANSPORT COST	COST	RECYCLING VALUE FOR SCAVENGERS	RECYCLING RATIO GLOBAL	WASTE IN RECYCLING
PET	Low	Low	High	High	Low
PS	3*PET	High	Low	Low	High

The above table 8. compares economic viability of recycling of PET and PS. The PET having higher economic viability has a higher recycling ratio. Therefore, the plastic management strategies should emphasize more on “reduce-ing” PS, as its recycling infrastructure and technology is still developing and at current rate, it is more expensive.

PS is recyclable, but costlier and complex to recycle than other plastics. Due to its lightweight like in the form of EPS, it is difficult to separate from other waste and to collect. Moreover, PS requires high-cost materials for recycling and gives low-quality products which can make recycling expensive. The average cost to recycle one ton of PS is $ 1,456, which is higher than other plastics like PP, LDPE and PET. The same study found that 80% of the PS waste ends up in landfills. The systems in place for recycling are outdated and do not document information on quality and quantity of recycled material. (Xu et al., 2024).

4.2.2. Policy Recommendation

- **Reuse of PS waste as fuel:** A Pakistani study found that waste of Polystyrene can be effectively converted into liquid fuel using the pyrolysis process and also by the presence of a catalyst as the natural clay. Moreover, during their research, they found that the maximum amount of oil (86.68%) is obtained under the temperature of 410°C and a reaction time of 60 minutes. The obtained oil in terms of its chemical composition is closely similar to gasoline and diesel which we can use for the industrial and domestic sectors (Ali et al., 2023). While another Pakistan study uses both methods, thermal pyrolysis and catalyst pyrolysis to convert the waste of polystyrene into fuel. They used a catalyst that is made of nickel oxide (NiO) deposited on zirconia (ZrO_2). They found that using a catalyst gave better results than thermal pyrolysis and catalysts that have 2% and 10% NiO gave higher amounts of oil (80%) and reduced the release of styrene monomers which can be harmful. The 10% NiO/ZrO_2 was more effective in generating fuel because it resembles with the chemical composition of diesel (Amjad et al., 2021).

- **Repurposing EPS waste for tertiary waste water treatment plant:** Another study used EPS waste in separating oil from water. The study suggests that a special membrane can be made from EPS waste and cotton. This membrane is both oil-attracting and hydrophobic due to which it is capable of dissolving and separate oil from water. By doing this the waste of EPS can be recyclable in different and useful ways (Shan et al., 2024). These innovations however still need to become commercially viable and safe in practice

- **Strategies to improve recycling:** Different study suggested the upcycling of PS waste. The study used different methods of upcycling which include composite materials, nanocomposites, hydrothermal, catalytic, photodegradation, enzymatic, microwave-assisted, and mechanical degradation processes. Found that each method had its own advantages and disadvantages as some methods are cheaper while others are eco-friendly but costly. There is a need to do further research on effective technologies for making PS upcycling and to make more valuable and quality products.

- Research on PS manufacturing: There is not much data and information on the manufacturing side of PS. There is a need for the government and non-government bodies to do research on the manufacturing of Polystyrene and its related subjects.

- **Ban on Styrofoam cups and plates: The** Punjab Food Authority has taken steps to ban the Styrofoam used in food packaging under the Packaging Material Regulation 2018. Similarly, the Punjab Environmental Protection Act, of 1997 also banned the use of single-use plastic, this regulation also included disposable cups and glasses made of polystyrene. There is a need for such regulation nationwide and its effective implementation.

4.3. Polyvinyl Chloride (PVC)

Polyvinyl Chloride, because of its resistance to moisture, is mostly used for building and construction in making Siding, Windows, Wiring, Cables and Water Pipes. It can also be used in healthcare, packaging and various household products. PVC is the third most widely used thermoplastic polymer and its production in Pakistan is 40 million tons per year. There are two types of PVC polymers, UPVC that is rigid and flexible PVC that contains bisphenol A (BPA) and phthalates plasticizers for improving the flexibility of the pipes and due to BPA, these pipes become unsuitable for flowing of water. (Khan et al., 2024). Rigid PVC comprises of 55% and soft PVC comprises of 45% share of market in Pakistan (Aslam et al., 2023). Some other different types of PVC are also mentioned in the below table 9.

Table 3.

Polyvinyl Chloride (PVC)		
Types	**Property**	**Used**
CPVC (Chlorinated PVC)	High chlorine content, Withstand a wide range of temperatures	Residential, commercial construction businesses
OPVC (Molecularly oriented PVC)	High strength, resistance to corrosion, stiffness, ductility, and flexibility	Pressure pipes for irrigation purpose

The PVC industry in Pakistan consists of more than 1150 small, medium and large-scale industries and has 28,750 employees roughly (Aslm et al., 2023). There are four hundred PVC pipe manufacturing units located in all major cities of Pakistan. It is estimated that 45,000 metric tons of different types of PVC plastics are produced in country each year (Khan et al., 2024). **Engro Polymer and Chemicals Limited (EPCL) is the only company that produces PVC resin in Pakistan and currently it produces 295,000 tons of PVC per year.** The PVC demand has also risen from 182,000 tons to 280,000 tons between the years 2015 to 2021 (The Express Tribune, 2021). To meet the increasing demand, Pakistan also imports PVC from different countries The Figure 6 shows the yearly import of PVC, there is the large amount of import in 2020 and then it decreases in 2021 and rose slightly again from 2021 to 2023.

Figure 5 shows that 70% of the market share of PVC products is of buildings and constructions while 14% of PVC products is used for packaging and 8% for agriculture and 8% for other consumer products (Aslam et al., 2023). According to UNESCO report on waste management in Islamabad, the most PVC generated waste is in hospitals as it is used for packaging and storing of medical products and it is also generated from homes in the form of wiring (UNESCO, 2019).

Sector	Products	Market Share (%)
Building & Construction	**Total**	**70%**
	Pipes and fitting	60%
	Cables	10%
Packaging	**Total**	**14%**
	Rigid sheet	8%
	Flexible & twist shrunk	6%
Agriculture	**Pipes and geomembrane**	**8%**
Consumer & Others	**Total**	**8%**
	Shoes	3%
	Garden Hose	3%
	Others	2%

Figure 3

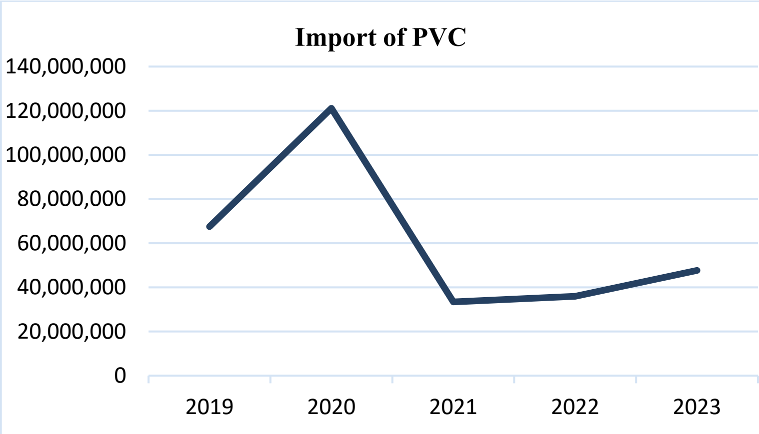

Figure 4.
Source: WITS

4.3.1. Green Status Analysis

To manufacture the PVC, first **Chlor-alkali Plant** is used in which sodium chloride is broken down through electrolysis in order to make chlorine and electricity for electrolysis process comes from on-site gas turbine. During this process the by-products like caustic soda, sodium hypochlorite, hydrochloric acid and hydrogen gas also created.

After the production of chlorine, it is then sent to the EDC-VCM Plant where it is mixed with ethylene, which is imported as a raw material, in a special reactor with a catalyst to make Ethylene Dichloride (EDC). Then EDC undergoes high temperature to produce Vinyl Chloride Monomer (VCM). Then VCM, water and other agents are passed through the polymerization reactor. After polymerization the additives may be added to obtain high-quality PVC. These additives include stabilizers, lubricants and modifiers etc. Small droplets of VCM are created through fast stirring and these droplets turn into PVC by applying proper temperature and pressure.

After that, **PVC resins** is then dried under dryer vent after that the dried PVC powder sent to product sieve for screening where large and small particles were separated. Then PVC powder will undergo for packaging and bags that pass quality control and will be sent for storage. Then the PVC undergoes the **compounding process** in which PVC resin blends with different additives to obtain high-quality PVC. These additives are required according to the material we used for certain applications. These additives have different properties like Plasticizers which can increase flexibility and softness, Stabilizers which are used to improve resistance to heat and UV light. Similarly, other additives like fillers, colorants and lubricants.

After this there is a need to shape the PVC material according to its requirement and application. This process involves **extrusion and molding**. In order to make UPVC pipes the mixture of PVC and additives are added to the extruder, there the mixture is heated and at the end of the extruder the die is used to make the right size of the pipe, from where it goes under the machine called haul off that gives proper shape to the pipe and then after cooling, the cutting machine is used to cut the UPVC pipe for meeting the desired length.

4.3.1.1. Environmental pollution and Waste produced during manufacturing

Polymerization process

During the production of PVC, approximately 38 to 41 cubic meters of the wastewater are produced each hour and it comes from different sources like leftover liquids from processes, water used for cleaning machines and from the ground. This waste water needs to be treated by the facility before release. The waste water treatment plants produce around 25 tons of solid dry sludge. According to NEXI report, during the manufacturing process, the plant release waste gas through dryer vent at a temperature of 100°C. This waste gas contains water vapors, 1.3 kg per hour or 18 mg per cubic meter of VCM and up to 100 per cubic meter of PVC powder.

Chlor-alkali Plant
Most of the wastewater comes from washing machines, equipment and floor which contain chemicals like chloride (CL-), sodium (Na+) and sulfate (SO4 2-). Some of that waste water is cleaned in a septic tank and then before being released from the plant it is mixed with other waste water from the plant. The amount of waste water released is between 6-12m3 /h and the PH of that release water is 6.0-9.0 and it contains maximum of 150 mg/l of Chemical Oxygen Demand (COD), 50mg/l of Biological Oxygen Demand (BOD) and 150-180 mg/l of Suspended Solids (SS).
Chlor-alkali plant mostly includes emissions of hydrogen, nitrogen, and water vapor. They also contain 10 ppm of HCL vapors.

EDC-VCM Plant
EDC-VCM plant produces 35 m3 /h of wastewater per hour and this wastewater contains chemicals like chloride, fluoride, sulfate, copper, lead, and many others. Most of the plants are reported to be treating the water before being released as required by law/ environmental standards. The plant also emits gases from its incinerator like carbon dioxide, carbon monoxide, chlorine, nitrogen oxides, sulfur dioxide, and hydrochloric acid. PVC waste generated per person has increased over the year that is 0.22kg 2017 and grows to 0.09kg in 2020, this increase in waste is because of how consumer use these PVC products and when these long-lasting products break (Aslam et al., 2023).

Due to its chemical property, PVC does not easily burn because it contains 56.8% of chlorine which make PVC fire resistant. However, it can burn due to continues high temperature (Saleem et al., 2022). During burning it releases many toxic gases like heavy metals, phthalates, dioxins, vinyl chloride and hydrogen chloride. Moreover, due to the presence of VCM in PVC, the heating of VCM releases dioxin that is highly toxic and causes developmental and reproductive problems damages the immune system and can also cause cancer.

4.3.1.2. Effect on environment and health

Although all types of plastic cause some harm to our ecosystem but PVC is known to cause more damage to the environment and is more toxic for the plants and animals. PVC is considered worse for global warming as it consumes more energy in production and releases more CO2 than any other plastics (Alsabri & Ghamdi, 2020).

Furthermore, the PVC additives cause additional harm to the environment by adding to the air and soil. These additives can leach harmful chemicals like phthalates and lead. It is considered that PVC releases toxic Chlorinated compounds and also emits toxic dioxin throughout PVC lifecycle during its production, use and disposal and these toxins added in the air, water, soil and enter our food chain and cause severe health issues like cancer, immune system damage, and hormone disruption and according to various studies everyone has a different amount of these chlorinated compounds in their bodies (Kudzin et al., 2023).

Due to its non-biodegradability, PVC can persist in the environment for decades and takes almost 1,000 years to decompose. PVC can become microplastic or nano-plastic. These microplastic enter into our food chain, water and soil. These microplastics can harm aquatic animals by affecting their brain function, damaging their tissues and changing their body chemistry and also harm developing embryos. The Pakistani study on microplastic in farm chickens found total 1227 microplastics and out of these they found polyvinyl chloride at 51.2%, LDPE at 30.7%, PS at 13.6% and PPH at 4.5% (Bilal., 2023). Also, during the production of these PVC materials workers and nearby communities are exposed to many harmful chemicals and gases like EDC/VCM, CO, SO2, NOx. VCM is considered a carcinogen and acute exposure of VCM affects the central nervous system, respiratory tract, cardiovascular and gastrointestinal systems. Three workers who worked in the manufacturing of PVC suffer from rare liver cancer (Petrović & Hamer, 2018).

4.3.1.3. Recycling challenges

PVC is recyclable but it is often seen as difficult to recycle due to its complex composition. Due to the additives in these PVC, the recycled product may be of low quality and make it less suitable for certain applications. Besides this, while recycling, the material releases harmful chemicals during the heating and melting process which is harmful for the environment and human health. Rigid PVC is often easier to recycle than flexible PVC as flexible PVC contains more additives.

The collection of PVC material for recycling is enhanced as per a study which found that 95% of the pipes and fittings are collected for recycling. The other PVC material recycling collection rates are also mentioned in figure 7. Moreover, the scrap of PVC produced in the packaging sector has also increased, for rigid sheets it was 9.2% in 2007 and 21.6% in 2020 and for flexible it increased from 3.3% in 2007 to 8.4% in 2020 (Aslam et al., 2023).

Sector	Products	Collection recycling
Building & Construction	Total	
	Pipes and fitting	95%
	Cables	75%
Packaging	Film & Packaging	
	Rigid sheet	80%
	Flexible & twist shrunk	50%
Agriculture	Pipes and geomembran	80%
Consumer & Others	Total	
	Shoes	65%
	Garden Hose	70%
	Others (e.g., composite textile, yarn, wallpapers, flooring, penaflex, car mats)	30%

Figure 5

Pakistan's recycling industry faces several challenges like lack of government support, ignorance towards the heath of workers, increasing cost of raw materials and poor or low-quality recycled material. Pakistani study found that the water consumed by the recycling industry is 3315L/ton and most of the water waste enters into nearby communities. Moreover, each recycling industry uses 172.5 kWh of power for processing 1 ton of plastic waste and the temperature of these industries was about 36.5°C and noise levels were also very high (Hashmi et al., 2023).

A study on using Green PVC, found that PVC plastic waste can be recycled only by controlling their contaminations, or by mixing with thermoplastic starches to make new material, which can be used in the electrical fittings and plumbing in a closed loom recycling system. Developing these eco-friendly solutions also faces technical challenges like the hygroscopic nature of glycerol-plasticized starch and high cost of production (Correa et al., 2019).

Moreover, the chemical and physical properties of PVC also make PVC recycling challenging. The different additives like Plasticizes, lubricants, antioxidants, fillers, and colorants make recycling of PVC harder especially during mechanical recycling in which keeping the pure PVC recycled material is important but these additives may mix with the material tightly and make difficult to separate. This shows that the sorting and separating process in PVC recycling makes the recycling process very challenging because due to the presence of a variety of additives, there is the need for specific techniques. Other additives like stabilizers during the recycling process may cause environmental issues and health risks for workers.

4.3.2. Policy Recommendations

- **Green alternatives to PVC in construction sector: There** is a need to adopt alternatives of PVC, especially in the construction sector as this sector consumes the largest amount of PVC. One of the studies recommended to use PVC alternatives for construction appliances like PE, HDPE and LDPE are safer PVC alternatives for pipes, tanks and electrical cables. Non-plastic alternatives can also use like metal pipes for smaller uses and vitrified clay and concrete for larger underground purposes. Use wood, tiles and cork which is the healthier alternative of PVC for flooring (Petrović & Hamer, 2018).

- **Promote PVC Recycling:** The Ministry of Industries and Production, government of Pakistan, needs to create awareness about the importance of PVC recycling to stakeholders, consumers, manufacturers and policymakers to enable adoption of eco-friendly recycling processes (Ait-Touchente et al., 2024, Ceptureanu et al., 2017).

- **Filtered ventilation and technologies:** For the manufacturing sector, there is a need for filtered ventilation and technologies in plastic manufacturing plants to control the release of harmful gases and fumes into the air. One of the studies suggested that adsorption and absorption are widely used conventional technologies for carbon capture. The government bodies like EPA, Engineering Development Board need to conduct feasibility studies on adopting advanced technologies such as membrane technology. It has been found that it can remove more than 80% of CO2 efficiently (Alsabri & Ghamdi, 2020).

- **Enhance recycling of PVC:** There is a need for waste management authority to collect and recycle PVC plastic. As PVC is 100% recyclable and using recycled PVC also saves natural resources. Moreover, one of the studies found that recycling of PVC is better for the environment as it reduces carbon emissions while making 1 ton of PVC from 36.21% to 15.53% (Alsabri & Ghamdi, 2020). Another study found that recycling of PVC can reduce 60% of air emissions and 60% of water emissions. Manufacturing window frames using recycled PVC instead of new PVC can reduce the environmental impact by 70% (Ait-Touchente et al., 2024).

- **Sustainable recycling techniques:** Also, there is a need to do further research in adopting more sustainable recycling techniques. One of the studies found that biological, plasma-assisted, and solvent-based recycling technologies were more sustainable and eco-friendly choices rather than traditional methods like mechanical, thermal, and chemical recycling but these technologies still need further research and development to improve their efficiency and cost-effectiveness (Ait-Touchente et al., 2024).

5. Draft National Mission on Plastic Sector Modernization-cum greening

With the help of the University of Engineering and Technology, we have proposed a National Mission, with details of the proposed interventions and indicative costs for the machinery replacement for further discussion.

Table 4. Matrix: Polymer Processing, Green Lean Interventions, and Cost Requirements (Large Organizations)

Processing Method	***Current Practices***	***Green Lean Interventions***	***Requirements***	***Estimated Cost (PKR)***
Extrusion	High energy usage, material waste	Energy-efficient extruders, material reuse, and real-time process control	- Replace old extruders with energy-efficient models - Install IoT monitoring - Use recycled polymers	3–5 million per machine 1–2 million/system
Injection Molding	Long cycle times, scrap material generation	Hot-runner systems, optimized mold designs, and energy-efficient molding machines	- Retrofit machines with hot-runner systems - Redesign molds for efficiency - Use variable-frequency drives (VFDs)	2–4 million/system 500,000–1 million/mold
Blow Molding	Excessive material usage, energy inefficiency	Lightweight molds, advanced process controls, and energy-efficient blow molding machines	- Procure lightweight aluminum molds - Upgrade machines for precision - Implement automated controls	1–2 million/mold 3–5 million/machine
Blown Film Extrusion	Excessive film thickness, low recyclability	Thin-film die upgrades, recycled material integration, and cooling efficiency	- Install dies for thin-film production - R&D for recycled material compatibility - Upgrade cooling systems	3–4 million/die 2–5 million for R&D

Rotational Molding	Long cycle times, high energy consumption	Insulated molds, energy-efficient rotation systems, and use of recycled powdered polymers	- Insulate molds - Install efficient rotation drives - Test compatibility of recycled powders	500,000–1 million/mold 1–2 million/system
Thermoforming	Excessive scrap, low material recovery	Precision CNC trimming systems, recyclable sheets, and multi-cavity molds	- Invest in CNC trimming systems - Use recyclable thermoplastics - Optimize mold design	3–6 million/system 500,000–1 million/mold

5.1. Details of Green Lean Interventions

1. **Energy Efficiency**:
- Extrusion & Injection Molding: Use energy-efficient motors and variable-frequency drives (VFDs). Estimated cost: PKR 3–5 million per machine.

2. **Material Optimization**:
- All Processes: Introduce recycled or bio-based polymers to reduce dependency on virgin materials. R&D cost: PKR 2–5 million/project.
- Blown Film Extrusion: Thin-film production die upgrades. Cost: PKR 3–4 million per die.

3. **Tooling Improvements**:
- Injection Molding: Hot-runner systems reduce material wastage from runners/sprues. Cost: PKR 2–4 million/system.
- Rotational Molding: Insulated molds improve heating efficiency.

Table 5. Matrix: Adjusted for Small Manufacturing Setups in Pakistan

Processing Method	***Current Practices***	***Green Lean Interventions***	***Requirements***	***Estimated Cost (PKR)***
Extrusion	Gas-based heating, high material wastage	Gas-to-electric heating conversion, retrofitting with insulation, material recycling	- Convert gas heating to electric - Insulate heating zones - Introduce pellet recycling	1.5–2.5 million/machine 500,000 for recycling
Injection Molding	Old hydraulic machines, excessive cycle times	Hydraulic-to-hybrid retrofits, mold optimization, and use of recycled plastics	- Retrofit hydraulic machines with energy-saving systems - Redesign molds for faster	1–2 million/machine 500,000–1 million/mold

			cooling - Recycle scrap	
Blow Molding	Poor cooling systems, thick-walled products	Cooling system upgrades, lightweight mold designs, and improved air pressure systems	- Upgrade cooling units - Use aluminum molds - Install efficient air compressors	1–1.5 million/system 500,000–1 million/mold
Blown Film Extrusion	Manual film thickness control, excessive energy	Automatic thickness control, energy-efficient cooling, and thin-film die retrofits	- Install affordable thickness control systems - Retrofit air rings - Use thin-film dies	1–1.5 million/system 500,000–1 million/die
Rotational Molding	High gas consumption, slow cycles	Gas burner efficiency upgrades, insulated molds, and low-energy motors for rotation	- Upgrade gas burners to high-efficiency versions - Insulate molds - Use variable-speed motors for rotation	500,000–1 million/mold 1 million for motors
Thermoforming	Manual trimming, excessive scrap generation	CNC trimming systems, multi-cavity molds, and recyclable thermoform sheets	- Invest in manual-to-CNC trimming retrofits - Use optimized sheets - Design multi-cavity molds	2–3 million/system 500,000/mold

5.2. Explanation of Adjusted Interventions

1. **Energy Efficiency Retrofits**:
- Replace gas-based heating systems with electric heating systems where feasible.
- Use high-efficiency gas burners for setups that cannot transition from gas.
- Cost-effective insulation of machines and heating zones.

2. **Material Recycling**:
- Introduce manual or semi-automated pelletizing systems to recycle scrap material directly on-site.
- Promote the use of locally sourced recycled polymers in small-scale setups.

3. **Tooling and Mold Optimization**:
- Invest in basic aluminum molds for reduced cycle times and material use.
- Redesign molds to allow faster cooling and lightweight product designs.

4. **Cooling and Automation**:
- Upgrade old cooling systems to energy-efficient models (e.g., chilled water systems or air cooling).
- Install basic automation, such as timers or thickness controls, to reduce human error.

5. **Training and Awareness**:
- Provide affordable training to workers on green lean practices, energy conservation, and material handling.

5.3. Low-Cost Solutions (Examples)

1. **Extrusion**:
- Retrofit a basic extruder with insulation and electric heating for PKR 1.5 million.
- Add a small-scale material recycling system for PKR 500,000.

2. **Injection Molding**:
- Retrofit a hydraulic machine with a variable-speed pump for PKR 1–2 million.
- Optimize a mold for PKR 500,000.

3. **Rotational Molding**:
- Replace standard gas burners with efficient versions for PKR 500,000.
- Add mold insulation for PKR 500,000.

4. **Blown Film Extrusion**:
- Install a manual thickness control system for PKR 1–1.5 million.
- Retrofit cooling air rings for PKR 500,000.

5.4. Considerations for Small Manufacturers in Pakistan

1. **Government Incentives**:
- Advocate for subsidies or loans to support small manufacturers in transitioning to greener practices.

2. **Collaborative Projects**:
- Set up shared recycling units or green facilities for small manufacturers in clusters (e.g., Lahore, Gujranwala, Faisalabad, Karachi).

3. **Gradual Implementation**:
- Focus on **modular retrofits** that allow incremental improvement without large capital investments.

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