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FEASIBILITY STUDY ON PLASTIC RECYCLING TOWARDS A CIRCULAR FUTURE IN PAKISTAN

Project Report

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Executive Summary

This feasibility study aims to assess the viability of plastic recycling initiatives in Pakistan, particularly within the Small and Medium Enterprises (SMEs) sector, to foster a transition towards a circular economy. The study explores the economic, environmental, and technological dimensions of plastic waste management, providing insights into market demand, financial sustainability, regulatory frameworks, and stakeholder engagement. Through data-driven analysis, the study seeks to identify barriers and opportunities, enabling the development of a strategic roadmap for sustainable plastic recycling.

Pakistan generates approximately 3.9 million tonnes of plastic waste annually, with a significant portion ending up in landfills, waterways, and open dumpsites. With an estimated plastic recycling rate below 10%, there is a critical need for improved waste management practices. The integration of circular economy principles in plastic recycling can create economic opportunities, reduce environmental pollution, and contribute to resource efficiency. SMEs play a pivotal role in driving innovation, bridging policy gaps, and engaging communities in sustainable waste management practices. Enhanced recycling infrastructure, policy incentives, and technological advancements are essential to accelerating the transition to a circular plastic economy.

Key findings indicate that SMEs play a crucial role in plastic recycling, yet they face numerous barriers, including financial constraints, technological limitations, policy gaps, and inadequate market incentives. Mechanical recycling remains the most feasible option for SMEs due to its lower operational costs and higher scalability, whereas chemical and biological recycling methods require significant investment and technological advancement.

A Life Cycle Assessment (LCA) conducted in this study highlights the environmental benefits of recycling, demonstrating that mechanical recycling can reduce greenhouse gas emissions by 70-80% compared to virgin plastic production. The LCA also reveals that closed-loop recycling of PET provides the highest climate change mitigation potential, while incineration and landfilling contribute significantly to carbon emissions and water scarcity. Additionally, optimizing energy use in recycling processes and integrating renewable energy sources can further reduce the environmental footprint of plastic waste management.

The study identifies key strategic findings across different actors involved in the plastic recycling value chain:

- Adoption of Extended Producer Responsibility (EPR) policies can incentivize industries to invest in sustainable packaging and recycling initiatives.
- Partnerships between industries and SMEs can enhance the supply chain for recycled plastic materials.
- Large-scale manufacturing units can integrate post-consumer recycled (PCR) plastics into production processes to reduce reliance on virgin materials.
- SMEs contribute significantly to plastic waste collection and recycling but face financial and regulatory challenges.
- Informal waste collectors handle a substantial portion of plastic waste, requiring integration into formalized recycling systems.
- Capacity-building programs and access to financing can improve the efficiency and scalability of SME-driven recycling initiatives.
- Strengthening policy frameworks, such as plastic bans and EPR regulations, can drive investment in sustainable recycling infrastructure.

- Local governments can establish decentralized recycling hubs to optimize waste collection and processing.
- Standardized policies across provinces can ensure consistency in waste management regulations and incentives.
- Increasing public awareness about waste segregation and recycling benefits is crucial for improving plastic waste collection rates.
- Community-led initiatives and behavior change campaigns can enhance participation in plastic recycling efforts.
- Incentive-based programs, such as plastic credits and return deposit schemes, can encourage responsible plastic consumption.

The study proposes a sustainable plastic recycling model tailored for SMEs, emphasizing stakeholder engagement, financing mechanisms, and capacity-building initiatives. Recommendations include the establishment of public-private partnerships (PPP), access to green financing, regulatory reforms to incentivize recycling, and the integration of Extended Producer Responsibility (EPR) frameworks. Successful case studies from countries such as Germany, Japan, and India illustrate the potential of policy-driven recycling initiatives and SME-led innovations.

By addressing these challenges and leveraging the opportunities presented in this study, Pakistan can significantly enhance its plastic recycling capacity, reduce environmental impacts, and transition towards a circular economy. The implementation of the recommended policy and business strategies will enable SMEs to contribute effectively to sustainable plastic waste management and drive economic growth through resource efficiency.

1. Introduction

Global plastic production has witnessed an exponential increase, growing from 2 million tonnes in the 1950s to a staggering 438 million tonnes in 2017 (Geyer, 2020). This surge in production is largely driven by the widespread use of plastics, with 99% of plastics being derived from non-renewable hydrocarbons (British Plastics Federation, 2019). However, The COVID-19 pandemic temporarily slowed plastic production, with an estimated decrease of around 0.3% in 2020 (Statista, 2021). China plays a significant role in the global plastic market, contributing to 28% of global production (UNEP, 2018). The packaging industry is the largest consumer of plastic, accounting for 36% of total plastic use (Geyer, 2020).

Historically, only less than 10% of plastic waste has been recycled, while 14% has been incinerated. The majority, approximately 76%, end up in landfills or the environment (Geyer, 2020). The issue of plastic pollution is exacerbated by the entry of large quantities of plastic waste into aquatic ecosystems, with 19-23 million tonnes of plastic waste entering oceans in 2016 alone (Borrelle et al., 2020). It is estimated that around 50 million tonnes per year of plastic wastes are openly burned, whilst 10 million tonnes per year enter the oceans aquatic environment (The Pew Charitable Trusts and SYSTEMIQ, 2020; Lau et al., 2020). If no significant changes are made to waste management practices, plastic waste in aquatic ecosystems is predicted to nearly triple by 2040 (UNEP, 2021). This highlights the urgent need for more effective recycling systems and global action to curb plastic waste.

Plastics have become the third most produced material globally, following only concrete and steel. Many plastic items take an exceptionally long time to degrade; for example, plastic bottles can take up to 450 years to break down (Watts, 2019). During this process, microplastics are created, which are consumed by marine life and subsequently end up in seafood, salt, and water consumed by humans (Kye et al., 2023). It is estimated that around 51 trillion microplastics are currently floating in the oceans.[1]

The issue of plastic recycling in Pakistan, particularly among small and medium enterprises (SMEs), is a critical component of the broader transition towards a circular economy. This transition is essential not only for environmental sustainability but also for economic development. The current linear model of plastic consumption and disposal has resulted in significant environmental degradation, necessitating a shift towards more sustainable practices. The concept of a circular economy emphasizes the importance of maintaining the value of products, materials, and resources in the economy for as long as possible, thereby minimizing waste and promoting recycling (Schyns & Shaver, 2020; Kumar et al., 2021).

1.1. Background on Plastic Waste in Pakistan

Out of the total solid waste produced in Pakistan, 9% is plastics. The country produces 55 billion plastic bags each year, significantly contributing to the plastic waste crisis (Mukheed & Alisha, 2020). Pakistan has the highest percentage of mismanaged plastic waste in South Asia, with much of it ending up in open dumps, landfills, or clogging municipal sewers. The country faces severe waste management challenges due to inadequate infrastructure, bureaucratic inefficiencies, and low public awareness,

[1] https://www.fau.edu/newsdesk/articles/missing-microplastics-ocean.php#:~:text=About%2051%20trillion%20microplastics%20are,near%20surface%20of%20the%20ocean.

particularly in major cities like Karachi, which produces over 13,000 tons of municipal waste daily (WWF, 2020).

The mismanagement of plastic waste poses serious environmental and health risks, including pollution of waterways, land, and marine environments. The Indus River is the second most plastic-polluted river globally.[2] Plastic waste also leads to health hazards, such as toxic emissions from burning plastics and contamination of the food chain through microplastics. Despite the growing waste problem, solid waste management remains largely informal and ineffective, and insufficient policies to regulate plastic consumption and promote recycling further exacerbate the issue.

1.2. Scope and Purpose of the Feasibility Study

This feasibility study aims to assess the feasibility of plastic recycling initiatives among Small and Medium Enterprises (SMEs) and promote circular economy principles within Pakistan. Through research, capacity-building, and stakeholder engagement, the study seeks to develop tailored solutions to address the unique challenges of plastic waste management in Pakistan. By fostering collaboration among government agencies, businesses, civil society organizations, and local communities, the study aspires to drive sustainable waste management reforms.

The study will be conducted through three key focus areas:

1. **Plastic Waste Market Analysis and Stakeholder Engagement:**
    a. Assess the current plastic waste management practices of SMEs.
    b. Identify market trends, regulatory frameworks, and operational challenges.
    c. Engage key stakeholders, including local businesses, waste collectors, and community representatives, to gather insights on market demands and sustainability opportunities.
    d. Evaluate the financial viability of SME plastic recycling ventures by analysing investment needs, revenue potential, and economic sustainability.
2. **Technological Feasibility and Life-Cycle Assessment (LCA):**
    a. Examine the available plastic recycling technologies in Pakistan, including mechanical, chemical, and biological processes.
    b. Assess the infrastructure, expertise, and scalability of recycling technologies for SME adoption.
    c. Conduct a Life-Cycle Assessment (LCA) to evaluate the environmental impact of plastic recycling operations from resource extraction to disposal.
    d. Identify barriers to technology adoption and recommend strategies for overcoming them.
3. **Development of a Sustainable Model for SMEs:**
    a. Design a localized SME-centric plastic waste recycling model encompassing collection, sorting, processing, and the sale of recycled materials.
    b. Engage stakeholders in model development to ensure alignment with local economic and social needs.
    c. Implement capacity-building and training programs to equip SMEs with the necessary skills and knowledge for sustainable recycling practices.

[2] https://tribune.com.pk/story/1728660/1-drowning-trash-pakistan-among-top-river-dumpers-plastics/

d. Develop an exit strategy to ensure the long-term sustainability of plastic recycling initiatives through funding mechanisms, partnerships, and policy support.

By addressing economic, technological, and environmental dimensions, the study will inform policy recommendations and business strategies to strengthen Pakistan's transition to a circular economy in plastic waste management.

1.3. Challenges in Plastic Waste Management

Plastics, known for their versatility, durability, and low cost, have become essential in modern society. However, their widespread use, often referred to as the "plastic age" (Thompson et al., 2009), has led to severe environmental consequences. The government of Pakistan is currently exploring ways to transition from a linear to a circular economy (Morseletto, 2020), with the Municipal Solid Waste (MSW) sector playing a crucial role in this shift by producing compost from the organic portion of waste. There are several challenges in plastic waste management in Pakistan. Some of these are as follows:

i. Infrastructure and System Issues

Plastic waste management in Pakistan faces multiple significant challenges across various sectors. One of the primary issues is the inadequate infrastructure and informal waste management systems operated by municipalities, which are becoming increasingly strained with population growth and industrialization (Mukheed & Alisha, 2020). The current urban waste management practices are particularly problematic, as they focus solely on collecting waste from communal bins and disposing of it in urban fringes without proper segregation, material recovery, or recycling processes (Khan & Nawaz, 2015).

ii. Economic and Technical Challenges

The economic context presents another significant challenge. Pakistan's struggling economy makes it difficult to implement comprehensive plastic ban, as plastics remain the cheaper, more durable, and accessible option. Any attempts at blanket bans could result in job losses or reduced business activity, particularly when affordable alternatives are not readily available. This economic constraint is further complicated by the limited capacity of waste management companies, which require extensive support from both public and private sectors to address the complex nature of plastic pollution effectively (Irfan et al., 2020).

iii. Policy and Implementation Gaps

A comprehensive policy framework addressing single-use plastics and plastic waste management is currently lacking at both the federal and provincial levels. Furthermore, there is poor implementation of existing regulations, with bags without degradable additives (D2W) still being widely used across Pakistan (Hassan & ul Haq, 2019). In addition, existing regulations often fail to incentivize recycling or impose penalties for non-compliance, leading to a lack of accountability among waste generators (Rehman et al., 2022; Kumar, Singh & Dwivedi, 2020).

iv. Environmental and Health Concerns

Plastic waste leads to severe environmental problems, including the clogging of sewage systems due to improper disposal. Large-scale plastic disposal has caused significant pollution, affecting both terrestrial and aquatic ecosystems (Heidbreder et al., 2019). Additionally, the greenhouse gas emissions associated with plastic production and disposal pose a threat to global climate objectives, particularly the goal of limiting global temperature rise to below 1.5 °C as set out in the Paris Agreement (Hamilton and Feit, 2019). Health risks arise from the burning of plastic waste, releasing toxic chemicals that contaminate the air. Furthermore, marine pollution resulting from plastic waste significantly affects coastal areas and freshwater bodies, posing a threat to ecosystems and public health (Qari & Shaffat, 2015).

v. Social and Behavioural Challenges

There is a lack of community awareness and participation in systematic plastic waste collection, which contributes to the widespread disposal issues. A pervasive disposable mentality has led to excessive plastic consumption, making the problem even more difficult to address. There is an urgent need for better education and awareness campaigns to inform the public about the consequences of plastic waste and promote better waste management practices (Sajid et al., 2015).

1.4. The Role of Small and Medium Enterprises (SMEs)

Small and medium enterprises (SMEs) play a crucial role in plastic waste management and the circular economy, although their impact is mixed. SMEs employ 50-60% of the global workforce and are essential to the global economy; however, their significant carbon footprints have drawn attention from policymakers and scholars (Meath et al., 2016). These enterprises are increasingly under pressure to adopt circular economy (CE) practices, which not only offer economic advantages but also address inefficiencies in supply chains (Rosa et al., 2019). Some progressive SMEs have embraced eco-friendly measures, such as closed-loop supply chains, sustainable innovation, and reverse logistics, to reduce their environmental footprint (Kristensen and Mosgaard, 2020).

Despite these efforts, widespread adoption of CE practices remains limited. SMEs rarely receive adequate incentives to explore solutions for plastic waste management (Meath et al., 2016) and face challenges distinct from those of larger organizations. Although the complete elimination of plastics may not be feasible, SMEs can reduce their environmental impact through improved packaging practices and eco-innovation (Geyer, Jambeck, and Law, 2017). Adopting effective waste management practices can have a significant impact on national GDP and environmental sustainability (Marino & Pariso, 2020). However, very few SMEs currently operate with CE-compliant systems aimed at reducing plastic waste (De-Jesus and Mendonça, 2018). As pressure mounts, especially in emerging economies, SMEs are being urged to transition towards environmentally sustainable operations through proper waste management practices (Choudhary, Jain, and Panda, 2022).

SMEs are uniquely positioned to drive innovation and implement sustainable practices due to their agility and ability to adapt to changing market demands (Kumar, Singh & Dwivedi, 2020; Bowen, Dowell & Morris, 2024). In the context of plastic waste management, SMEs can serve as key players in the recycling supply chain, providing essential services such as collection, sorting, and processing of plastic materials (Rehman et al., 2022; Vollmer et al., 2020). By integrating recycling into their business models, SMEs can not only reduce their environmental footprint but also create new revenue streams and enhance their competitive advantage (Dey et al., 2022; Kumar, Singh & Dwivedi, 2020). Moreover, SMEs have the potential to foster community engagement and raise awareness about the importance of recycling. By collaborating with local governments and organizations, SMEs can promote sustainable practices and educate consumers about the benefits of plastic recycling (Marrucci et al., 2022; Rehman et al., 2022).

However, to fully realize their potential, SMEs must overcome the barriers that currently hinder their engagement in plastic recycling. This includes addressing financial constraints, enhancing technological capabilities, and fostering a culture of sustainability within their organizations (Bowen, Dowell & Morris, 2024; Rehman et al., 2022).

1.5. Current involvement of SMEs in waste management and recycling

Many SMEs involved in waste management prioritize high-value recyclables, such as metals and paper, often neglecting plastics due to perceived economic unviability (Rehman et al., 2022). This mindset must shift to recognize the potential of plastic recycling as a viable business opportunity within the circular economy framework (Vollmer et al., 2020).

Despite the challenges, there are notable examples of SMEs in Pakistan that have successfully engaged in waste management and recycling initiatives. These enterprises have demonstrated that it is possible to integrate sustainability into their operations while achieving economic viability (Rehman et al., 2022; Kumar, Singh & Dwivedi, 2020). For instance, some SMEs have adopted innovative business models that prioritize the collection and recycling of plastic waste. These businesses often collaborate with local communities to establish collection points and raise awareness about the importance of recycling (Dey et al., 2022; Rehman et al., 2022).

Additionally, some SMEs have begun to explore partnerships with larger corporations and NGOs to enhance their recycling capabilities. These collaborations can provide SMEs with access to funding, technical expertise, and market opportunities, enabling them to scale their operations and increase their impact (Rehman et al., 2022; Vollmer et al., 2020). However, the overall involvement of SMEs in plastic recycling remains limited. Many enterprises still prioritize traditional business practices that do not incorporate sustainability, often due to a lack of awareness or understanding of the benefits associated with circular economy principles (Dey et al., 2022; Kumar, Singh & Dwivedi, 2020).

1.6. Contribution to plastic recycling and the circular economy

Small and Medium Enterprises (SMEs) in Pakistan are key players in managing plastic waste and advancing the circular economy. They step in where formal waste management struggles, taking charge of waste collection, sorting, processing, and manufacturing recycled products. In fact, most recycling in Pakistan is driven by informal and small-scale actors: individuals scavenge plastics from dumps and sell to SME recyclers, while street hawkers (*raddiwalas*) buy recyclables from households and trade them up the chain. Through these channels, SMEs convert discarded plastic into valuable raw materials and products, effectively turning waste into a resource. For example, many startups and local businesses have launched initiatives to repurpose plastic waste into items like construction materials, furniture, and other useful products – directly embodying circular economy principles.

SMEs’ contributions yield significant sustainability benefits. By recycling plastic that would otherwise pollute land and water, they reduce the volume of waste in dumps and lower environmental contamination. Their recycling efforts also cut demand for virgin plastic, saving energy and raw materials and thereby reducing greenhouse gas emissions. Moreover, the SME-driven recycling sector provides important socio-economic benefits, including the creation of thousands of jobs across the value chain. From waste pickers and sorters to machine operators and entrepreneurs, a wide spectrum of workers earn livelihoods through recycling activities. This not only supports community incomes but also fosters grassroots environmental awareness, as SMEs often engage local communities in collection programs and educate them on recycling practices. In sum, SMEs act as engines of a circular economy in Pakistan – safeguarding the environment by closing the materials loop and simultaneously stimulating economic growth and job creation.

1.7. Barriers faced by SMEs

Small and medium enterprises face several barriers to effectively implementing waste management (WM) techniques, which can be broadly categorized into financial, regulatory, technological, technical, and external challenges.

i. Financial Barriers

One of the most critical obstacles for SMEs is the shortage of financial resources required to adopt and implement WM practices. High initial costs of new waste management technologies, expensive waste disposal, and limited budgets constrain SMEs from investing in sustainable practices (Leite et al., 2019; Fahad et al., 2022). Furthermore, SMEs often lack access to financial incentives such as tax benefits, subsidies, or loans that could support their transition to circular economy principles (Mura, Longo and Zanni, 2020). This lack of capital and investment capacity further exacerbates the issue, making it difficult for SMEs to allocate resources for sustainable initiatives (Fleiter, Schleich and Ravivanpong, 2012). Limited investment capacity, coupled with the perception of sustainability as an additional cost, further discourages SMEs from prioritizing WM practices (Sharma et al., 2021). Finally, the high ongoing expenses associated with waste disposal and management create a persistent financial burden for these enterprises (Woodard, 2020, 2021).

ii. Regulatory Barriers

Ineffective regulations and bureaucratic hurdles are significant impediments for SMEs attempting to integrate WM into their operations. Inconsistent or unclear legislation, coupled with poor enforcement of environmental laws, creates challenges in compliance and implementation (Cantú, Aguiñaga and Scheel, 2021; Pozo et al., 2019). Additionally, excessive bureaucracy and a lack of coordinated policies make it difficult for SMEs to align their practices with sustainability goals (Mura, Longo and Zanni, 2020). The lack of coordinated policies and inconsistent enforcement weaken the regulatory framework, making it difficult for SMEs to align their practices with sustainability goals (Pozo et al., 2019). In some cases, SMEs may also lack sufficient knowledge about existing environmental regulations, further hindering compliance (Salvioni, Bosetti and Fornasari, 2021).

iii. Technological Barriers

The adoption of novel technologies critical for effective WM is often constrained by a shortage of technological capacity and infrastructure. SMEs frequently lack access to modern waste recycling systems, cleaner production techniques, and advanced tools like lean and six sigma strategies, which are essential for efficient waste reduction (Singh & Rathi, 2021; Fahad et al., 2022). Poor infrastructure and spatial constraints further hinder the integration of innovative solutions, particularly in smaller facilities (Woodard, 2020). Additionally, many SMEs do not invest in research and development to identify or create customized technological solutions for waste management (Fahad et al., 2022).

iv. Technical and Organizational Barriers

SMEs face significant technical and organizational challenges when adopting waste management (WM) practices. A major hurdle is the lack of skilled personnel, with many SMEs suffering from a shortage of trained professionals and expertise in WM techniques, limiting their capacity to implement effective strategies (Sodhi, Singh and Singh, 2020; Sahoo & Yadav, 2018). This issue is compounded by insufficient training, as employees often lack proper education on sustainable practices and lean tools essential for effective waste reduction (Salma et al., 2021). Additionally, resistance to change within organizations presents a significant barrier, with worker reluctance and a lack of cooperation or understanding hindering the successful execution of new strategies (Sodhi et al., 2020b). Weak leadership and vision further exacerbate these challenges, as poor organizational commitment, limited top management support, and the absence of clear goals negatively impact the adoption of green practices (Salma, Anas and Mohammed, 2021). Finally, time and resource constraints pose a persistent challenge, as SMEs often grapple with limited time and inadequate infrastructure to seamlessly integrate WM into their daily operations (Caldera, Desha and Dawes, 2019).

v. Lack of Awareness and Knowledge

SMEs frequently lack awareness about the environmental and economic benefits of adopting WM practices. There is often limited knowledge regarding the long-term advantages of sustainability, such as reducing operational costs and improving efficiency (Mitchell, O'Dowd and Dimache, 2020). Many SMEs involved in waste management prioritize high-value recyclables, such as metals and paper, often neglecting plastics due to perceived economic unviability (Rehman et al., 2022). Additionally, a lack of understanding of circular economy principles and insufficient research on WM practices within SMEs exacerbate the issue (De-Jesus and Mendonça, 2018; Nunes et al., 2019).

vi. External Barriers

External factors, such as weak government support and insufficient public services, also contribute to the slow adoption of WM practices in SMEs. Limited access to suitable recycling services, insufficient infrastructure for waste handling, and inadequate national programs further compound the problem (Badraddin et al., 2021; Woodard, 2021).

2. Methodology

2.1. Research Design

The study employed a mixed-method research design, combining qualitative and quantitative approaches to ensure a comprehensive analysis of plastic recycling feasibility among SMEs in Pakistan. This approach integrated stakeholder engagement, market assessments, and environmental impact evaluations to provide well-rounded insights into the recycling sector. The flowchart of research methodology is given in Figure 1.

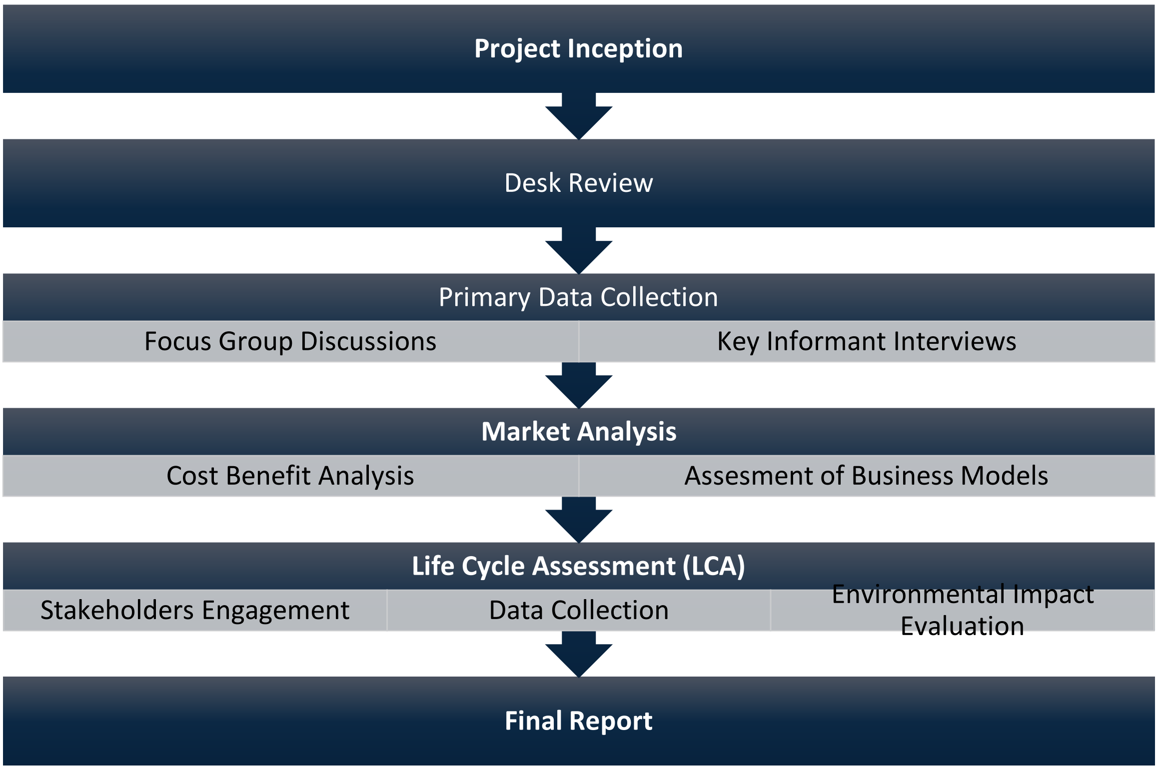

Figure 1: Research Methodology Flowchart

2.2. Data Collection Methods

The data collection phase employed purposive sampling to identify stakeholders. The data was collected through questionnaires which were prepared for the specific stakeholders, including both close-ended and open-ended questions. To gather information for this study, key informant interviews and focus group discussions were used. Secondary data collection included desk research on market dynamics, current technologies, capacity, policies, and reports to document challenges and celebrate successes. Lastly, data was analysed to meet the study objectives.

Surveys and Questionnaires

The research adopted a comprehensive approach to primary data collection, utilising sector-specific tools (questionnaires) tailored for the SMEs, waste collectors, local businesses, and community members. The questionnaires incorporated both fixed prompts and open-ended questions to gather detailed information on plastic waste generation, recycling practices, market demands, and operational challenges. The surveys were conducted through online platforms, telephone interviews, and face-to-face interactions to ensure broad participation.

Key informant interviews were conducted using these data collection tools to capture insights on various parameters. This included risks and gaps within the plastic recycling value chain, existing operations and technologies, market demands, financial and operational challenges.

Focus Group Discussions

Focus group discussions (FGDs) were held with key stakeholders, including SME representatives, government officials, waste collectors, and industry experts. These discussions provided qualitative insights into regulatory barriers, business opportunities, and challenges faced in plastic recycling. The FGDs facilitated collaborative problem-solving and helped identify tailored interventions for SMEs.

2.3. Market Analysis Approach

The market analysis approach for the feasibility study on plastic recycling in Pakistan focused on assessing the operational environment of SMEs involved in plastic waste management. It evaluated the economic viability of recycling initiatives through a comprehensive cost-benefit analysis, considering factors such as raw material costs, operational expenses, and revenue potential. Additionally, the study explored various business models for plastic waste collection, processing, and the sale of recycled materials to identify sustainable and profitable approaches for the sector.

2.4. Life Cycle Assessment (LCA) Framework

The Life Cycle Assessment (LCA) framework was designed to evaluate the environmental impacts of SME-level plastic recycling activities in Pakistan by providing a comprehensive assessment of the plastic recycling value chain, including waste collection, sorting, transportation, and recycling processes. To ensure a robust and context-specific LCA, stakeholder engagement was integrated into the framework through consultations with SMEs, startups, and industry experts, KIIs and FGDs to identify regulatory barriers and opportunities, and field investigations to document on-ground plastic waste management practices.

To ensure accurate modelling, data was collected in a structured manner using a detailed spreadsheet divided into four main sections: *Current Waste Management, Plastic Collection, Plastic Sorting (Pre-Processing), and Plastic Recycling*. The data collection sheet included both quantitative and qualitative parameters, with input fields for actual values and default benchmark figures sourced from literature. Data points covered waste collection and recycling rates, source and quality of collected plastic, transportation modes and distances, electricity and chemical consumption, and overall recycling efficiency. The LCA framework helped in assessing the key components of plastic recycling in Pakistan, given as follow:

Current Waste Management

- Evaluated recycling and waste collection rates to identify efficiency gaps.

Plastic Collection

- Analyzed waste sources—households, businesses, landfills, and industries—impacting material quality and contamination, refining collection strategies.

Plastic Sorting (Pre-Processing)

- Examined manual and mechanical sorting methods, transport distances, and export destinations, incorporating data on sorting volumes and energy consumption.

Plastic Recycling

- Assessed recycling efficiency through input-output analysis, industry demand, resource consumption, and chemical use, quantifying its environmental footprint.

Market Demand & Trends

- Investigated pricing, demand fluctuations, and government policies shaping recycling practices.

By integrating quantitative LCA modelling with stakeholder insights, this framework delivered a comprehensive assessment of plastic recycling in Pakistan, supporting informed decision-making for sustainable waste management strategies.

3. Contextual Analysis

3.1. Pakistan's Waste Management Landscape

Currently, Pakistan generates approximately 30 to 48.5 million tonnes of solid waste annually, with megacities like Karachi and Lahore contributing significantly to this total. On average, nationwide waste generation ranges from 0.24 to 0.65 kg per capita per day, with this figure growing at a rate of 2.4% annually. [3] [4] However, the country faces a major challenge in waste management due to the absence of a comprehensive and standardized approach across regions. The informal sector plays a crucial role in waste collection and separation, with local authorities and municipal governments primarily responsible for managing waste.

In many areas, waste is either burned openly or dumped in vacant lots due to the lack of adequate facilities for material recovery and sustainable waste treatment. The government estimates that around 87,000 tons of waste are produced weekly, with Karachi, Pakistan's largest city, generating over 16,500 tons of municipal waste daily. Other major cities face similar challenges, with problems such as bureaucratic delays, poor urban planning, insufficient waste management technology, and limited public awareness (ITA, 2024). An overview of the solid waste generated in major cities across Pakistan is given in Table 1.

Table 1: Solid waste generation in the major cities of Pakistan

City	Population (millions)	Solid Waste Generation/Day (tons)
Karachi	20.5	16,500
Lahore	10.0	7,690
Faisalabad	7.5	5,017
Rawalpindi	5.9	4,500
Hyderabad	5.5	3,973
Multan	5.2	3,680
Gujranwala	4.8	3,480
Sargodha	4.5	3,072
Peshawar	2.9	2,048
Quetta	0.6	716
		Source: (International Trade Administration, 2024)

Despite moderate waste collection rates of 60-70%, only a fraction of waste reaches its final disposal point. Municipalities rely on street sweepers and sanitary workers, alongside staff and informal workers using donkey carts, open trucks, trolleys, and wheelbarrows for waste collection. Waste is typically dumped in temporary storage areas, where scavengers often sift through it to recover recyclables. This leads to the formation of informal recycling channels. Unlike developed nations

[3] Ghauri, W. U. (2018). *Waste to energy potential in Pakistan*. Expert Group Meeting on Sustainable Application of Waste-to-Energy in the Asian Region, Busan, Republic of Korea. United Nations. https://sustainabledevelopment.un.org/content/unosd/documents/37697.Waste%20to%20Energy%20Potential%20in%20Pakistan.pdf

[4] Khan, I. U., Waseer, W. A., Ullah, S., & Khan, S. A. (2019). 'Wasteaware' indicators: An assessment of the current solid waste management system in Lahore, Pakistan. *Asia Pacific Journal of Energy and Environment, 6*(2), 49–58. https://doi.org/10.18034/apjee.v6i2.264

where waste is often treated, landfilled, or incinerated, much of the waste in Pakistan ends up in final dumping sites (SWITCH-Asia SCP Facility, 2022).

Waste management systems across Pakistan vary greatly by province. In Islamabad, waste management falls under the Capital Development Authority (CDA), but the city lacks a formal landfill site. Currently, much of the waste is disposed of at a dumpsite in Sector I-12, with plans for a proper landfill at Sangjiani, as decided by the Senate in April 2019.[5] In Punjab, Lahore has an operational waste management system, which has been outsourced to Turkish companies Albayrak and OzPak. The provincial government plans to extend such systems to secondary cities across Punjab. Meanwhile, in Sindh, the SSWMB is actively working on improving services in 20 cities and regularly announces tenders for various waste management projects. Khyber Pakhtunkhwa's Water and Sanitation Services Peshawar (WSSP) is also in the process of constructing a sanitary landfill. However, Balochistan, the largest province by area, lacks significant waste management infrastructure due to its low population density.

The Lahore Waste Management Company (LWMC) has established Pakistan's first scientific landfill at Lakhodhair, designed with four lots.[6] By 2016, Lot I and II were completed, providing a combined capacity to process 35,000 tonnes of waste. Karachi, on the other hand, has two main sanitary landfill sites: Jam Chakro and Gond Pass. Additionally, the Sindh Solid Waste Management Board (SSWMB) is planning to establish a new landfill in the eastern parts of Karachi, with 3,000 acres of land allocated at the Dhabeji site (Sohoo et al., 2022).

3.2. Current Policy Frameworks and Regulations

The Table 2 below outlines a range of policies, acts, and regulations implemented across Pakistan to address environmental concerns, particularly those focusing on waste management and sanitation.

Table 2: Key policy frameworks and regulations related to SWM in Pakistan

Sr. #	Policy/Act/Initiative	Regulatory Authority	Key Provisions/Description
1.	Punjab Prohibition Ordinance on Polythene Bags, 2002[7]	Government of Punjab	- Prohibits manufacture, sale, use, and import of black polythene bags. - Bans bags below 15 microns in thickness to reduce environmental harm.
2.	National Sanitation Policy, 2006[8]	Federal Government	- Aims to provide adequate sanitation coverage. - Improves the quality of life. - Ensures a healthy physical environment for residents.
3.	The Sindh Prohibition of Non-degradable Plastic Products Rules, 2014[9]	Sindh Environmental Protection Agency (Sindh-EPA)	- Ban on non-degradable plastic products. - Regulation of oxo-biodegradable plastic products.

[5] https://tribune.com.pk/story/1946373/1-islamabad-build-landfill-site-near-sangjiani
[6] https://www.lwmc.com.pk/sanitary-landfill.php
[7] https://punjabcode.punjab.gov.pk/uploads/articles/the-punjab-prohibition-on-manufacture-sale-use-and-import-of-polythene-bags-black-or-any-other-polythene-bag-below-fifteen-micron-thickness-ordinance-2002-pdf.pdf
[8] https://mocc.gov.pk/PolicyDetail/OTYyZjg5ODktYjE2ZS00NmZiLWI3YTktMjJmMDgwMTdjMjU2
[9] http://sindhlaws.gov.pk/setup/publications_SindhCode/PUB-15-000259.pdf

			- Registration of manufacturers, wholesalers, and retailers. - Marking recycled plastic products as unsafe for food contact.
4.	Khyber Pakhtunkhwa Prohibition of Non-Biodegradable Plastic Products and Regulation of Oxo-Biodegradable Plastic Products Rules, 2017[10]	Khyber Pakhtunkhwa Environmental Protection Agency (KP-EPA)	- Ban on non-biodegradable plastic carrier bags. - Ban on plastic bags with thickness less than 50 microns. - Requires labeling with essential information. - Prohibits the use of hazardous raw materials.
5.	Ban on Polythene Bags Regulations, 2019[11]	Islamabad Capital Territory Authority (ICTA)	- Prohibits the unauthorized manufacture, import, sale, purchase, storage, and use of polythene bags in Islamabad Capital Territory.
6.	National Climate Change Policy, 2021[12]	Federal Government	- Build resilience to climate change through adaptation measures. - Reduces emissions and promotes renewable energy. - Focus on afforestation and climate action.
7.	National Hazardous Waste Management Policy, 2022[13]	Federal Government	- Framework for managing hazardous waste. - Covers licensing, handling, storage, and transportation under PEPA Act, 1997.
8.	World Economic Forum's National Plastic Action Partnership (NPAP) Program, 2022[14]	Federal Government	- Focuses on reducing plastic waste through a circular economy. - Phases out single-use plastics. - Promotes industry-wide sustainable practices.
9.	Single-use Plastics (Prohibition) Regulations, 2023[15]	Pakistan Environmental Protection Agency (Pak-EPA)	- Ban on single-use plastic bags, crockery, cutlery, food containers, stirrers. - Ban on single-use plastic straws (effective by August 2025). - Beverage containers to be made of 50% recycled plastic by 2028. - Mandatory Extended Producer Responsibility (EPR) for producers.
10.	Production and Consumption of Single-Use Plastic Products Regulations, 2023[16]	Environmental Protection and Climate Change Department, Government of Punjab	- Ban on single-use plastics such as disposable utensils, cutlery, food boxes, plastic flags. - Ban on PVC banners with thickness less than 80 microns.

10 http://kpcode.kp.gov.pk/uploads/Prohibition_of_Non-Biodegradable_Plastic_Products_and_Regulation_of_Oxo-Biodegradable_Plastic_Products_Rules_2017.pdf

11 https://environment.gov.pk/SiteImage/Misc/files/Regulations/PlasticBan2019.pdf

12 https://mocc.gov.pk/SiteImage/Policy/NCCP%20Report.pdf

13 https://mocc.gov.pk/SiteImage/Misc/files/National%20Hazardous%20Waste%20Management%20Policy%202022.pdf

14 https://www.globalplasticaction.org/pakistan-partners-with-world-economic-forum-to-fight-plastic-pollution

15 https://www.mocc.gov.pk/PublicationDetail/Mzk2ZmQ1ZTAtMzA2Ny00NjFlLWFlOWYtMGU1MDI1MmQ4YWUy

16 https://punjablaws.punjab.gov.pk/uploads/articles/punjab-environmental-protection-production-and-consumption-of-single-use-plastic-product-regulations-2023-95-of-2023-pdf.pdf

			- Registration of manufacturers, consumers, collectors, and recyclers. - Mandatory EPR for plastic products.
11.	Extended Producer Responsibility (EPR) in the Single-Use Plastic Regulations, 2023[17]	Federal Government	- Requires producers, importers, and beverage manufacturers to create plans for plastic waste collection and recycling. - Plans are subject to federal approval.
12.	The Plastic Management Strategy, Punjab, 2023[18]	Environmental Protection and Climate Change Department, Government of Punjab	- Bans production, sale, and use of certain single-use plastic products. - Penalties for non-compliance. - Development of EPR regulations. - Public education and infrastructure for recycling. - Support for eco-friendly alternatives. - Financial incentives for biodegradable and compostable plastics.
13.	Punjab Environmental Policy, 2015[19]	Government of Punjab	- Provides a framework for addressing environmental issues, focusing on pollution of water bodies, air pollution, lack of proper waste management, and climate change.
14.	Punjab Hospital Waste Management Rules, 2014[20]	Government of Punjab	- States that every hospital, public and private, is responsible for the proper management of waste generated until its final disposal.
15.	The Balochistan Use of Plastic Shopping and Flat Bags Act, 2023[21]	Balochistan Environmental Protection Agency (Balochistan-EPA)	- Ban on plastic carrier bags with thickness less than 50 microns. - Exemption for biodegradable, compostable bags, industrial packing, and hazardous waste. - Development of solid waste management plans.
16.	The Collect and Recycle (CoRe) Alliance[22]	Producer-led Initiative	- Focuses on testing and implementing solutions for plastic packaging and recycling. - Primarily targets downstream recycling solutions.
17.	Plastic Road Initiatives[23]	Federal and Provincial Governments	- Uses plastic waste in road construction. - Aims to protect the environment and improve infrastructure in both rural and urban areas.

[17] https://resolutions.unep.org/resolutions/uploads/pakistan_16112023_extended_producer_responsibility.pdf
[18] https://punjablaws.punjab.gov.pk/uploads/articles/the-plastic-management-strategy-punjab-pdf1.pdf
[19] https://epd.punjab.gov.pk/system/files/Draft%20Punjab%20Environment%20Policy%202015_0.pdf
[20] https://epd.punjab.gov.pk/system/files/Punjab%20Hospital%20Waste%20Management%20Rules%2C%202014_0.pdf
[21] https://balochistancode.gob.pk/Document.aspx?wise=opendoc&docid=224&docc=204
[22] https://weforum.ent.box.com/s/ktt9gdte1ldo4pwtaa9lbyxrushils3q
[23] https://www.coca-cola.com/pk/en/sustainability/pakistans-first-plastic-road-inauguration#:~:text=Chiefly%2C%20the%20objective%20of%20the%20project%20is,the%20strategic%20leadership%20of%20the%20National%20Incubation

3.3. Stakeholder Overview

The plastic recycling ecosystem requires coordinated efforts from various sectors, each playing a key role. Government agencies formulate and enforce waste regulations while collaborating with other sectors on policies. Development organizations provide global best practices and promote circular economy principles. Research institutions offer data-driven insights for policy development, while SMEs and local businesses drive innovation in recycling and sustainable packaging. Informal waste collectors play a vital role in waste management, though often lack support. Financial institutions provide funding, and technology providers advance recycling solutions. All these stakeholders collaborate to create a sustainable recycling system. The Table 3 shows the roles and current interactions of these key players in this study and the plastic recycling ecosystem.

Table 3: Roles and Current Interactions of Key Players in the Study

Stakeholder Group	Role in Plastic Recycling	Current Interactions
Government Agencies	Formulate and enforce plastic waste regulations, implement Extended Producer Responsibility (EPR), and provide funding for recycling initiatives.	Collaborate with regulatory bodies, local municipalities, and private sector on waste management policies.
United Nations Environment Programme (UNEP-IETC)	Provide the best global practices, technical guidance, and funding for sustainable plastic management projects.	Works with government agencies, NGOs, and research institutions on policy advocacy and capacity-building initiatives.
Living Indus Team	Promote circular economy principles and sustainable waste management within Pakistan's environmental policy framework.	Collaborate with government institutions and civil society organizations for ecosystem restoration projects.
Sustainable Development Policy Institute (SDPI)	Conduct policy research, provide data-driven insights, and recommend strategies for sustainable plastic waste management.	Advises government agencies, industry players, and NGOs on environmental policies and sustainability initiatives.
Small and Medium Enterprises (SMEs)	Innovate in recycling technologies, plastic alternatives, and circular economy business models.	Engage with industry experts, technology providers, and investors to explore recycling opportunities.
Local Businesses & Entrepreneurs	Reduce plastic use, adopt sustainable packaging, and invest in recycling solutions.	Partner with SMEs, waste collectors, and consumers to encourage plastic waste reduction.

Waste Collectors & Informal Sector	Collect, sort, and supply plastic waste to recycling units, playing a crucial role in waste management.	Engage with recyclers and municipalities for waste collection but lack social security and fair wages.
Community Representatives & Civil Society Organizations (CSOs)	Raise awareness, mobilize communities for waste reduction, and advocate for sustainable policies.	Partner with government agencies, businesses, and informal waste collectors to promote sustainable plastic disposal.
Financial Institutions & Investors	Provide funding, green financing options, and impact investment for recycling projects and startups.	Offer loans and investment opportunities to plastic waste management ventures.
Industry Experts & Researchers	Conduct studies on plastic pollution, recycling technologies, and market trends.	Advise policymakers, investors, and industry players on sustainability strategies.
Regulatory Bodies & Environmental Agencies	Monitor compliance with plastic bans, recycling targets, and EPR regulations.	Work closely with government agencies, businesses, and waste management companies.
International Donors & Development Partners	Provide funding, technical assistance, and policy support for plastic waste management initiatives.	Partner with governments, NGOs, and businesses to implement sustainability projects.
Technology Providers & Recycling Industry	Develop and implement plastic recycling technologies, waste sorting systems, and biodegradable alternatives.	Engage with businesses, investors, and government agencies to scale up recycling solutions.

3.4. International Best Practices in Plastic Waste Management

Effective plastic waste management requires a combination of regulatory frameworks, technological innovation, and active community participation. Several countries have successfully implemented best practices that serve as models for addressing plastic waste challenges.

Japan exemplifies a highly structured approach to plastic waste management, integrating strict regulations with public education campaigns. The country's extensive waste classification system encourages systematic recycling, with educational initiatives embedded within schools to instil sustainable waste practices from an early age. Such policies foster community engagement and have significantly reduced non-recyclable waste (Zicha et al., 2021).

Germany's circular economy model has been pivotal in its success. The country enforces extended producer responsibility (EPR) laws, requiring manufacturers to take responsibility for the end-of-life management of their products. This approach not only stimulates the recycling industry but also incentivizes sustainable packaging solutions and eco-friendly product designs (Wu et al., 2021). The strong regulatory framework ensures high compliance and innovation, making Germany a leader in plastic waste management.

Taiwan's strategy focuses on collaborative networks and adaptive governance. The country has developed an integrated recycling system that emphasizes industrial-level circular economies, where SMEs play a crucial role in plastic waste recycling. These businesses contribute to both local and global waste reduction efforts by implementing innovative recycling technologies and business models (Wu et al., 2021). The government actively supports these efforts through policy incentives and funding for sustainable enterprises (Huang & Mirza, 2022).

These best practices underscore the importance of policy support, industry collaboration, and consumer awareness in driving effective plastic waste management. Countries that combine stringent regulations with business incentives and public participation are more likely to achieve long-term success in mitigating plastic pollution.

3.5. Case studies from countries with successful SME-driven recycling initiatives

SMEs have played a significant role in developing innovative recycling solutions worldwide. Case studies from India, South Africa, Malaysia, and the Philippines illustrate how SMEs contribute to effective plastic waste management by leveraging policy support, technology, and market incentives.

India's SMEs have shown remarkable adaptability in integrating sustainable materials into their production cycles, particularly in the consumer goods and packaging sectors. Many businesses are replacing single-use plastics with biodegradable alternatives, aligning their operations with national waste reduction policies. This transition not only improves brand competitiveness but also fosters consumer trust in eco-friendly products. Additionally, local enterprises actively promote recycling awareness campaigns, strengthening community engagement in waste management and fostering a culture of sustainability. These efforts contribute to a more circular economy while enhancing the reputation and long-term viability of SMEs in the country (Pereira et al., 2022).

In **South Africa**, SMEs have embraced green marketing strategies and water conservation measures in response to extreme environmental conditions, particularly prolonged droughts in the Western Cape. These businesses have adopted innovative water-efficient techniques such as rainwater harvesting and greywater recycling to reduce their reliance on limited water resources. By implementing these measures, SMEs not only address immediate resource constraints but also gain a competitive edge in the market by positioning themselves as environmentally responsible enterprises. Furthermore, many SMEs have launched community-oriented recycling programs, raising awareness about sustainable water use and fostering a broader culture of environmental responsibility among consumers (Duffett et al., 2018).

Malaysia's SME-driven concrete recycling initiatives serve as an exemplary model of circular economy integration. Research highlights that strategic partnerships and government support play crucial roles in fostering a favorable environment for sustainable practices in the construction industry. Many SMEs actively source waste concrete, process it, and reintroduce it into new construction projects, significantly reducing landfill waste and raw material consumption. These recycling efforts not only contribute to environmental conservation but also enhance the financial performance of SMEs by lowering material costs and creating new revenue streams. The success of Malaysia's concrete recycling industry demonstrates the effectiveness of collaboration and policy incentives in promoting sustainability among small businesses (Badraddin et al., 2022).

In the **Philippines**, SMEs are increasingly prioritizing environmental sustainability, driven by both regulatory pressures and market demand. Many small enterprises have implemented recycling initiatives to comply with national environmental policies while also appealing to eco-conscious consumers. This proactive approach allows SMEs to enhance their competitiveness in the marketplace by aligning their operations with sustainable business practices. Beyond regulatory compliance, the adoption of environmentally friendly measures has helped businesses build a positive brand image, attract a growing segment of sustainability-minded customers, and improve overall operational efficiency (Roxas & Chadee, 2012).

These case studies highlight the transformative potential of SMEs in plastic waste management. Through policy alignment, technological advancements, and consumer-driven demand, SMEs can drive the transition toward sustainable waste practices and contribute to the global circular economy.

4. Plastic Waste Market Analysis

4.1. Overview of Plastic Waste Generation and Management in Pakistan

Pakistan generates approximately 30 to 48.5 million tons of solid waste annually[24] [25], with plastics accounting for 9% of this total. The country produces around 55 billion plastic bags each year, contributing significantly to its plastic waste crisis (Mukheed & Alisha, 2020). It has the highest percentage of mismanaged plastic waste in South Asia, with a significant portion of single-use non-biodegradable plastic bags ending up in open dumps, landfills, or clogging municipal sewers.

Pakistan struggles with an inadequate waste management system, lacking proper methods for the disposal and post-use treatment of plastics. This has led to significant environmental challenges. Most municipal waste is either burned, dumped, or buried in open spaces, posing serious risks to public health and safety. Government estimates indicate that Pakistan produces approximately 77,000 tonnes of solid waste daily, with a significant portion coming from major metropolitan areas. Karachi, the country's largest city, generates over 13,000 tonnes of municipal waste every day. Urban centers across Pakistan face severe difficulties in handling waste effectively, primarily due to bureaucratic inefficiencies, poor urban planning, insufficient waste management infrastructure, and low levels of public awareness (WWF, 2020). Inadequate infrastructure further exacerbates the issue, leading to plastic pollution in waterways and landfill sites. According to the UN Environment Programme (UNEP), Pakistan's Indus River ranks as the second most plastic-polluted river globally, carrying over 164,332 tonnes of plastic waste annually.[26]

Plastic waste in Pakistan poses serious environmental and health risks, contaminating soil, air, land, and marine environments. It clogs drainage systems, damages seashores, and disrupts irrigation. Health hazards include toxic emissions from burning plastics, contamination of drinking water, and microplastics entering the food chain (Zhao et al., 2017; Mukheed & Alisha, 2020; Waring, Harris & Mitchell, 2018). Plastics production has been shown to emit 1.78 Gt of CO_2-eq in 2015. These emissions will increase to 6.5 Gt. CO_2-eq in 2050 (Zheng & Suh, 2019). According to the United Nations, 80% of ocean pollution originates from land-based sources, contributing 8 million tons of plastic waste each year. This waste causes the death of over 1 million marine animals and 100,000 sea birds and mammals annually.[27]

Pakistan produces around 55 billion plastic bags annually, and food wrappers and containers contribute significantly to environmental pollution, accounting for 31.15% of waste in the country (Irfan et al., 2020; Khan and Nawaz, 2015). Despite this alarming statistic, solid waste management practices remain largely informal and inadequate, especially in rapidly growing urban areas. As the population increases and industrialization expands, the existing waste management systems are expected to be further overwhelmed, exacerbating the plastic waste crisis (Mukheed & Alisha, 2020). A lack of comprehensive federal and provincial policies addressing single-use plastics and waste

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[24] Ghauri, W. U. (2018). *Waste to energy potential in Pakistan*. Expert Group Meeting on Sustainable Application of Waste-to-Energy in the Asian Region, Busan, Republic of Korea. United Nations. https://sustainabledevelopment.un.org/content/unosd/documents/37697.Waste%20to%20Energy%20Potential%20in%20Pakistan.pdf

[25] Khan, I. U., Waseer, W. A., Ullah, S., & Khan, S. A. (2019). 'Wasteaware' indicators: An assessment of the current solid waste management system in Lahore, Pakistan. *Asia Pacific Journal of Energy and Environment, 6*(2), 49–58. https://doi.org/10.18034/apjee.v6i2.264

[26] https://tribune.com.pk/story/1728660/1-drowning-trash-pakistan-among-top-river-dumpers-plastics/

[27] United Nations, 2020. Ocean factsheet: Pollution. Available at: https://sustainabledevelopment.un.org/content/documents/Ocean_Factsheet_Pollution.pdf

management contributes to the persistence of the issue, as there is little regulation to curb plastic consumption or promote effective recycling.

The widespread use of cheap, durable, and accessible plastics makes them a popular choice in Pakistan, but their environmental impact is significant. A blanket ban on plastic products could result in job losses and economic disruption, particularly in the absence of viable alternatives (Irfan et al., 2020). While higher-value plastics like PET bottles are often recycled, most single-use plastics, including non-biodegradable bags, end up in landfills or clogging sewage systems, intensifying waste management challenges. A culture of disposability, where plastic products are hoarded and discarded without consideration for environmental harm, continues to fuel the growing plastic pollution problem in Pakistan (Khan & Nawaz, 2015).

4.2. Role of SMEs in Plastic Recycling

Pakistan's plastic industry, the fifth-largest employer in the country, has experienced rapid growth, expanding annually by 7–9%.[28] With approximately 6,000 plastic processing units, mostly self-financed SMEs, the industry employs around 470,000 individuals directly and indirectly. Punjab accounts for 60% of these units, followed by Sindh (30%), Khyber Pakhtunkhwa (7%), and Balochistan (3%). The sector contributes approximately 8 billion Pakistani Rupees to the national exchequer.[29]

SMEs play a crucial role in the economic landscape of Pakistan, contributing significantly to GDP and employment generation. However, their potential to influence environmental sustainability through plastic recycling remains largely untapped (Dey et al., 2022; Rehman et al., 2022). SMEs are vital in Pakistan's plastic recycling ecosystem. They bridge the gap between plastic waste generation and its reuse by collecting plastic waste from industries, households, waste collectors, and private companies, then processing it into new products like pipes, building blocks, trays, hangers, tiles, bags, and table mats. This process not only reduces waste but also generates employment and supports local economies. Despite these contributions, SMEs face significant challenges, including high raw material costs, logistical difficulties, and quality control issues that hinder their overall productivity.

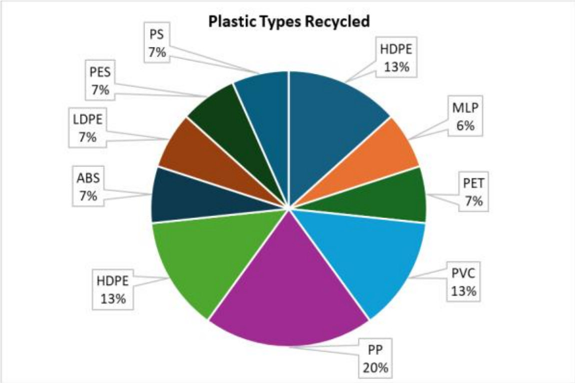
4.3. Market Demand and Business Trends

The demand for recycled plastic products has proven to be volatile, largely due to price instability and the availability of cheaper virgin plastic. In Pakistan, different types of plastic waste i.e., HDPE, LDPE, PVC, PP, MLP, etc. are transformed into a diverse range of products such as pipes, tiles, trays, bags, building blocks, pavers, manholes, bricks etc., catering to both industrial and consumer segments (Figure 2). Innovative startups are focusing on plastic waste avoidance through refill stations for water, dishwashing liquid, oils, and sanitary napkins. Their products, tested by PCSIR, offer 35-40% cost savings, showing potential for behavioural shifts towards waste reduction.

Many SMEs targeting local consumers, manufacturers, exporters, and corporate entities report difficulty in achieving consistent sales due to these price fluctuations. The persistent reliance on virgin plastic remains a key challenge, as it is often more affordable and easier to procure than recycled materials. In addition, limited consumer awareness regarding the environmental and economic benefits of recycled plastic products exacerbates the situation. Despite these challenges, emerging

[28] http://atozplastics.com/upload/literature/pakistan.asp
[29] Ibid.

trends provide new opportunities for SMEs in the recycling sector. For example, growing government procurement programs focused on sustainability and the circular economy could present significant opportunities for expansion. Export opportunities for recycled plastic products also hold great potential, particularly as global demand for sustainable products rises.



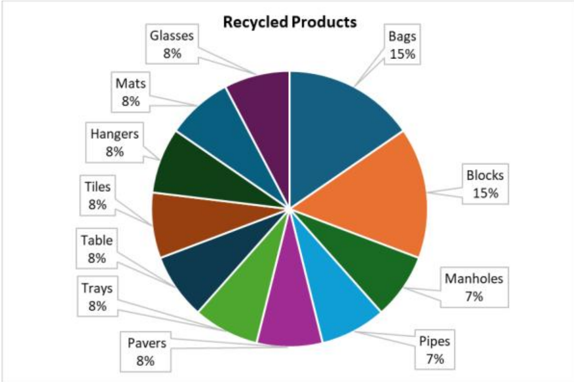


Figure 2: Types of Plastic Waste Processed and Corresponding Recycled Products

4.4. Economic Viability of Recycling Initiatives

Cost-Benefit Analysis

i. **Raw Material Costs:** The cost of raw plastic materials is one of the most significant expenses for SMEs (Figure 3 (a)). The pricing of plastic materials varies widely depending on the type:

- ***PVC and Polypropylene (PP):*** 155 PKR/kg
- ***Acrylonitrile Butadiene Styrene (ABS) and polyester:*** 250–350 PKR/kg
- ***Polyethylene Terephthalate (PET) and High-Density Polyethylene (HDPE):*** 30–200 PKR/kg

I. **Product Pricing**: The price of recycled products varies depending on their quality and market demand. Typically, recycled products are sold at prices ranging between 101 PKR and 1000 PKR per unit (Figure 3 (b)).

II. **Operational Costs**: Monthly operational costs for SMEs range between 0.5–5 million PKR. These costs include labour, equipment maintenance, utilities, and waste collection (Figure 3 (c)). In addition, initial investment requirements for establishing a recycling unit can range from 1 million to 20 million PKR, depending on the scale of operations and technology adopted (Figure 3 (d)).

III. **Profitability Challenges**: While the margins for recycled plastic products are relatively low due to high raw material and operational costs, SMEs in the recycling sector often face difficulty in sustaining profitability (Figure 3 (e)). This is mainly due to the unpredictable pricing of recycled plastic and competition from virgin plastic producers.

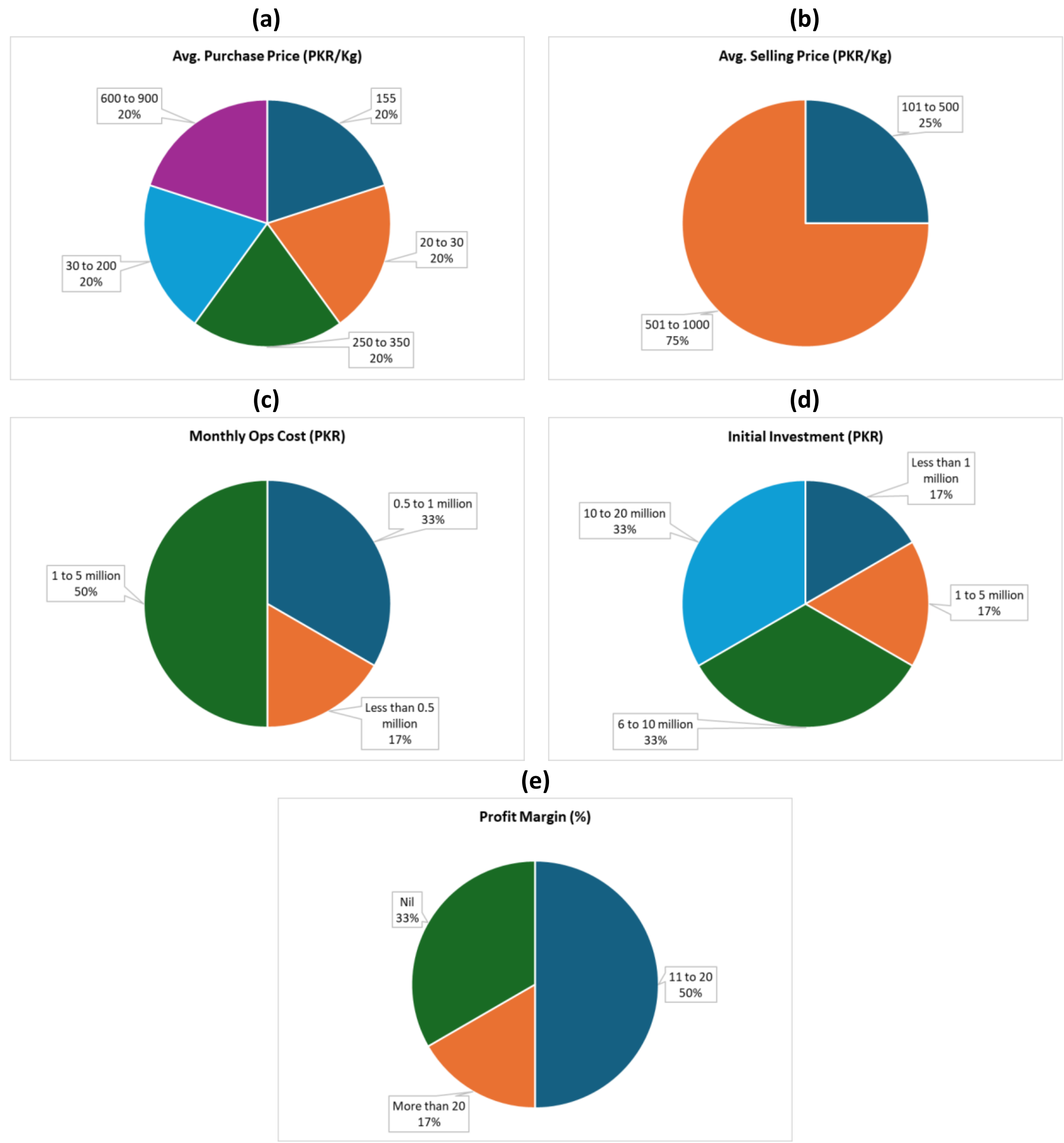


Figure 3: Key Financial Metrics in Plastic Recycling Operations

Opportunities and Barriers for SMEs

Based on the survey findings, Figure 4 presents the SWOT Analysis highlighting Strengths, Weaknesses, Opportunities and Threats for the SMEs in Pakistan's recycling industry.

STRENGTHS	WEAKNESSES	OPPORTUNITIES	THREATS
+***Diverse Products:*** Pipes, tiles, bags, etc., expand market reach. +***Efficient Recycling Tech:*** Manual & automated processes improve productivity. +***Low Rejection Rate:*** <5% rejection shows efficient processing. +***Stable Workforce:*** 90%+ retention supports continuity. +***Sustainable Energy:*** Solar adoption reduces costs. +***Broad Customer Base:*** Local & international buyers, industries, government.	–***High Costs:*** Expensive raw materials, energy, and operations. –***Quality Issues:*** Contamination and irregular supply affect production. –***Funding Gaps:*** Limited access to loans, grants, and capital. –***Regulatory Burdens:*** Lack of subsidies, tax breaks, and policy support. –***Resource Constraints:*** Limited access to tech, skilled labour, and quality raw materials.	+***Rising Demand:*** Growing interest in eco-friendly products. +***Government Support:*** Potential subsidies, tax breaks, and incentives. +***Export Potential:*** Increasing global demand for recycled plastics. +***Innovation:*** Startups offering plastic-free solutions. +***Business Ecosystem Growth:*** Policy and infrastructure improvements.	–***Price Instability:*** Fluctuating raw material and product prices. –***High Competition:*** From virgin plastic producers and larger recyclers. –***Unregulated Waste Market:*** Waste mafias disrupt supply chains. –***Quality Challenges:*** Contamination and irregular supply lower product acceptance. –***Strict Regulations:*** Complex waste policies limit scalability.

Figure 4: SWOT Analysis for SMEs in Pakistan's Plastic Recycling Industry

4.5. Segmented Analysis of SMEs

SMEs involved in plastic recycling in Pakistan can be segmented by their scale of operations, activities, and market reach. Each segment – micro, small, and medium enterprises – plays a distinct role and faces unique challenges and opportunities:

- **Micro Recyclers (Informal & Community-Level)**: These are very small operators, often in the informal sector, with a limited reach (neighbourhood or town). They include individual waste pickers and family-run scrap shops that collect and sort plastic waste by hand. Operating with minimal capital and basic tools, micro enterprises focus on collecting and aggregating recyclable plastics to sell up the value chain. For instance, in urban centres it is common to find *kabari* or *raddiwala* (an informal scrap dealer in South Asia who collects, buys, and resells recyclable waste like plastic, metal, and paper) shops buying waste plastic from households and waste pickers, then sorting and selling it to larger recyclers.
  - **Challenges**: Lack of formal recognition, unsafe working conditions, and volatile income are major issues. These micro actors often work in silos and face difficulty getting fair prices or accessing credit.
  - **Opportunities**: Because they have deep community ties, they can achieve high collection rates; with better organization (e.g. cooperatives or integration into municipal systems), they could significantly increase recycling while improving their livelihoods.

- **Small-Scale Recyclers (Local SMEs & Startups)**: These are formal or semi-formal businesses with some machinery and a broader market reach (city or regional). Small recyclers typically handle processing tasks – such as cleaning, shredding, and melting plastics – to create recycled raw materials (like pellets or flakes) or simple finished products. Many innovate by upcycling plastic into value-added products for local markets. For example, a Lahore-based startup *Bigger Bricks* recycles plastic waste into large, durable construction bricks for building projects. Such small enterprises often cater to niche markets like alternative building materials, crafts, or bespoke recycled goods.
    - **Challenges**: They commonly struggle with limited financing and technology. Scaling up production or improving product quality requires capital for better equipment and training. They also face an inconsistent supply of sorted plastic and competition from cheaper virgin plastics.
    - **Opportunities**: Small recyclers are agile and innovative. With targeted support (grants, incubation programs, or partnerships), many have the potential to expand and capture new markets for recycled products. Their success stories (e.g. turning plastic bags into tiles or furniture) can inspire further entrepreneurship in recycling.
- **Medium-Sized Recyclers (Established Enterprises)**: These are larger SME firms, often formally registered, operating recycling plants or factories with significant processing capacity and distribution networks nationwide (and even internationally). They engage in industrial-scale recycling, producing high-quality recycled polymers that can substitute virgin materials. A prime example is a Karachi-based company that processes post-consumer PET bottles into clean plastic flakes – over 5,000 tons per month – and exports this recycled material worldwide. Medium recyclers like this run sophisticated operations (spread over acres, with advanced equipment) and hold certifications for quality and environmental standards.
    - **Challenges**: Medium enterprises require steady feedstock and must maintain quality to meet client specs, which can be difficult given Pakistan's fragmented collection system. They also need to comply with environmental regulations (e.g. managing wastewater from plastic washing) and can be affected by global oil/plastic price swings.
    - **Opportunities**: These firms are well-placed to benefit from economies of scale and emerging policies like Extended Producer Responsibility. They can form partnerships with multinational corporations looking for recycled content and potentially tap into export markets for recycled pellets and fibres. Their relatively larger size also means they can pilot new technologies (for instance, trying chemical recycling for hard-to-recycle plastics) with support. Successful medium SMEs help formalize the sector by demonstrating that recycling can be a profitable, large-scale industry, not just an informal activity.

Notably, across all segments, Pakistani SMEs in recycling have begun to collaborate more through networks and alliances. For example, the *CoRe Alliance* (Coalition for Recycling) brings together companies to promote packaging collection and recycling. Sharing of best practices and resources between micro, small, and medium recyclers can address the current gap where many operate in isolation. By working collectively – e.g. small startups supplying raw material to medium processors, or larger firms providing mentorship to informal collectors – these segmented players can complement each other. This integrated approach enhances the overall efficiency of the recycling sector and drives the country closer to a circular economy model, with benefits flowing from the grassroots collector to the industrial recycler.

5. Technological Feasibility

5.1. Assessment of Available Recycling Technologies

SMEs in the Pakistan's recycling sector employ a variety of technologies (Figure 5), each with its own set of advantages and challenges:

- **Manual Sorting**: This basic method involves sorting plastic waste by hand and is often prone to inefficiencies. While it's low-cost, it requires significant labour and can result in contamination of the materials.
- **Automated Sorting**: Automated sorting systems improve efficiency and reduce the need for manual labour. However, they require significant capital investment, which is often unaffordable for smaller SMEs.
- **Injection Moulding**: Injection moulding is a widely used technology that allows SMEs to produce high-quality recycled plastic products. However, it requires specialized machinery, which many SMEs lack due to financial constraints.
- **Manual Separation**: This labour-intensive method involves the separation of different plastic types, which can be time-consuming and prone to errors.

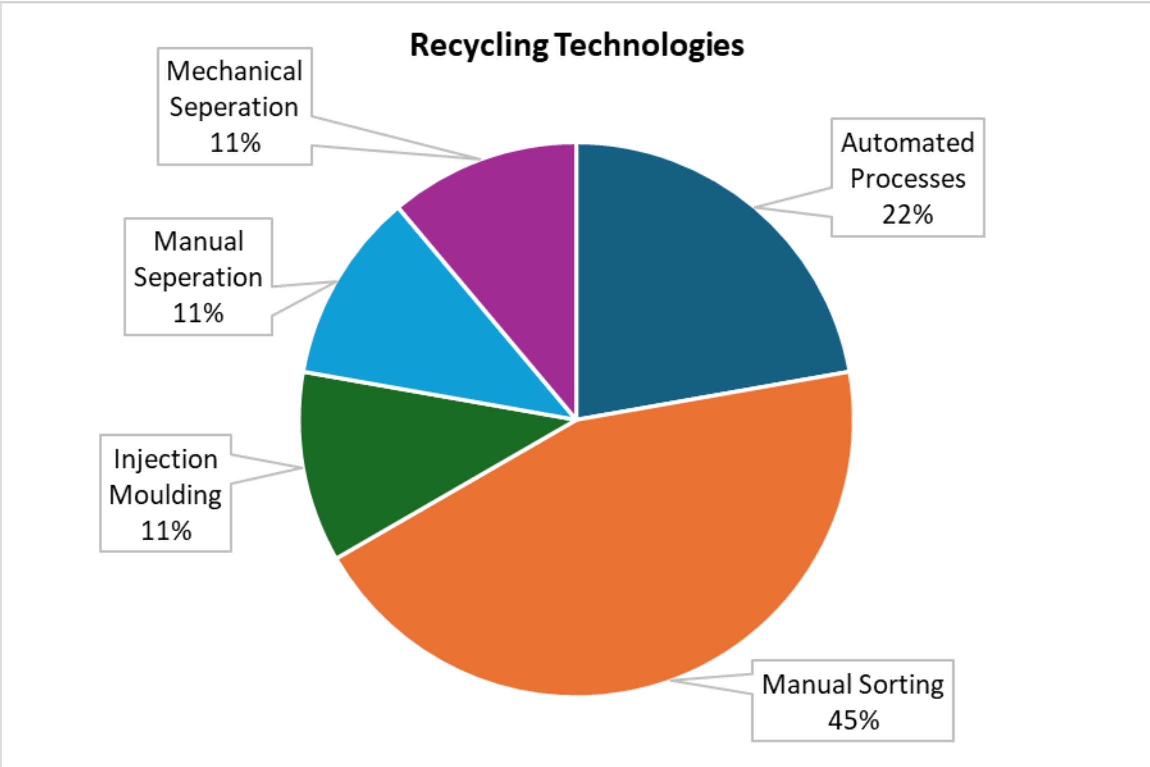


Figure 5: Available recycling technologies in Pakistan's SMEs/Startups

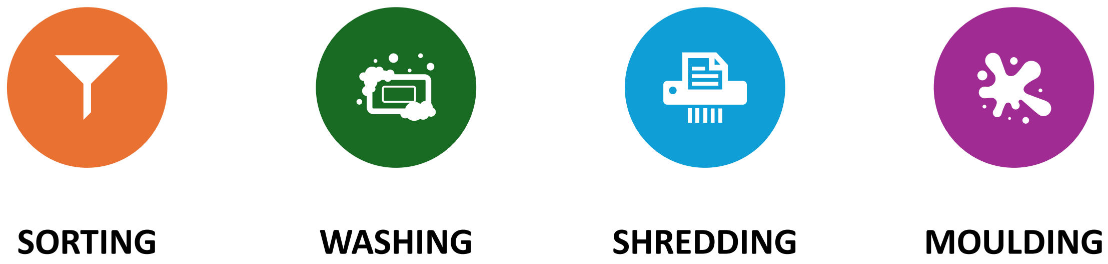


Figure 6: Typical recycling processes in Pakistan's SMEs

Many SMEs still rely on outdated machinery, which increases processing times, energy consumption (50 to 700 kWh per ton of plastic processed), and overall operational costs. Furthermore, a shortage of skilled technicians complicates the adoption of modern, more efficient technologies, limiting SMEs' ability to scale their operations.

5.2. Scalability and Sustainability of Technologies

The scalability of plastic recycling operations largely depends on investments in modern and automated sorting and processing technologies. Automation would increase operational efficiency and reduce reliance on manual labour, enabling SMEs to process larger volumes of plastic waste more cost-effectively. Moreover, integrating sustainable practices such as solar energy can reduce energy consumption, lower operational costs, and contribute to a greener environment. Moreover, integrating sustainable practices such as solar energy can reduce energy consumption, lower operational costs, and contribute to a greener environment. Some startups have already implemented solar energy systems to power their operations, reducing reliance on conventional energy sources. Additionally, certain SMEs have installed emissions monitoring systems and automatic energy control systems to enhance efficiency and minimize environmental impact.

Investing in research and development (R&D) to innovate new recycling techniques or improve existing ones could also enhance the scalability and sustainability of recycling technologies. However, these initiatives require strong financial backing, which remains a significant barrier for many SMEs in Pakistan.

5.3. Comparative Analysis of Plastic Recycling Technologies for SMEs

Plastic recycling technologies available to SMEs generally fall into mechanical, chemical, and (emerging) biological methods. Each has different cost implications, scalability potential, efficiency levels, and environmental impacts, which determine their feasibility in Pakistan's context.

Mechanical Recycling (Conventional Recycling)

Mechanical recycling involves physically processing waste plastics—through steps like sorting, grinding, washing, and remelting – into new plastic materials or products. It is the most common and accessible method for SMEs. One of its biggest advantages is cost-effectiveness: the process is relatively simple and uses significantly less energy than manufacturing plastics from virgin petrochemicals. Many Pakistani SMEs already practice mechanical recycling because equipment such as shredders, extruders, and moulding machines are readily available and can be operated at small to medium scale. The method works well for thermoplastics like PET, PE, and PP that can be melted and reformed. For example, an SME might collect PET bottles, shred them into flakes, and then extrude those into pellets or fibres for reuse in textile or packaging industries. Mechanical recycling also tends to have a lower environmental footprint in terms of greenhouse gas emissions compared to chemical processes, as it avoids large chemical reactions and simply reuses the polymer in a new form.

However, mechanical recycling has limitations that affect efficiency and output quality. Plastics can typically be mechanically recycled only a few times before their polymer chains degrade, leading to weaker material each cycle. This means recycled plastic may be of lower quality (e.g. brittle or discoloured), limiting its applications unless blended or downcycled. Another challenge is that not all plastics are suitable: multi-layer packaging, heavily contaminated plastics, or certain thermoset plastics cannot be easily processed by mechanical means. SMEs often require relatively clean and sorted plastic feedstock, which incurs extra effort and cost (sorting and washing). If the input waste is mixed or dirty, the efficiency drops, and the recycling output can be unusable for high-end uses. Despite these issues, mechanical recycling remains the workhorse technology for SMEs – it's scalable from micro-operations (hand-sorting and flaking) up to medium factories, and its environmental impact is generally positive (significantly reducing waste and CO_2 emissions by substituting virgin plastic). For Pakistan, strengthening mechanical recycling (via better collection of clean plastics and improved equipment for SMEs) is the most feasible path in the near term.

Chemical Recycling (Advanced / Feedstock Recycling)

Chemical recycling refers to technologies that break down plastics into their chemical building blocks, which can then be used to make new plastics or other chemicals. Methods include pyrolysis (heating plastics in absence of oxygen to produce oils and gases), gasification (converting to syngas), and chemical depolymerization (using solvents or catalysts to revert polymers into monomers). The appeal of chemical recycling lies in its ability to handle a broader range of plastic waste than mechanical methods – even dirty, mixed, or non-meltable plastics can potentially be processed. It can also produce output like fuel or virgin-quality petrochemicals. For example, laboratory studies in Pakistan have shown pyrolysis can convert waste plastics into oil with high efficiency – one experiment achieved an 82% fuel yield from high-density polyethylene (HDPE) plastic. Moreover, chemical processes can theoretically be repeated without degrading material quality (since they rebuild polymers afresh), enabling upcycling back to like-new plastic.

In practice, however, chemical recycling is costly and technically complex, which makes it challenging for SMEs. These technologies often require large capital investment in specialized reactors, strict temperature control, and expertise to operate safely. The operational costs (energy, catalysts, etc.) are high, and scaling down to an SME level can be inefficient – many chemical recycling plants only become economically viable at industrial scales that are beyond a typical SME's reach. Environmental impact is another concern. If not managed properly, processes like pyrolysis can emit hazardous pollutants. A stark example is in Punjab, Pakistan, where several small, unregulated pyrolysis plants (turning scrap plastic and tires into fuel) caused serious air pollution. Authorities in Lahore eventually banned pyrolysis units after they were found to release toxic emissions contributing to smog. This illustrates that without robust emission controls (which add cost), chemical recycling can undermine its environmental benefits. Additionally, while chemical recycling can in theory produce high-quality outputs, in practice the resulting oils or monomers may require further refining, and there's often a question of market demand – e.g. whether it's more profitable to sell pyrolysis oil as low-grade diesel or to refine it back into plastic.

Given Pakistan's local context, chemical recycling is less feasible for most SMEs at present. It may hold promise for medium-sized enterprises or consortiums that can pool resources – especially to tackle hard-to-recycle plastics that mechanical methods cannot handle. Some pilot initiatives (possibly in partnership with universities or larger companies) could introduce modular pyrolysis units or solvent-based recycling on a trial basis. But broadly, due to high costs and regulatory hurdles, chemical recycling is likely to play a limited role for SMEs in the short term. Any adoption should be coupled with training and pollution control measures to ensure it truly contributes to a circular economy without creating new environmental problems.

Biological Recycling (Emerging Methods)

Biological recycling of plastics involves using living organisms (like specialized bacteria or fungi) or enzymes to degrade plastics into simpler molecules, which can then be reused. This is a relatively new and experimental field. Some microbes have been discovered that can slowly consume certain plastics (for example, *PET-degrading enzymes* that break PET into its constituent monomers). The potential advantage of biological methods is that they could be low-energy and eco-friendly – essentially letting nature do the work of decomposition in a controlled way, without the high temperatures or harsh chemicals of other methods. In theory, biological recycling could handle mixed plastic waste if the organisms are engineered to digest various polymers, and it might eliminate plastics' environmental footprint by fully mineralizing them.

However, biological techniques are not yet commercially viable for mainstream plastic recycling, especially for SMEs in Pakistan. The processes developed so far are confined to laboratories or pilot plants. They often require specific conditions (certain temperature, nutrients, and lots of time) for microbes to break down plastic, which makes them far too slow for the volumes of waste that even a small recycler deals with. Moreover, currently known plastic-eating bacteria mostly work on a narrow range of plastics (for instance, PET), so they wouldn't address the full spectrum of waste. Cost and scalability are major bottlenecks – producing the necessary enzymes or maintaining bioreactor farms of microbes can be expensive, and ramping this up to treat tons of waste is an ongoing challenge in research. Given these factors, biological recycling is *not* a feasible option for Pakistani SMEs in the near term. It remains a longer-term prospect: as global R&D progresses, we might see deployable kits or bio-additives that SMEs could use to degrade residual plastics that mechanical recycling leaves behind. Until then, SMEs can focus on mechanical recycling improvements and perhaps participate in trials or academic partnerships exploring bio-recycling on a small scale. For now, mechanical recycling stands out as the most viable technology for SMEs, with chemical methods as a distant second (in select cases), and biological methods largely on the horizon.

5.4. Integration of low-tech solutions

The integration of low-tech solutions within Pakistan's plastic recycling sector reflects the socio-economic and infrastructural realities confronting SMEs. Manual processes, including hand-sorting and sun-drying, underpin 80% of operations due to their affordability (initial costs under 1 million PKR) and adaptability to fragmented supply chains, particularly in regions with limited industrial infrastructure, such as Khyber Pakhtunkhwa and Balochistan. These methods, however, face challenges such as contamination and labour inefficiencies, necessitating strategic adaptations. Hybrid models, which combine manual labour with basic mechanization, have emerged as a pragmatic approach. For example, DAVAAM, a startup funded by the World Bank, employs manual refill stations for dispensing household products but integrates PCSIR-certified quality testing to ensure cost reductions of 35–40% compared to conventional bottled goods.

Skill development initiatives further enhance the efficacy of low-tech methods. Training programs focused on waste segregation – particularly for MLP, which constitutes 20–30 PKR/kg of low-value waste – have improved sorting accuracy, reducing rejection rates to less than 5%. Community-based collaborations also play a pivotal role; IRVERDE's engagement with female workers and informal waste pickers (*safai walas*) not only mitigates logistical costs but also fosters social inclusivity, aligning with Sustainable Development Goals (SDGs) related to gender equity and decent work.

Energy constraints are addressed through innovations such as solar-powered crushers, adopted by SMEs in Punjab to reduce reliance on grid electricity. Case studies like eco-paver production at Concept Loop & Artistic Milliners, a blend of 30% recycled plastic and 70% manually mixed concrete, demonstrate the viability of low-tech solutions in generating affordable construction materials, despite competition from virgin plastic markets. Nevertheless, systemic barriers persist, including policy gaps in Extended Producer Responsibility (EPR) and unregulated competition from informal networks. To mitigate these, policymakers must prioritize subsidies for solar adoption, formalize informal waste collectors, and establish platforms for public-private collaboration, ensuring that low-tech solutions evolve in tandem with Pakistan's circular economy aspirations.

6. Life Cycle Assessment (LCA) of Recycling Technologies

The Life Cycle Assessment (LCA) conducted in this study evaluates the environmental impacts of various plastic recycling technologies and other end-of-life management options in Pakistan. The goal of the LCA is to quantify the life cycle environmental impacts of these technologies, focusing on their sustainability and alignment with circular economy principles. The study is a "gate-to-grave" LCA, meaning it covers the entire lifecycle of plastic waste management from collection to final disposal or recycling. The complete report is given in ***Annex 04 – Life Cycle Assessment (LCA) on Feasibility of Plastic Waste Recycling Technologies in Pakistan***.

6.1. Environmental Impact of Plastic Recycling Processes

The Life Cycle Assessment (LCA) results demonstrate that diverting plastic waste from landfills, open dumps, and especially open burning has substantial environmental benefits. Recycling options, including low-technology mechanical recycling, higher-technology open-loop recycling, and closed-loop recycling of PET, significantly reduce the life cycle impacts of plastic waste management. These benefits are observed across all environmental impact categories, including climate change, human health, ecosystem quality, and non-renewable resource depletion. Recycling also aligns with circular economy principles, ensuring that the value of plastics is not lost from the economy and that less plastic enters the natural environment and water systems.

The study highlights that the recycling process itself has environmental impacts, primarily due to energy consumption, chemical use, and waste generation. However, these impacts are more than offset by the avoided production of virgin plastic. For example, low-technology mechanical recycling, as practiced by SMEs in Pakistan, results in a net reduction in environmental impacts due to the avoided production of virgin plastic, which is a highly energy-intensive process. Primary data collected from six SME recyclers in Pakistan revealed that the recycling yield for low-technology mechanical recycling averages 84%, meaning that 84% of the plastic waste input is converted into recyclate, while the remaining 16% is disposed of as waste. This yield is influenced by the quality of incoming plastic waste, with cleaner inputs resulting in higher yields and lower waste generation.

Figure 7 illustrates the aggregated life cycle human health and ecosystem quality impacts of various plastic waste management options in Pakistan. The results are presented using system expansion, which credits the recycling system for avoiding the production of virgin plastic. The figure shows that all three recycling options (low-technology, high-technology, and closed-loop recycling) have net negative impacts, meaning they provide overall environmental benefits. In contrast, landfilling, incineration with energy recovery, and RDF production have higher impacts compared to the baseline scenario. The recycling options are dominated by the avoided impacts of virgin plastic production, which significantly reduce the overall environmental burden. This figure highlights the importance of recycling in reducing human health and ecosystem quality impacts, particularly when compared to traditional waste management methods like open burning and landfilling.

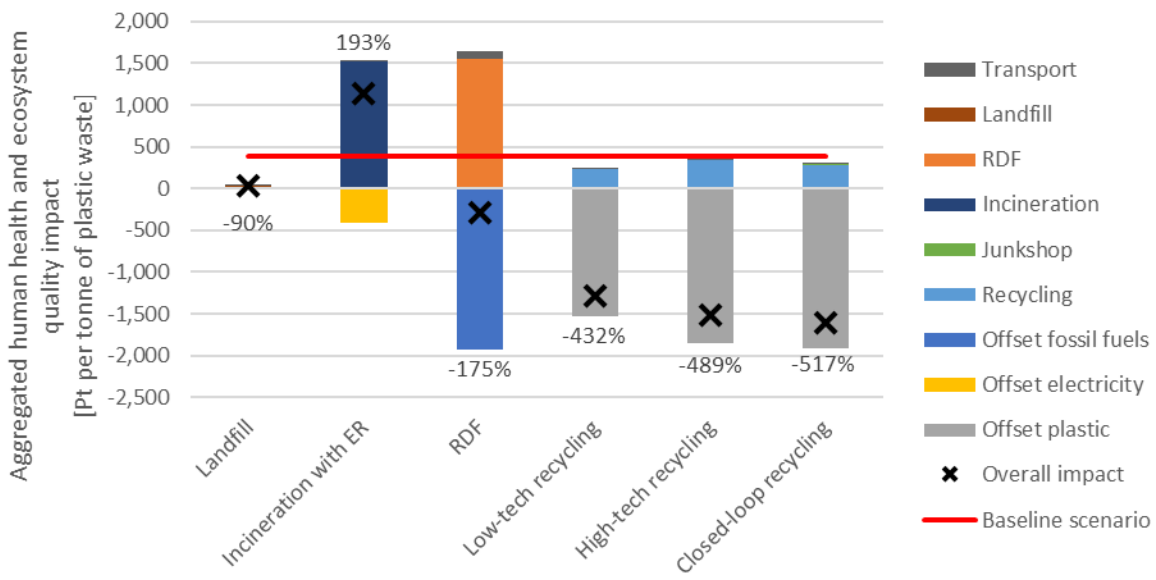


Figure 7: Aggregated life cycle impacts on human health and ecosystem quality for plastic waste management in Pakistan, segmented by life cycle stage. Crosses indicate net results, with percentages showing differences.

According to secondary research, plastic recycling's environmental impact depends on technology and polymer characteristics (Schwarz et al., 2021). Mechanical recycling, the most common method, reduces GHG emissions by 70–80% compared to virgin plastic production but degrades material quality over time, increasing resource demand (Alhazmi et al., 2021; Schwarz et al., 2021). Its benefits depend on substitution rates—if below 75%, residual waste may offset emission reductions (Alhazmi et al., 2021). Tertiary recycling, such as pyrolysis and gasification, effectively recovers polyolefin monomers but has high energy demands and CO_2 emissions (Perugini et al., 2005; Schwarz et al., 2021). Primary recycling (e.g., solvent-based dissolution) minimizes environmental harm but requires high-purity input streams, limiting its application (Schwarz et al., 2021).

Incineration with energy recovery reduces landfill use but generates the highest CO_2 emissions and toxic byproducts (Alhazmi et al., 2021; Vlasopoulos et al., 2023). Landfilling, the least sustainable option, emits methane and produces leachate with minimal energy recovery (Arena et al., 2003). Key factors include transportation emissions and chemical use, such as sodium hydroxide and flame retardants, which risk ecosystem contamination (Schwarz et al., 2021; Vlasopoulos et al., 2023). Optimized mechanical recycling remains the most viable option for GHG reduction, while tertiary methods require improvements to mitigate energy intensity. Incineration and landfilling, though practical for waste management, pose significant environmental risks.

6.2. Carbon Footprint, Energy Use, and Waste Reduction

The carbon footprint of plastic recycling processes is a crucial consideration in life cycle assessments (LCA). Both primary analysis and secondary research highlight that recycling options offer significant environmental benefits compared to landfilling, open dumping, and incineration. Recycling processes, despite their energy consumption, result in a net reduction of greenhouse gas (GHG) emissions due to the avoided production of virgin plastic.

Closed-loop recycling of PET demonstrates the highest climate change benefit, with net negative climate impacts attributed to the high-quality recyclate produced, which offsets significant amounts of virgin plastic production. The study also reveals that energy use in recycling varies based on mechanization levels and the quality of plastic waste inputs. In Pakistan, small and medium enterprises (SMEs) engaging in low-technology recycling have lower energy consumption, whereas high-technology recycling, despite its higher energy demands, produces better quality recyclate that displaces more virgin plastic. Enhancing energy efficiency and transitioning to renewable energy sources can further minimize the carbon footprint of recycling.

Waste reduction is another critical advantage of recycling. The primary analysis indicates that low-technology recycling in Pakistan achieves an 84% recycling yield, meaning only 16% of input plastic waste is discarded. Improving waste sorting and contamination control can further enhance recycling yields, reducing the proportion of plastic waste ending up in landfills or the environment. Figure 8 presents the short-term climate change impacts of different plastic waste management strategies in Pakistan, showing that recycling—especially closed-loop recycling—has net negative climate impacts. Conversely, incineration with energy recovery increases climate impacts as the emissions from plastic combustion are not fully offset by avoided grid electricity. Refuse-derived fuel (RDF) production, however, yields net negative climate change impacts by displacing fossil fuel combustion.

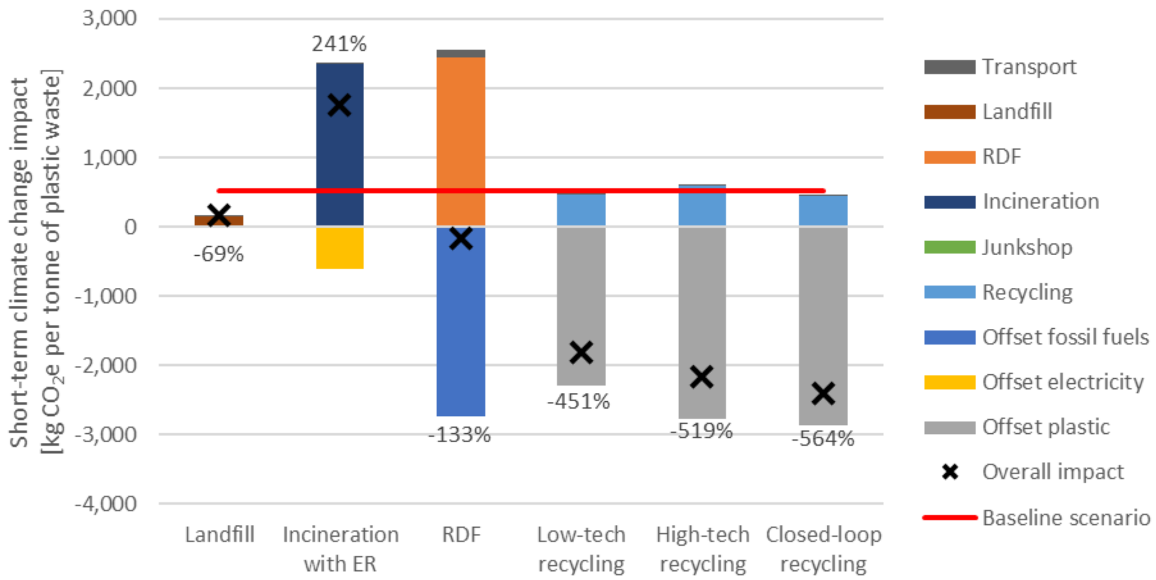


Figure 8: Short-term climate change impacts of plastic waste management in Pakistan, segmented by life cycle stage. Crosses indicate net impacts, with percentages showing differences relative to the national baseline.

Water use in recycling processes is another environmental consideration. Figure 9 illustrates the water scarcity impacts of different plastic waste management options in Pakistan, revealing that recycling reduces overall water consumption due to avoided virgin plastic production. While the recycling process itself requires water for cleaning and processing, these impacts are outweighed by the water savings achieved through reduced demand for virgin plastic. In contrast, landfilling, incineration, and RDF production contribute to greater water scarcity impacts.

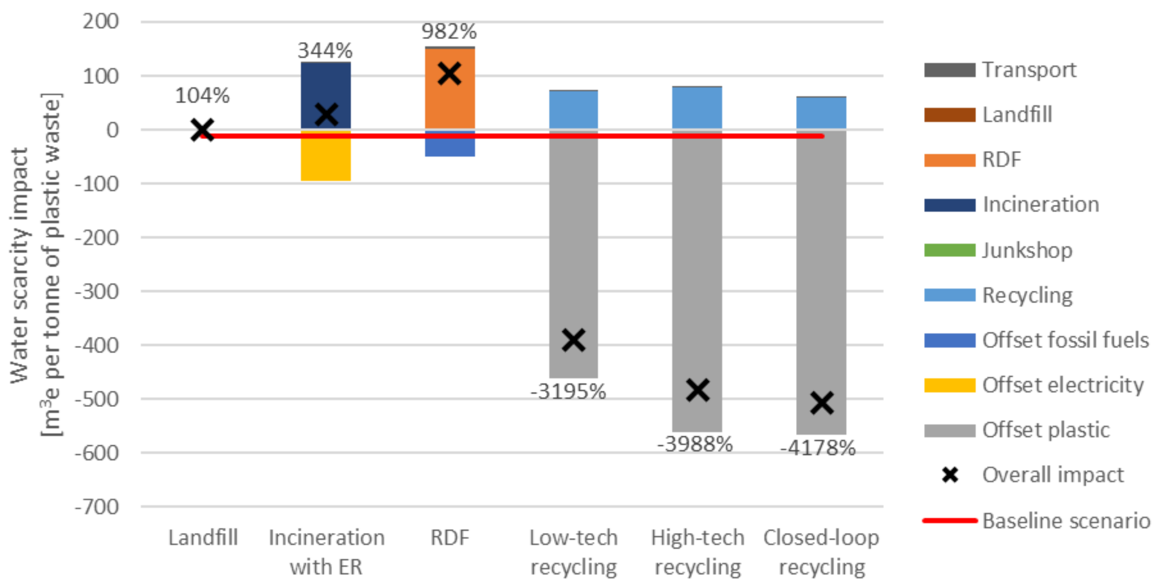


Figure 9: Water scarcity impacts of plastic waste management in Pakistan, segmented by life cycle stage. Crosses indicate net impacts, with percentages showing differences relative to the baseline scenario.

Figure 10 breaks down the climate change impacts of recycling processes by key contributors, including electricity use, heat generation, and solid waste disposal. In low-technology recycling, electricity and fuel use account for 50% of the climate change impact, with solid waste disposal contributing 34%. For high-technology and closed-loop recycling, energy use dominates, accounting for 66% and 52% of impacts, respectively. These findings underscore the need for improving energy efficiency in recycling processes and minimizing waste generation, particularly in low-technology setups where disposal impacts are higher.

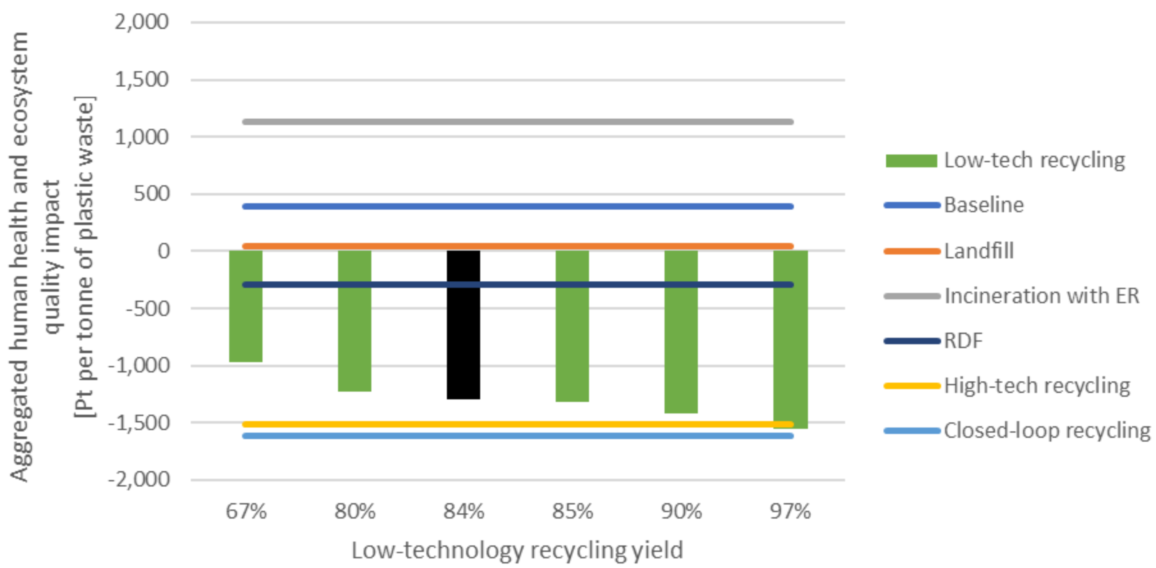


Figure 10: Human health and ecosystem quality impacts of varying recycling yields in low-tech mechanical recycling. The black column represents the default scenario (83.9% yield).

Secondary research corroborates these findings, emphasizing the emissions reduction potential of recycling. Gasification of polyolefins (PE, PP) produces syngas with minimal CO_2 emissions (Schwarz et al., 2021), while pyrolysis of polystyrene (PS) and polymethyl methacrylate (PMMA) reduces emissions by 80% compared to virgin plastic production (Schwarz et al., 2021). Mechanical recycling lowers the carbon footprint by 1.4–2.0 kg CO_2-equivalent per tonne, significantly less than landfilling (5.3 kg CO_2-eq) and incineration (7.3 kg CO_2-eq) (Alhazmi et al., 2021).

Energy demands vary by recycling method. Closed-loop mechanical recycling consumes 110–200 kWh per tonne, while pyrolysis requires approximately 400 kWh due to high-temperature processing (Vlasopoulos et al., 2023). Recycled PET production is more energy-efficient than virgin PET (Arena et al., 2003). Hydrocracking in feedstock recycling displaces fossil fuel use, reducing energy consumption by 11 MJ per kilogram of processed plastic (Perugini et al., 2005).

Waste reduction efficiency depends on yield rates and contamination management. Mechanical recycling achieves a 70% yield, whereas tertiary methods like pyrolysis and gasification reach 85%, with losses mainly due to impurities (Schwarz et al., 2021). Advanced mechanical systems recover over 90% of plastics, while landfilling retains only 55% of untreated waste, leading to resource inefficiency (Alhazmi et al., 2021).

Maximizing the environmental benefits of plastic recycling requires balancing carbon footprint reduction, energy efficiency, and waste recovery. Gasification and pyrolysis provide superior carbon savings for specific polymers, while mechanical recycling remains the most energy-efficient option for high-purity plastic streams. Improved sorting technologies and contamination control are crucial for enhancing recycling outcomes. Policymakers and industry stakeholders must adopt method-specific strategies aligned with polymer characteristics and circular economy principles to optimize recycling benefits.

6.3. Analysis of Sustainable Practices

The LCA identifies several sustainable practices that can improve the environmental performance of recycling technologies. These include improving the quality of incoming plastic waste, minimizing energy consumption, and reducing chemical use. Cleaner incoming plastic waste reduces the need for water and chemicals in the cleaning process, improves the quality of output recyclate, and reduces waste generation. Energy efficiency measures, such as switching from diesel and LPG to electricity, can also reduce the environmental impacts of recycling processes. Additionally, larger, mechanized plants could switch to renewable energy sources, such as solar PV, to further mitigate impacts.

The study also highlights the importance of closed-loop recycling, which produces recyclate of equivalent quality to virgin plastic. Closed-loop recycling of PET, for example, has the highest environmental benefits, as it offsets the production of virgin PET, which is a highly energy-intensive process. However, the study notes that the results for closed-loop recycling are not robust within the data limitations of the study, as the higher technology and closed-loop recycling options have higher recycling processing impacts due to increased energy, material, and water inputs.

Figure 11 summarizes the plastic footprint and material circularity indicator (MCI) for different plastic waste management options in Pakistan. The plastic footprint measures the amount of plastic leaked into the marine environment, while the MCI quantifies the circularity of the system. The results show that recycling options have a plastic footprint of 0%, as they effectively manage plastic waste. In contrast, landfilling has a higher plastic footprint than the baseline scenario due to poor landfill management. The MCI values for recycling options are around 90% of the maximum achievable, indicating high levels of circularity. This table underscores the importance of recycling in achieving a circular economy and reducing plastic pollution.

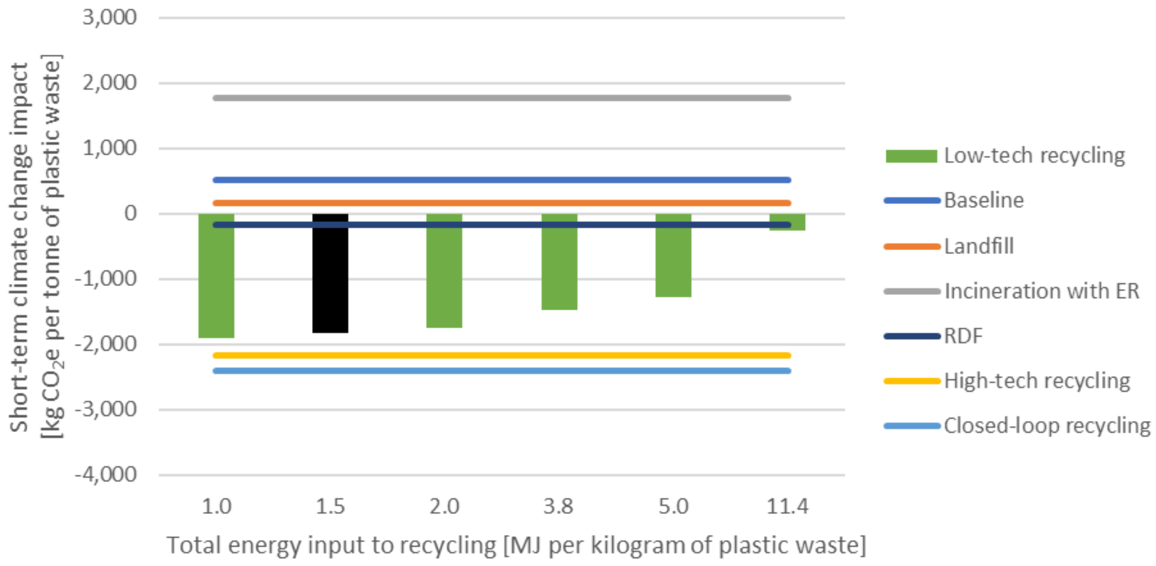


Figure 11: Short-term climate change impacts of varying energy input in low-tech mechanical recycling. The black column represents the default scenario (1.5 MJ/kg).

Secondary research highlights that plastic recycling efficiency varies by region, technology, and policy. Developed regions, such as Europe, achieve 60–90% recycling rates through advanced sorting technologies and strict policies like the EU's circular economy directives (Alhazmi et al., 2021). In contrast, developing nations rely on informal waste networks, limiting scalability and efficiency (Alhazmi et al., 2021). Post-2018 import bans in China and Thailand have reduced transport emissions but exposed infrastructure gaps (Schwarz et al., 2021).

Hybrid systems combining mechanical and feedstock recycling improve material recovery and energy efficiency, while automated sorting enhances scalability (Perugini et al., 2005; Schwarz et al., 2021). Closed-loop water recycling further minimizes freshwater consumption in processing (Vlasopoulos et al., 2023). However, mechanical recycling often results in material degradation, restricting high-value applications (Schwarz et al., 2021).

Regulatory frameworks significantly influence recycling outcomes. The EU's circular economy policies promote high recycling rates, while global import restrictions on plastic waste have driven uneven improvements in domestic recycling capacity (Alhazmi et al., 2021; Schwarz et al., 2021).

6.4. Recommendations for Environmentally Sound Recycling Technologies

Based on the LCA results, the study recommends the following environmentally sound recycling technologies and practices:

- **Improve the Quality of Incoming Plastic Waste**: Cleaner incoming plastic waste reduces the need for water and chemicals in the cleaning process, improves the quality of output recyclate, and reduces waste generation. This can be achieved through source-separated collection or increased upstream pre-processing.

- **Minimize Energy Consumption**: Energy efficiency measures, such as switching from diesel and LPG to electricity, can reduce the environmental impacts of recycling processes. Larger, mechanized plants could also switch to renewable energy sources, such as solar PV, to further mitigate impacts.
- **Promote Closed-Loop Recycling**: Closed-loop recycling, which produces recyclate of equivalent quality to virgin plastic, has the highest environmental benefits. However, the study notes that the results for closed-loop recycling are not robust within the data limitations of the study, and further research is needed to confirm these findings.
- **Increase Recycling Yields**: Improving the quality of incoming plastic waste and optimizing recycling processes can increase recycling yields, reducing the amount of waste generated and improving the overall sustainability of recycling operations.
- **Adopt System Expansion for Allocation**: The study recommends using system expansion to fully account for the benefits of recycling, as it avoids allocation choices that can significantly alter LCA results. System expansion credits the recycling system for avoiding the production of virgin plastic, resulting in a more accurate assessment of the environmental benefits of recycling.
- **Adopt Hybrid Sorting Systems**: Combine manual labour with low-energy automation (e.g., optical sensors) to improve sorting accuracy and throughput while minimizing energy use.
- **Transition to Renewable Energy**: Integrate solar power into energy-intensive processes (e.g., pyrolysis) to reduce grid dependence and lower carbon footprints.
- **Optimize Logistics**: Use electric vehicles for short-distance transport and consolidate collection routes to minimize fossil fuel consumption.
- **Enforce Extended Producer Responsibility (EPR)**: Mandate corporate accountability for plastic waste through EPR laws, incentivizing eco-design and recycling investments.

7. Development of a Sustainable Plastic Recycling Model for SMEs

7.1. Stakeholder Engagement and Capacity Building

Effective plastic recycling requires the involvement of a broad set of stakeholders in Pakistan, including government bodies, businesses, civil society, and local communities. Key stakeholders and their roles include:

- **Government Agencies:** At the national level, the Ministry of Climate Change (MoCC) is central to policymaking on plastic waste (e.g. it has introduced plastic bag bans and is formulating a national plastics policy). Provincial Environmental Protection Agencies (EPAs) enforce regulations and standards for waste management facilities. Local government and municipal corporations (such as city waste management companies in Lahore, Karachi, etc.) are responsible for waste collection services and can integrate recycling into municipal systems. Their support is crucial for providing an enabling regulatory framework, incentives (or enforcement) for recycling, and infrastructure (like land for recycling parks or collection centres). Engaging government stakeholders involves ensuring that recycling SMEs' perspectives inform policy – for instance, including SME representatives in consultations on rules for waste segregation or Extended Producer Responsibility. Policymakers are increasingly recognizing the need for such inclusion: a recent dialogue stressed that multiple ministries (Climate Change, Commerce, Finance, etc.) must work jointly with industry and communities to address plastic pollution. Strengthening this coordination and political will is a cornerstone of stakeholder engagement.
- **Private Sector Businesses:** This category spans both large companies and SMEs. On one side are the manufacturers and brand-owners who generate plastic packaging – consumer goods companies, retailers, etc. They have a responsibility (and now, under emerging EPR regulations, an obligation) to participate in recycling efforts, for example by funding take-back schemes or using recycled content in products. On the other side are the recycling businesses themselves (SMEs) who collect and process plastic waste. Additionally, there are industry associations like the Pakistan Plastic Manufacturers Association which can champion recycling initiatives among their members. Many businesses in Pakistan are already active – for instance, startups and SMEs have launched recycling ventures as part of corporate sustainability and entrepreneurship. However, these efforts can be fragmented. More unified engagement is needed, such as public-private partnerships where corporations support SME recyclers with financing or supply agreements, and in return improve their plastic footprint. As one report noted, SMEs and startups working on waste recycling are often in silos, underscoring the need for collaborative strategies with public sector support. Engaging the private sector means creating platforms (alliances, roundtables) where large companies, recycling SMEs, and startups can share knowledge and forge partnerships to scale up recycling collectively.
- **Non-Governmental Organizations (NGOs) and Academia:** NGOs play a dual role in both advocacy and implementation. Environmental NGOs (like WWF-Pakistan, which has campaigned on plastic pollution) raise awareness and hold stakeholders accountable. Development organizations and community-based NGOs often pilot solutions on the ground – for example, setting up community recycling centres or running behaviour-change campaigns to encourage waste segregation. They can facilitate training for waste workers and link informal collectors to formal markets. Academia and research institutions contribute by developing appropriate recycling technologies and conducting studies (such as material flow analyses or life-cycle assessments) that inform policy

and business decisions. To engage these stakeholders, it is effective to include them in multi-stakeholder forums and working groups. Their insights ensure that strategies are evidence-based and socially inclusive. NGOs can also act as intermediaries, convening dialogues between the government, citizens, and businesses. For instance, SDPI (an Islamabad-based think tank) has been working on fostering business engagement for circular economy, emphasizing collaboration among corporations, SMEs, startups, and researchers. Leveraging NGOs' convening power and neutral stance can help align the sometimes-differing interests of public and private players toward common recycling goals.

- **Local Communities and Informal Sector:** Ultimately, the success of recycling initiatives hinges on community participation. This group includes the public (households who must segregate and dispose of waste properly) and informal waste workers (waste pickers, scavengers, junk dealers) who are on the frontlines of recycling. Any engagement strategy must recognize and empower informal waste workers, who currently collect most recyclable materials in Pakistan. Including them means working to formalize their role – for example, through cooperatives or by integrating them into municipal waste collection programs with proper compensation. Communities can be engaged through awareness campaigns led by local leaders, schools, and religious centres, educating citizens on the importance of reducing, reusing, and recycling plastics. Notably, involving community stakeholders in planning and decision-making increases buy-in; for instance, consult local neighbourhood committees when setting up a recycling collection point or scheduling pickups. Providing incentives at the community level (such as exchange schemes where people can swap recyclables for useful items or discounts) can also spur participation. Capacity building for these groups is vital – teaching waste pickers safer handling methods or providing carts and protective gear improves efficiency and dignity, while teaching households how to sort waste can dramatically improve the quality of recyclables entering the system.

Strategies for engaging stakeholders revolve around building partnerships, communication, and mutual benefits. A multi-stakeholder platform or task force on plastic waste (comprising government, private sector, NGOs, community reps) can institutionalize regular dialogue and coordinated action. This could be aligned with initiatives like the Global Plastic Action Partnership or Pakistan's own "Living Indus" project, ensuring high-level support. Public awareness drives (via media, community workshops, school programs) are crucial to get citizens on board – these can be led jointly by government and NGOs, with businesses sponsoring campaigns as part of their corporate social responsibility. On the business front, implementing Extended Producer Responsibility (EPR) schemes will formalize engagement by requiring producers to finance recycling efforts, effectively partnering them with recyclers. The government can encourage this through policy while facilitating connections (e.g., maintaining a registry of certified SME recyclers that producers can work with). Public-private partnerships (PPP) are another strategy: for example, a city could contract an SME consortium to manage plastic waste, providing technical assistance and shared revenue. Such models have dual benefits – they engage SMEs in service delivery and give them support from authorities.

In terms of capacity-building initiatives to support SMEs, several measures can strengthen their ability to scale up recycling:

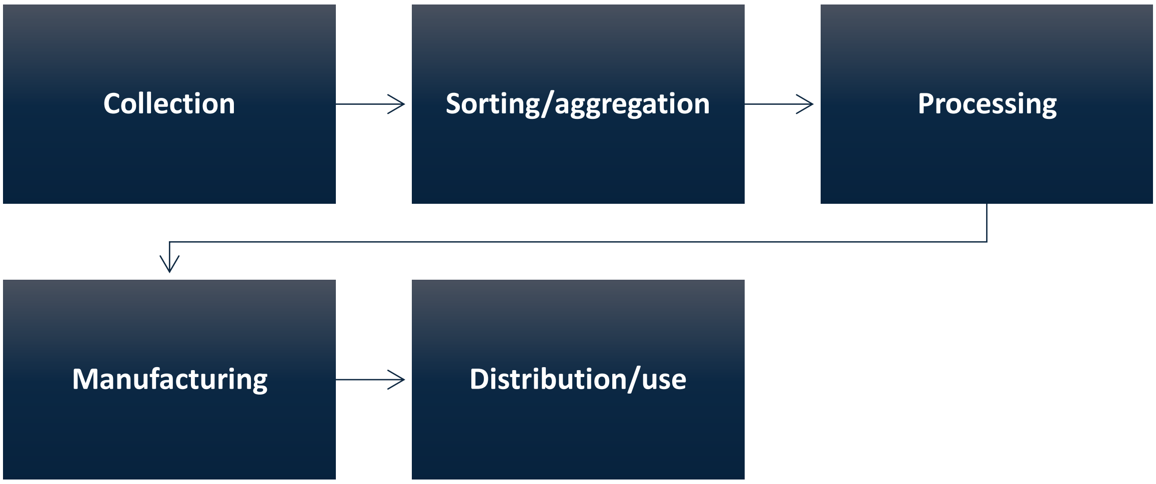
- **Technical Training and Skill Development:** Workshops and training programs can be conducted to teach SME owners and workers about improved recycling techniques, equipment maintenance, and safety standards. This includes introducing modern machinery operation, quality control for recycled outputs, and even advanced topics like conducting life-cycle assessments. Building these *"green skills"* and business skills (like product design using recycled material) will help SMEs innovate and improve efficiency.

- **Mentorship and Knowledge Sharing:** Pairing SMEs with mentors from established industries or academia can help them solve technical and managerial challenges. Experienced professionals might guide them on process optimization, product development, or navigating regulatory requirements. Knowledge-sharing platforms (online forums or periodic meetups) among recycling entrepreneurs allow exchange of lessons learned. Such peer networks prevent SMEs from feeling isolated and can spur collective problem-solving.
- **Financial and Entrepreneurship Support:** Access to finance is consistently cited as a major hurdle for recycling SMEs. Capacity building should thus include financial literacy, business plan development, and linkage to funding sources. This could take the form of partnerships with microfinance institutions for tailored loans, or government grants/tax incentives for recycling projects. Incubator and accelerator programs (like UNDP's Innovation Labs or university incubation centres) have started to include circular economy startups – providing seed funding, mentorship, and workspace. Expanding these programs will help more recycling-focused SMEs get off the ground and become investment-ready.
- **Organizational and Cooperative Development:** Many micro recyclers would benefit from forming cooperatives or associations. Training them in how to organize, register officially, and collectively market their services can increase their bargaining power. For example, a capacity-building project might help informal waste pickers form a union or cooperation, train a leadership committee, and then interface with the city authorities on their behalf. Such an organization enables small players to operate at a quasi-medium scale through aggregation of resources.
- **Public-Private Partnership Initiatives:** As a form of capacity building, government and large corporations can create funding pools or support programs specifically for SMEs in recycling. One recommendation is for the corporate sector to offer direct support in areas like product registration, quality certification, and scaling of ideas. This might involve corporate volunteers or engineers working with SMEs to improve their operations, or companies providing guarantees to banks for SME loans. Ensuring SMEs know about and can access these support programs is part of the capacity-building challenge.

Overall, stakeholder engagement and capacity building go hand in hand: by actively involving all players – from government policymakers to the rag-pickers – and investing in the skills and resources of recycling SMEs, Pakistan can create a supportive ecosystem for sustainable plastic recycling. The end goal is a well-coordinated sector where each stakeholder's strengths are harnessed: authorities enabling wise policies, businesses innovating and financing solutions, communities participating enthusiastically, and SMEs equipped to deliver results on the ground.

7.2. Design of a Plastic Waste Recycling Value Chain

Designing an effective plastic waste recycling value chain in Pakistan involves mapping out each stage from waste generation to the final recycled product and defining the roles of the actors at each stage. A simplified value chain can be described in sequential steps:



- **Waste Generation and Collection:** The chain begins with waste being generated by households, commercial establishments, and industries. Currently, a large portion of plastic waste is collected by the informal sector – individual waste pickers roam neighbourhoods and dumps, salvaging plastic, and some municipal collection systems also exist (especially for mixed waste). In many cities, residents typically dispose of unsorted trash in communal bins or on curbs, where informal collectors recover recyclables. These informal actors, including itinerant buyers and scavengers at landfills, are effectively the first link in the recycling chain, diverting plastics from the waste stream. They often focus on high-value plastics (like PET bottles and HDPE containers) because those yield the best returns, while low-value plastics may be left behind. Improving this stage of the chain could involve establishing organized door-to-door collection programs for segregated plastics (either by municipalities or in partnership with SMEs) and providing incentives for communities to separate recyclables. Integrating waste pickers by formalizing their role (e.g., giving them collection contracts or spaces to aggregate materials) would greatly enhance efficiency and ensure a steady supply of plastics into the recycling chain.
- **Sorting and Aggregation:** Once collected, plastic waste needs to be sorted by type (PET, PE, PP, etc.) and cleaned to be of use to recyclers. In the current chain, sorting is often done by small-scale traders or scrap shops. Waste pickers sell mixed recyclable material to these neighbourhood scrap dealers (*kabaris*), who then sort it into categories and bulk it up. From there, larger aggregators or traders purchase sizable quantities of sorted plastic and transport it to recycling facilities. Value addition happens at this stage by improving purity and volume – sorted, clean plastic fetches a higher price per kilogram. The role of SMEs here can be significant: many micro and small enterprises specialize in sorting/compacting plastic (some operate ballers to compress plastics for easier transport). However, a noted gap is the lack of formal sorting facilities or material recovery centres in Pakistan's waste management system. To strengthen the value chain, investments should be made in setting up sorting centres, perhaps at town or city levels, possibly through public-private partnerships. These centres could employ local workers (including former waste pickers) to do systematic segregation of plastic from municipal waste, using simple conveyor belts and manual sorting or even semi-automated sorting technologies. By doing so, contamination is reduced, and the downstream recyclers receive higher-quality feedstock, thereby increasing overall chain efficiency.
- **Processing (Recycling Operations):** This is the core of the value chain where the actual recycling technology is applied. The sorted plastic is processed by recycling SMEs or larger facilities – through mechanical recycling mainly (as discussed in section 5.3). They shred the plastic into flakes, wash it, and then melt and extrude it into granules or new products. For instance, a typical medium-scale recycler might take bales of PET bottles, grind and wash them, and produce PET

flakes which are then sold to manufacturers (locally or exported) as raw material. At this stage, different types of plastic take different routes: PET and HDPE might become flakes/pellets (raw material), whereas some SMEs directly mould products (e.g., making plastic rope, buckets, or construction blocks from mixed plastic). The actors here are the recycling companies (SMEs and a few larger enterprises) and their workers who operate the machinery. Efficiency in this link depends on technology and skill – modern machines can yield higher throughput and better-quality output. Supporting actors include machinery suppliers and possibly financing institutions (since processing equipment can be costly). Ensuring environmental compliance at this stage is also key – e.g., installing proper filtration for fumes or effluent treatment for washing units. The value chain design should incorporate feedback loops: recyclers can communicate back to collectors about what materials are needed or problematic (for example, if multi-layer plastics cannot be processed, that information should guide future collection and innovation efforts).

- **Manufacturing and End-Product Distribution:** After processing, the outputs (recycled materials) enter manufacturing. Some recycling SMEs are vertically integrated – they turn their recycled plastic directly into finished products like garbage bags, plastic furniture, textile fibres, etc. In other cases, the recycled granules or flakes are sold to other manufacturers who use them as input. For example, a textile factory might buy recycled PET flakes from a recycler to spin polyester yarn, or a packaging company might buy recycled pellets to make new bottles (if quality permits). The market reach of this stage can be local or international: as noted, Pakistani firms like one in Karachi export PET flakes to buyers abroad, meaning the value chain can extend across borders. The final products are then distributed through normal commercial channels – wholesale, retail – or delivered to industrial clients. Actors here include product manufacturers, distributors, and consumers. A healthy value chain ensures there is demand for recycled products, which "closes the loop." Creating local market demand might involve encouraging companies to use recycled content (through green procurement policies or consumer awareness that favours recycled products). When consumers purchase items made from recycled plastic, the circular economy completes its cycle.

Throughout this value chain, there are points where inefficiencies can be addressed, and sustainability can be enhanced. Some key improvements to consider:

- **Strengthening Linkages and Collaboration:** Currently, many segments of the chain operate in isolation, with poor coordination (informal collectors, for instance, rarely interact directly with recycling factories). Facilitating better linkage – for example, a digital marketplace or network where waste collectors can connect with SMEs needing material – would reduce transaction costs and material going to waste. As one analysis highlighted, SMEs and startups in waste recycling often work in silos and need strategies to collaborate with the public sector and each other. A more integrated value chain (possibly through cooperatives or alliances) could streamline the flow of materials from one stage to the next.
- **Introducing Source Segregation and Formal Collection Systems:** Encouraging or mandating segregation of waste at the source (household level) greatly improves the efficiency of the entire chain. If households' separate recyclables (like plastics) from organic waste, the collection stage becomes more effective and yields cleaner material. Cities could roll out dual-bin systems or door-to-door recyclable pickup days. This directly feeds into better sorting and reduces contamination. It also lessens the burden on informal pickers. Municipal involvement is crucial here: a policy push for source segregation, combined with public awareness campaigns, can change how the chain starts – with far less contamination and higher volumes of recyclables captured.

- **Upgrading Sorting and Pre-processing Infrastructure:** Establishing proper material recovery facilities (MRFs) or aggregation hubs in cities will professionalize the middle of the chain. These hubs can be run as social enterprises or SME cooperatives with support from local authorities. By having designated places where plastics are sorted by trained workers (with appropriate protective gear and tools), the quality of output for recyclers improves. The business case can be enhanced by also sorting other recyclables (paper, metal) at the same facility, thus generating multiple revenue streams. Government incentives or subsidies may be needed initially to set up these facilities, but they create local jobs and improve recycling rates, aligning with circular economic goals.
- **Technology and Process Innovation:** To improve efficiency, the value chain can incorporate better technology at various points. Simple examples include using compactors or ballers at collection points to reduce volume of plastics (making transport to recyclers cheaper) or using shredders at the community level so that SMEs receive pre-shredded plastic. More advanced innovations could involve mechanized sorting (optical sorters to separate plastic types), which, while currently costly, may become viable through pilot projects in large cities. Supporting SMEs to adopt cleaner and more efficient machinery in processing (energy-efficient extruders, for instance) also enhances sustainability – possibly through low-interest loans for equipment upgrades.
- **Policy and Economic Incentives:** The government can implement policies that bind the value chain together and make it more sustainable. One example is Extended Producer Responsibility (EPR), which makes producers financially responsible for the end-of-life of plastics they put on the market. If implemented, EPR schemes could channel funds from large manufacturers to collection and recycling infrastructure, effectively injecting resources into the value chain at critical points (collection and processing). This creates a more stable demand and supply dynamic – producers might contract SMEs to handle a certain amount of plastic waste, guaranteeing business for recyclers and materials for producers. Additionally, incentives like tax breaks for using recycled material, or higher landfill fees (to discourage dumping and encourage recycling), will tilt the economics in favour of recycling activities throughout the chain.
- **Improving Market for Recycled Products:** A recycling chain is only as strong as its endpoint – the use of recycled outputs. Efforts to standardize the quality of recycled plastic (through certifications) and to promote its adoption in industry are necessary. This might include government procurement rules that require a percentage of recycled plastic in certain products (garbage bags for municipal use, construction items in public works, etc.), thus providing a stable market. Educating consumers to prefer products made with recycled content can also pull materials through the chain by increasing demand for such products. As demand rises, the whole chain becomes more profitable and can expand.

In designing the plastic waste recycling value chain, it's important to view it holistically – improving one link will have positive knock-on effects on others. For instance, better collection and sorting (upstream) directly results in higher efficiency and output at the processing stage (midstream), which in turn provides more and cheaper recycled material for manufacturers (downstream). By mapping every actor and ensuring each has the capacity and incentive to perform their role, Pakistan can move from the current ad-hoc chain to a more organized, efficient, and sustainable value chain. This means a transition from an almost entirely informal flow to a hybrid system where informal efforts are augmented by formal mechanisms and support. In practice, a well-designed chain might see a waste picker cooperative collecting plastic in a town, sending it to a regional sorting centre, from which bales go to an SME recycler, who then sells recycled pellets to a factory making new bottles – with each step properly compensated and supported. Such a model not only recovers value from waste and reduces pollution but also distributes economic benefits among a wide range of participants, truly embodying the principles of a circular economy.

7.3. Financing Models

In Pakistan, the financing models for plastic recycling small and medium-sized enterprises (SMEs) are critical to fostering sustainable and economically viable operations. Three prominent financial mechanisms include Public-Private Partnerships (PPP), access to local funds, and self-sustaining financial models, each playing a distinct role in the success and sustainability of plastic recycling enterprises.

Public-Private Partnerships (PPP)

Public-Private Partnerships (PPPs) are instrumental in improving plastic waste management infrastructure by leveraging government support and private sector investment. These collaborations facilitate financial investments, risk-sharing, and enhanced service delivery in recycling operations. Successful PPPs worldwide have enabled local governments to partner with private firms to improve waste management systems, recycling rates, and infrastructure development. Governments often provide incentives such as tax rebates, funding for recycling technology, and policy support to encourage private sector participation.[30]

One notable example in Pakistan is Unilever Pakistan's "Accelerating Plastic Reduction" program, launched in May 2023. This initiative invites startups, SMEs, and individuals to propose innovative solutions for plastic waste reduction. In partnership with SEED, the program offers mentorship, capacity-building, and networking opportunities to strengthen the informal recycling sector.[31] Another example is Unilever's collaboration with Green Earth Recycling, which repurposes plastic waste into sustainable furniture for public spaces, creating jobs while diverting waste from landfills.[32]

Pakistan's National Plastic Action Roadmap highlights PPPs as a key strategy for mobilizing investments through blended finance models, such as multi-donor trust funds, to develop waste management infrastructure. The Public Private Partnership Authority, in collaboration with the Ministry of Climate Change, is working to attract private capital for waste collection and recycling facilities. Similarly, Extended Producer Responsibility (EPR) schemes have encouraged companies like PepsiCo and Nestlé to invest in collection infrastructure and recycling technologies.[33] These examples show how PPPs drive investment, innovation, and efficiency in plastic recycling.

Access to Local Funds for SMEs

For small-scale plastic recyclers, access to local financing is essential for startup costs, operational expenses, and business expansion. SMEs can secure funding through microfinance institutions, bank loans, government grants, and impact investment programs. Many microfinance organizations in Pakistan recognize the environmental and economic potential of recycling businesses and offer

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[30] Afful, B. E. B., Addaney, M., Anaafo, D., Akudugu, J. A., Borkor, F. K., Yeboah, E. O., & Sampana, J. (2023). Public-private partnership in municipal solid waste management in the Sunyani municipality of Ghana. *Journal of Property, Planning and Environmental Law*, *16*(3), 201-217.

[31] https://plastipackpakistan.com/news/accelerating-plastic-reduction-program/

[32] https://www.unilever.pk/news/press-releases/2021/with-unilever-pakistan-and-green-earth-recycling-plastic-to-convert-plastic-waste-into-park-benches/

[33] https://weforum.ent.box.com/s/te1bc60c0dgm3p4tartzjrz8ojsex9p3

accessible capital with favourable terms. To qualify, SMEs must demonstrate viable business plans, sustainability practices, and adherence to environmental regulations.[34]

The Higher Education Commission's Innovator Seed Fund awarded Savvy Engineers Private Limited PKR 7.99 million to develop 3D printing filaments from recycled plastic, fostering a new market for eco-friendly materials.[35] Similarly, the South Asia Regional Competitive Block Grants provide up to USD 1.5 million for projects aligned with the Parley AIR framework (Avoid, Intercept, Redesign), supporting SMEs piloting innovations like biodegradable packaging.[36]

UNDP Pakistan's Plastic Pollution & Circular Economy Portfolio connects SMEs with global funding sources such as the Green Climate Fund, helping them scale technologies like plastic-to-fuel conversion. Additionally, Akhuwat Microfinance offers low-interest loans to recycling businesses with minimal collateral requirements but strict environmental compliance conditions. Provincial initiatives like the Clean Green Pakistan Index prioritize grants for SMEs that integrate marginalized groups, such as women-led cooperatives.[37]

One success story is Unilever Pakistan's Dastan-e-Plastics initiative, which secured funding by demonstrating its impact on job creation and plastic waste recovery.[38] However, SMEs still face challenges such as stringent eligibility criteria, lack of awareness about funding opportunities, and difficulty accessing long-term investment capital. Davaam Life, a Karachi-based startup, successfully raised USD 1.8 million to develop refill stations, helping businesses cut packaging costs and reduce plastic waste.[39]

Self- Sustaining Financial Models

Self-sustaining financial models typically involve revenues from selling recycled products, charging collection fees, and forming strategic partnerships. By developing a diversified revenue stream, recyclers can cushion against fluctuations in the market for recycled materials, which can be volatile due to changes in demand and quality issues related to the contamination of recycled plastics.[40] For instance, successful case studies indicate that companies that establish effective collection systems and partnerships for end products can enhance their profitability. Challenges, however, remain, including market volatility, costs related to sorting and processing, and competition with lower-cost virgin plastic products. A notable sustainable model can be observed in community-based initiatives where collection fees are introduced, generating steady income while increasing local engagement in waste management.[41]

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[34] Kamanga, T. W., Chitete, M. M., Kamanga, B. C., Damazio, C., Yafeti, Y., & Sibande, M. (2024). Towards sustainable solid waste management systems: empirical evidence from Northern Malawi. *Environmental Health Insights*, *18*, 11786302241255800.

[35] https://www.hec.gov.pk/english/services/RnD/ISF/Pages/Research-Outcomes.aspx

[36] https://www2.fundsforngos.org/latest-funds-for-ngos/south-asia-regional-competitive-block-grants-to-reduce-plastic-waste/

[37] https://weforum.ent.box.com/s/te1bc60c0dgm3p4tartzjrz8ojsex9p3

[38] https://www.unilever.pk/news/press-releases/2022/unilever-pakistan-recycles-plastic-waste-equal-to-half-of-plastic-used-in-local-operations/

[39] https://profit.pakistantoday.com.pk/2024/03/17/these-green-startups-want-to-help-the-environment-and-make-money-in-the-process-but-what-do-their-potential-investors-have-to-say/

[40] Grigore, M. E. (2017). Methods of recycling, properties and applications of recycled thermoplastic polymers. *Recycling*, *2*(4), 24.

[41] Ramasubramanian, B., Tan, J., Chellappan, V., & Ramakrishna, S. (2023). Recent advances in extended producer responsibility initiatives for plastic waste management in Germany and UK. *Materials Circular Economy*, *5*(1), 6.

Davaam Life's refill stations, operating in 30 Karachi locations, eliminate packaging costs for FMCG vendors, saving 20-30% on logistics and attracting investor interest. However, challenges like volatile plastic prices and high operational costs for advanced technologies hinder scalability. Initiatives like the Climate Finance Accelerator bridge gaps by connecting startups with investors, emphasizing solutions that balance environmental and economic returns.[42]

7.4. Pilot Testing and Implementation

To translate these ideas into action, a pilot initiative for SME-driven plastic recycling can be structured as a proof of concept. The pilot should be scoped to a manageable scale – for example, targeting a particular city neighbourhood, town, or district – and involve a partnership of key stakeholders (an SME or a group of SMEs, the local municipal authority, an NGO for community engagement, and possibly a corporate sponsor under an EPR scheme). The goal of the pilot would be to implement an end-to-end recycling model on a small scale and gather data on its performance, viability, and impact.

Structure of the Pilot

The pilot area would first establish a system for plastic waste collection. This could mean deploying labelled bins for plastic recyclables and organizing weekly pickups or enlisting local waste pickers and training them to do door-to-door collection with proper segregation. A local SME (or a micro-enterprise cooperative) would act as the operator – responsible for collecting the plastic and running a mini sorting and processing facility. For instance, they might set up a small centre with equipment like a baling machine and a shredding unit. Collected plastics are brought here, sorted into categories (e.g., PET, HDPE, polypropylene), and then processed. If the SME has the capacity, they could further recycle on-site (like shredding and extruding plastic into some product). Alternatively, the sorted plastics can be sent to a nearby larger recycler for processing, while the pilot SME focuses on collection and sorting. Throughout this process, local community engagement is maintained – residents are informed of the pilot and encouraged to participate (through awareness drives and maybe small incentives such as redeemable points for providing clean recyclables). The municipal government can assist by redirecting its waste trucks to support the pilot (ensuring the pilot area's general waste is picked up minus the plastics, etc.), and by granting any necessary permits quickly (for the SME's facility, for example). During implementation, it's important to monitor and document everything meticulously. This includes tracking quantities of plastic collected, any issues faced in sorting, the operational costs incurred by the SME, community feedback, and so on. Pilot testing in real-world conditions will inevitably surface challenges – perhaps certain types of plastic dominate the waste and need a solution, or community participation starts strong then drops off. The pilot team should be ready to troubleshoot and adjust the model on the flight (for example, if contamination is high, they might add an extra training session for households, or if volumes are low, they might expand the collection zone). Regular meetings among the stakeholders to review progress will keep everyone aligned and allow quick resolution of problems.

Key Performance Indicators (KPIs) for Success

To evaluate the pilot's success, clear KPIs should be defined from the start. These KPIs should cover the environmental, social, and economic dimensions of the project. Important indicators include:

[42] https://profit.pakistantoday.com.pk/2024/03/17/these-green-startups-want-to-help-the-environment-and-make-money-in-the-process-but-what-do-their-potential-investors-have-to-say/

- **Plastic Collection Rate** – the total quantity of plastic waste collected for recycling in the pilot area, typically measured in kilograms or tons per month. This can be further broken down into percentage of plastic waste diverted from landfill (e.g., if the area generates X tons of plastic waste monthly and the pilot collects Y tons, the diversion rate is Y/X). A higher diversion rate signifies success.
- **Recycling Output** – the amount of material recycled into usable form. This could be measured as kilograms of recycled plastic flakes or products produced. It's important to track yield (how much of collected plastic was successfully converted versus lost in process or rejected due to contamination).
- **Operational Financial Metrics** – such as cost per kilogram of plastic collected and processed, and revenue generated from selling recycled material or products. The pilot's economic feasibility will be judged by whether the SME can cover its costs (or come close) through the proceeds from recyclables (plus any subsidies). An indicator like a revenue-to-cost ratio or even a simple profit/loss calculation is critical. Additionally, Return on Investment (ROI) for any equipment bought can be noted (though a full ROI might be seen only in the longer term, not just during pilot).
- **Community Participation Level** – this could be measured by the percentage of households in the pilot area that are separating plastics and contributing to the scheme, or the number of collection points successfully used. Surveys or counts can be done to see how engaged the residents are. A high participation rate (and low contamination in the collected recyclables) would indicate a strong community buy-in.
- **Job Creation and Social Impact** – number of jobs created, or livelihoods supported by the pilot. For example, if the pilot engaged 10 waste pickers and 5 sorting staff, that's 15 jobs. Also, improvement in income for those participants (did waste pickers earn more under the organized system than they did informally?). Social indicators could also include any improvements in working conditions (like provision of gloves, uniforms, etc., measured by whether those were provided to all workers).
- **Environmental Impact Metrics** – while harder to measure in a short pilot, one can estimate the reduction in CO_2 emissions achieved by recycling X tons of plastic (using known conversion factors for avoiding virgin plastic production). Also, qualitatively or quantitatively, the cleanliness of the area could be noted (perhaps a reduction in plastic litter observed in the streets or drains). If feasible, water or soil samples could be tested to see if plastic pollution indicators changed, but that might be beyond pilot scope. At least, the pilot should report the volume of waste kept out of landfill or water bodies as a direct environmental metric.
- **Stakeholder Engagement Index** – e.g., number of local stakeholders (community groups, schools, religious institutions, etc.) actively involved, and number of awareness sessions or trainings conducted. This reflects the capacity-building and awareness component of success.
- **Scalability Indicators** – such as cost per capita served or plastic per capita collected. These helps infer if the model would scale to a city level. If the pilot manages, say, 100g of plastic per person per day in that area, one can compare it to city-wide waste generation averages to see potential impact when scaled.

Data for these KPIs would be collected throughout the pilot duration (which might run for 6 months to a year to account for learning curve and seasonal variations). At the end, an evaluation against the baseline (pre-pilot situation) will show the delta achieved.

Strategies for Scaling Up Successful Pilots: If the pilot demonstrates positive results – for instance, a high collection rate, community enthusiasm, and at least break-even economics with the help of modest subsidies – the next step is to replicate and expand the model. Scaling up can happen in a few ways:

- **Geographical Expansion:** The model could be rolled out to other neighbourhoods or towns. This could be done by the same SME expanding its operations, or by recruiting new SMEs in other areas and training them based on the pilot's success. The pilot area can serve as a "showcase" – organizing exposure visits for officials and entrepreneurs from other areas to see the working model can build confidence for expansion. When scaling geographically, it's crucial to adapt to local conditions (for example, adjusting collection methods for different community layouts, or accounting for different types of plastic waste in another city).
- **Institutionalizing Support:** Learnings from the pilot should be documented and shared with policymakers to inform waste management planning. If the pilot is successful, government bodies can be lobbied to formally support its expansion – for example, the city could incorporate the recycling micro-enterprise model into its official solid waste management plan and allocate budget to it. Policy incentives (like partial subsidies or performance-based payments for recyclers) can make the model more financially attractive to replicate. The pilot's data will provide evidence to back these policy measures.
- **Capacity Building for Scale:** To scale up, more people and organizations need to be equipped. The pilot team can develop a toolkit or manual detailing the operational procedures, stakeholder engagement tactics, and troubleshooting tips. This toolkit can be used to train new SME operators in other locations. Essentially, turn the pilot's knowledge into a repeatable template. Workshops or training sessions (possibly with support from NGOs or the project team) can kickstart the model elsewhere. Scaling might also involve setting up a mentorship where the original pilot team mentors' new teams.
- **Financial Scaling:** A successful pilot can attract funding – both public and private. The results demonstrated might encourage local governments to provide grants or purchase equipment for new sites. Similarly, CSR arms of corporations or development agencies might fund replication in other communities as part of their sustainability initiatives. Creating a business case from the pilot (showing how much waste was diverted and what social impact achieved per dollar invested) will be useful in pitching for such funding. In some cases, impact investors could be interested in funding the scale-up if a revenue model exists (for instance, if the pilot SME made a small profit, an investor might inject capital to help them grow to multiple localities).
- **Technology Scaling:** As the program scales, consider integrating more technology to handle larger volumes. For example, if scaling to a whole city, one might incorporate a fleet management app for coordinating collections or invest in a semi-automated sorting line. The pilot's simple methods worked at small scale; for large scale, incremental tech upgrades ensure efficiency isn't lost. The pilot gives a baseline of what's needed; scaling may also involve procuring additional or bigger machinery. Planning for that – perhaps through pooled procurement for multiple new SMEs to get a bulk discount on equipment – can be a scaling strategy.
- **Monitoring and Continuous Improvement:** Even as the program scales, keep the habit of monitoring KPIs. What worked in the pilot might encounter new obstacles on a scale, so a mechanism for feedback and continuous improvement is key. Regular forums for the operators of each scaled unit to share experiences can help replicate success and avoid repeated mistakes. Essentially, building a community of practice among all SMEs that spin off from the pilot will sustain quality during expansion.

A well-structured pilot can serve as a microcosm of the desired recycling value chain, and its results will guide larger implementation. By carefully measuring outcomes and refining the model on the ground, stakeholders can gain the confidence to invest in a wider rollout. The transition from pilot to scale should be gradual but deliberate – possibly moving from one locality to a whole city zone, then city-wide, then to multiple cities. At each step, the lessons learned compound. With supportive policies, engaged communities, and empowered SMEs, the pilot's success can be multiplied manyfold, helping Pakistan dramatically improve its plastic recycling rates and circular economy performance. The ultimate vision is that what starts as a small pilot project becomes mainstream practice, leading to lasting reductions in plastic pollution and new green jobs across the country.

7.5. Monitoring and Evaluation of Recycling Initiatives

Effective monitoring and evaluation (M&E) are critical to ensuring the success, accountability, and scalability of plastic recycling initiatives. By systematically tracking progress and outcomes, stakeholders can identify gaps, optimize resource allocation, and demonstrate the social, economic, and environmental value of recycling efforts.

Framework for M&E

Objectives

- Assess the efficiency of recycling operations (e.g., collection rates, processing yields).
- Measure environmental impact (e.g., waste diversion from landfills, carbon emissions avoided).
- Evaluate socioeconomic outcomes (e.g., job creation, income improvements for informal workers).
- Gauge stakeholder engagement and community participation.
- Inform policy adjustments and scaling strategies.

Key Indicators

Building on the KPIs defined in pilot testing (Section 7.4), the M&E framework incorporates following additional metrics:

Indicator Type	Description
Process Indicators	- Number of training sessions conducted for SMEs/waste workers. - Frequency of stakeholder coordination meetings. - Time taken to address operational bottlenecks (e.g., equipment breakdowns).
Outcome Indicators	- Reduction in plastic leakage into water bodies (measured through audits). - Percentage increase in households practicing source segregation. - Revenue growth for SMEs linked to recycled product sales.
Impact Indicators	- Long-term behavioural change in communities (survey-based metrics). - Contribution to national circular economy targets (% recycled annually).

Data Collection Methods

Data collection methods for assessing plastic recycling initiatives encompass both quantitative and qualitative approaches. Quantitative methods include the use of digital tools such as mobile applications for real-time tracking of collection volumes and IoT sensors embedded in recycling machinery to monitor operational efficiency. Additionally, financial records from SMEs and municipal bodies provide valuable insights into revenue streams and cost structures, while environmental audits using standardized carbon footprint calculators help assess the ecological impact of recycling processes. On the qualitative side, data collection involves focus group discussions with waste pickers, SMEs, and community members to understand on-the-ground challenges and opportunities. Case studies document specific innovations and barriers faced by different stakeholders, providing a deeper contextual analysis. Furthermore, stakeholder feedback surveys, such as those evaluating satisfaction with Public-Private Partnership (PPP) arrangements, help gauge the effectiveness of collaborative recycling initiatives.

Frequency and Responsibility

Short-term	Monthly reporting by SMEs on operational metrics (managed internally or via NGO partners).
Mid-term	Quarterly evaluations by independent auditors or academia to assess environmental and social impact.
Long-term	Annual impact assessments aligned with national policies (e.g., Pakistan's National Plastic Action Roadmap).

Technology Integration

The integration of digital tools enhances efficiency, transparency, and data accessibility in M&E processes:

- **GIS Mapping:** Identify waste hotspots and optimizes collection routes.
- **Dashboard Analytics:** Provide real-time data visualization for stakeholders, highlighting trends in key indicators such as diversion rates and contamination levels.

Challenges and Mitigation

Challenge	Mitigation Strategy
Data Reliability: Informal sector data may be inconsistent.	Partner with NGOs to train waste pickers in basic data logging.
Resource Constraints: SMEs often lack technical capacity.	Integrate M&E training into capacity-building programs (refer to Section 3.3).

Stakeholder Buy-in: Ensuring inclusivity in M&E processes.	Use participatory M&E approaches, such as community scorecards.

Linking M&E to Policy and Scaling

Insights derived from M&E should directly inform policy decisions and scaling strategies, for example:

- If contamination rates exceed 20%, policymakers may introduce stricter source segregation laws.
- If SME profitability declines, adjustments to Extended Producer Responsibility (EPR) schemes may be necessary to increase corporate contributions.
- Successful pilot initiatives can leverage M&E data to attract public-private partnerships (PPPs) and expand sustainable recycling models to new regions.

8. Policy and Regulatory Recommendations

As plastic waste continues to pose significant environmental and economic challenges, a robust policy and regulatory framework is essential to promote sustainable recycling practices in Pakistan. Strengthening local governance, enforcing EPR, and integrating circular economy principles can drive systemic change. This section outlines key policy recommendations at both the national and provincial levels, addressing region-specific challenges and regulatory barriers while proposing actionable reforms to enhance plastic waste management and recycling efforts.

8.1. Enabling Policy Framework for Plastic Recycling

Through Local Governance Systems

- **Strengthen Municipal Partnerships:** Integrate informal waste collectors (e.g., *safai walas*) into formal municipal waste management systems to improve collection efficiency and ensure fair wages. Local governments should provide training, safety equipment, and access to segregated waste streams.
- **Decentralized Recycling Hubs:** Establish localized recycling centres managed by municipalities to reduce transportation costs and emissions. For example, replicate Lahore Waste Management Company's (LWMC) model of outsourcing waste management to private entities like Albayrak and OzPak.
- **Extended Producer Responsibility (EPR) Enforcement:** Mandate municipalities to collaborate with producers under EPR regulations (e.g., Single-Use Plastics Regulations, 2023) to ensure compliance with plastic waste collection and recycling targets.

Region-Specific Policy Recommendations for Different Provinces

- **Punjab:** Expand the Plastic Management Strategy (2023) to include tax incentives for SMEs adopting low-tech solutions (e.g., manual sorting) and solar-powered technologies.
- **Sindh:** Enforce the Sindh Prohibition of Non-Degradable Plastic Products Rules (2014) strictly in Karachi, prioritizing landfill development at Dhabeji and formalizing partnerships with SSWMB.
- **Khyber Pakhtunkhwa (KP):** Leverage KP-EPA's Prohibition of Non-Biodegradable Plastic Products Rules (2017) to regulate cross-border plastic waste inflows and fund SME-driven recycling clusters.
- **Balochistan:** Implement the Balochistan Use of Plastic Shopping and Flat Bags Act (2023) with grants for low-tech recycling (e.g., donkey cart-based collection) in rural areas.

8.2. Integration of Circular Economy Principles

- **Provincial Circular Economy Strategies:** Align provincial policies (e.g., Punjab's Environmental Policy, 2015) with circular economy goals by incentivizing SMEs to adopt closed-loop systems, such as plastic-to-paver production (e.g., Concept Loop's 30% recycled plastic mix).
- **Green Procurement Policies:** Mandate provincial governments to allocate 20–30% of public procurement budgets (e.g., road construction, packaging) to recycled plastic products, as seen in Punjab's Plastic Road Initiative.

- **Circular Economy Hubs:** Develop provincial clusters (e.g., Punjab's industrial zones) to foster SME collaboration with research institutions like PCSIR for innovations in chemical recycling and biodegradable alternatives.

8.3. Regulatory Barriers and Proposed Reforms

- **Develop a National EPR Framework:** Draft a formal EPR law, building on the previous existing regulations and case studies from international practices, to hold producers accountable for plastic waste collection and recycling. Pilot EPR schemes in industrial hubs like Lahore, Karachi, Faisalabad etc.
- **Harmonize Provincial Regulations:** Create a federal task force to align provincial plastic bans (e.g., Sindh's 2014 rules, KP's 2017 rules) under a unified National Plastic Recycling Policy while allowing flexibility for regional needs.
- **Formalize Informal Sector Roles:** Recognize informal waste pickers as stakeholders under the National Sanitation Policy (2006), ensuring fair wages and access to formal markets.
- **Subsidize Technology Adoption:** Use programs like World Economic Forum's NPAP Program to fund SME access to automated sorting (e.g., optical sensors) and renewable energy integration (e.g., solar-powered crushers).
- **Strengthen Enforcement:** Establish a federal monitoring body to track compliance with provincial bans on non-degradable plastics and penalize non-compliance (e.g., unregulated sale of D2W bags).

9. Challenges and Opportunities

9.1. Social, Environmental, and Economic Challenges

The plastic recycling industry in Pakistan faces numerous barriers across social, environmental, and economic dimensions. Despite global advancements in circular economy practices, local adoption remains limited due to consumer preferences, financial constraints, and regulatory gaps. Informal networks control a significant portion of the waste market, while environmental challenges like microplastic pollution and toxic emissions further complicate sustainability efforts. The table below outlines key challenges hindering the sector's growth and efficiency.

Category	Challenges	Details
Social Challenges	**Low Demand for Recycled Products**	65% of households prioritize cost over sustainability, favoring virgin plastics.
	Acceptability & Knowledge Gaps	70% of SMEs struggle to educate consumers on circular economy benefits.
	Unregulated Waste Market & Waste Mafia	40% of SMEs face extortion or price manipulation by informal actors.
Environmental Challenges	**Contamination of Plastic Waste**	85% of collected plastics require intensive cleaning (e.g., Envirogreen uses 1.536 kL/tonne of water).
	Toxic Emissions	Open burning of plastics releases carcinogens, worsening air pollution beyond WHO guidelines in cities like Karachi.
	Microplastic Pollution	The Indus River transports 164,332 tonnes of plastic annually, threatening marine ecosystems and food security.
Economic Challenges	**High Costs**	Raw material prices fluctuate (PET: 30–200 PKR/kg), and operational expenses range from 0.5–5 million PKR/month.
	Price Instability	Virgin plastics undercut recycled markets by 15–20%.
	Financial Barriers	Only 12% of SMEs secure formal credit due to high collateral requirements.
	Unregulated Competition	Informal sectors divert 55% of high-value recyclables, impacting SME revenues.

9.2. Opportunities for Innovation and Entrepreneurship

Technological Advancements

Technological advancements are playing a crucial role in improving the efficiency and sustainability of plastic recycling. The integration of renewable energy, such as solar-powered shredders used by SMEs in Punjab, has reduced energy costs by 30%, aligning with Sustainable Development Goal (SDG) 7. Additionally, low-tech hybrid solutions, combining manual sorting with optical sensors, have enhanced processing efficiency, as seen in Green Earth Recycling, where 40% of sorting is now mechanical. Innovations in waste-to-product technologies are also emerging, with startups like Concept Loop producing eco-pavers containing 30% recycled plastic, thereby reducing landfill dependency.

Market development

Market development efforts are further driving the growth of recycled products. Consumer awareness campaigns have demonstrated success, with pilot programs in Lahore increasing the demand for recycled goods by 25% through school partnerships. Corporate partnerships are also fostering scalability, as exemplified by Engro Corporation's offtake agreements with SMEs for recycled PET. Furthermore, the global demand for certified recycled materials, particularly under frameworks like the EU Circular Economy Package, presents untapped export potential for Pakistan's recycling sector.

Circular business models

Circular business models are gaining traction, offering sustainable solutions to waste management. Closed-loop systems, such as DAVAAM's refill stations, have led to a 35–40% reduction in consumer costs while encouraging behavioural shifts toward sustainability. Additionally, formalizing waste collection networks, such as IRVERDE's training programs for safai walas, has improved supply consistency and reduced logistics costs by 20%.

Policy-driven opportunities

Policy-driven opportunities are also shaping the recycling industry. Extended Producer Responsibility (EPR) regulations, such as Pakistan's Single-Use Plastics Regulations (2023), could mandate brands to fund recycling initiatives, potentially generating 2 billion PKR annually for SMEs. Moreover, green procurement initiatives, like Punjab's Plastic Road Initiative incorporating 30% recycled content, set a strong precedent for increased public-sector demand for recycled materials.

9.3. Role of SMEs in Transitioning to a Circular Economy

Small and medium enterprises play a critical role in transitioning Pakistan toward a circular economy by bridging the gaps between policy, technology, and grassroots implementation. Their efforts span across supply chain integration, technology adoption, policy advocacy, community engagement, and circular value chain development, making them key drivers of sustainable change.

In supply chain integration, SMEs are enhancing efficiency through decentralized hubs and digital connectivity. The establishment of 15 collection centres in Khyber Pakhtunkhwa (KP) and Balochistan has successfully reduced transportation costs by 18%.

Technology adoption is another crucial area where SMEs are driving impact. Scalable solutions, such as automated shredding systems with an investment of 5–10 million PKR, can process up to 2 tonnes of plastic waste per hour, effectively doubling production capacity. Moreover, research and development collaborations with institutions like the Pakistan Council of Scientific and Industrial Research (PCSIR) have led to the development of chemical recycling prototypes for mixed plastics, addressing a key challenge in waste management.

Policy advocacy and collaboration efforts are helping SMEs access funding and expertise. The Plastic Management Strategy, Punjab (2023) has allocated 500 million PKR in grants to support SME-driven initiatives. Additionally, partnerships with organizations such as WWF-Pakistan have led to circular economy workshops that have trained 120 SMEs in sustainable business practices, equipping them with the necessary skills to operate in an evolving market.

Community engagement is another vital aspect of SME contributions. Awareness drives led by female cooperatives in Multan have successfully increased household waste segregation rates by 40%, fostering behavioural shifts at the grassroots level. Inclusive employment practices are also evident, with 65% of IRVERDE's workforce comprising women, aligning with Sustainable Development Goal (SDG) 5 on gender equality.

Finally, SMEs are strengthening circular value chains through innovative approaches. Upcycling initiatives have repurposed multilayer plastic (MLP) films, valued at 20–30 PKR per kilogram, into construction materials, diverting 1,200 tonnes of waste from landfills annually. Furthermore, pilot projects in Karachi have introduced plastic credits, monetized 500 tonnes of recycled waste and generated 10 million PKR in revenue, providing financial incentives for sustainability.

Through these multifaceted efforts, SMEs are emerging as essential players in Pakistan's transition to a circular economy, integrating policy frameworks, innovative technologies, and community-driven solutions to create a more sustainable future.

10. Conclusion

The study found that Pakistan's plastic waste management infrastructure remains inadequate, with high levels of mismanaged waste leading to severe environmental and health impacts. SMEs and informal waste collectors play a crucial role in plastic recycling but require financial, technical, and policy support to scale their operations. Limited adoption of advanced recycling technologies hinders efficiency and material recovery rates, necessitating investments in scalable solutions. While recent policy efforts, such as the Single-Use Plastics Regulations (2023) and Punjab's Plastic Management Strategy, are steps in the right direction, there is a need for stronger enforcement on a national level along with attractive incentives. Transitioning to a circular economy in plastic waste management can generate employment opportunities, reduce pollution, and strengthen Pakistan's sustainability goals.

Economic viability remains a key consideration for SMEs. The cost of raw plastic materials varies widely, with prices ranging from 30 PKR/kg for PET and HDPE to 350 PKR/kg for high-value plastics such as ABS and polyester. Product pricing fluctuates based on market demand, with recycled plastic products selling between 101 PKR and 1000 PKR per unit. Monthly operational costs for SMEs range from 0.5 to 5 million PKR, covering expenses such as labour, equipment maintenance, utilities, and waste collection. Initial investment requirements can be substantial, ranging from 1 million to 20 million PKR depending on the scale of operations and technology adopted. Due to these high costs and unpredictable pricing, SMEs often struggle to sustain profitability. However, new market trends, including increased demand for eco-friendly products and export opportunities, provide avenues for revenue growth.

LCA conducted in this study further reinforces the need for scaling up recycling initiatives. The LCA demonstrates that plastic recycling significantly reduces greenhouse gas emissions, water consumption, and waste disposal impacts compared to landfilling and incineration. The study emphasizes that mechanical recycling, particularly at the SME level, offers the best balance between environmental benefits and economic feasibility. However, optimizing waste segregation, improving energy efficiency, and transitioning towards renewable energy sources are essential steps to maximize sustainability gains.

Based on survey findings, key strengths of the recycling sector in Pakistan include the production of diverse plastic products (pipes, tiles, bags, etc.), the presence of efficient recycling technologies, and a stable workforce with low rejection rates in processing. However, challenges persist, including high operational costs, contamination issues, limited access to funding, and regulatory burdens. Opportunities exist in the form of rising demand for sustainable products, potential government support through subsidies and tax breaks, and increasing global interest in recycled plastics. Conversely, threats include price instability, competition from virgin plastic producers, an unregulated waste market, and stringent regulations limiting scalability.

A strategic roadmap for a circular plastic waste economy in Pakistan should focus on several key areas:

- **Regulatory and Policy Enhancements**: Stronger EPR regulations, standardized waste segregation policies, and incentives for industries to integrate recycled content in production.
- **Infrastructure Development**: Localized recycling hubs, improved waste collection mechanisms, and investment in scalable recycling technologies.
- **Financial Incentives**: Low-interest loans, green financing options, and government subsidies to support SME-led recycling initiatives.

- **Technological Integration**: Promotion of advanced recycling techniques such as chemical and biological recycling to enhance material recovery.
- **Community Engagement and Education**: Public awareness campaigns to encourage responsible plastic consumption and waste segregation.
- **Public-Private Partnerships (PPPs)**: Collaboration between government agencies, private sector players, and development organizations to scale sustainable recycling models.

By implementing these strategic recommendations and leveraging LCA insights, Pakistan can significantly advance its transition towards a circular plastic economy, reducing environmental degradation while creating sustainable economic opportunities.

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12. Annexures

Annex 01 – Survey Questionnaire for KIIs

Name of Enumerator	
Date of Survey	

Respondent Information	
Name of Respondent	
Age	
Gender	□ Male □ Female □ Other (Please specify): ____________
Contact Number	
Email Address (Optional)	
Role within the Organization	□ Owner □ Manager □ Employee □ Other _____________

SMEs (Plastic Recycling Companies)		
Sr. #	**Question**	**Response**
	Company Information & Demographics	
1.	Name of Organization	
2.	Location	
3.	Years in Operation	□ Less than 1 year □ 1-3 years □ 3-5 years □ 5-10 years □ More than 10 years
4.	Type of Ownership	□ Sole Proprietorship □ Partnership □ Private Limited □ Other (Please specify): ____________
5.	Size of Organization	□ Micro □ Small □ Medium
6.	What is the geographic scope of your operations?	□ Local □ Regional □ National □ International
7.	How many employees do you have in your organization?	□ 1-10 □ 11-50 □ 51-100 □ 101+
	Current Operations	
8.	How do you source plastic waste for recycling?	□ Directly from households □ Waste collection agencies □ Industrial waste □ Others (specify): ____________
9.	What types of plastics do you primarily recycle?	□ PET □ HDPE □ LDPE □ PVC □ PP □ PS □ Other (specify): ___________
10.	What is the estimated quantity (in tons) of plastic waste you process monthly?	□ Less than 5 ton □ 5-20 tons □ 21-50 tons □ 51-100 tons □ More than 100

11.	What products are manufactured from recycled plastics?	
12.	What are the main challenges in sourcing plastic waste?	□ Irregular supply □ Contamination □ Quality issues □ Logistics □ Others (specify): ___________
13.	What are the primary sources of plastic waste for your operations?	□ Waste collectors □ Industries □ Households □ Import □ Other
14.	What is the average purchase price per kilogram for different types of plastic waste you source?	
15.	What are the main challenges in sourcing plastic waste in terms of cost and supply?	□ High cost □ Low supply □ Quality issues □ Other (specify): ___________
16.	What are your quality requirements for incoming waste?	□ Clean □ Sorted □ No contaminants □ Other (specify): ___________
17.	Who are your main customers for recycled products?	□ Manufacturers □ Retailers □ Exporters □ Other (specify): ___________
18.	What is the average selling price of your recycled products?	□ Less than 100 PKR □ 101-500 PKR □ 501-1000 PKR □ More than 1000 PKR
19.	What are the main challenges you face in the market for your recycled products?	□ Low demand □ High competition □ Price instability □ Other (specify): ___________
20.	How do you rate the market growth potential for your business on a scale of 1 to 5?	□ 1 (Very Low) □ 2 (Low) □ 3 (Moderate) □ 4 (High) □ 5 (Very High)
Technical Assessment		
21.	What recycling technologies are currently used in your operations?	□ Manual sorting □ Mechanical separation □ Automated processes □ Other (specify): ___________
22.	How old is your main recycling equipment?	□ Less than 5 years □ 5-10 years □ 11-20 years □ More than 20 years
23.	What processing steps are implemented in your recycling operations?	□ Sorting □ Washing □ Shredding □ Pelletizing □ Other (specify): ___________
24.	What are the major technical challenges you face in your recycling process?	□ Equipment failure □ High energy use □ Lack of skilled labour □ Other (specify): ___________
25.	What are the primary markets for your recycled plastic materials?	□ Local □ Export □ Construction □ Packaging □ Other (specify): ___________
26.	What are the barriers you face in selling your recycled plastic products?	□ Market demand □ Lack of awareness □ Competition □ Price sensitivity □ Other (specify): ___________
27.	How do you ensure the quality of recycled products?	□ Quality checks □ Testing □ Certification □ Customer feedback □ Other (specify): ___________
28.	What quality control measures do you implement in your operations?	□ Visual inspection □ Laboratory testing □ Automated monitoring

		□ Other (specify): ___________
29.	What is the rejection rate (%) of incoming materials?	□ Less than 5% □ 6-15% □ 16-30% □ More than 30%
30.	What final product quality standards do you follow?	□ ISO 9001 □ Local standards □ Other (specify): ___________
Economic Viability		
31.	What was the initial investment in your recycling facility?	□ Less than 1 million PKR □ 1-5 million PKR □ 6-10 million PKR □ More than 10 million PKR
32.	What are your monthly operational costs?	□ Less than 500,000 PKR □ 500,000-1 million PKR □ 1-5 million PKR □ More than 5 million PKR
33.	What is your average monthly revenue?	□ Less than 500,000 PKR □ 500,000-1 million PKR □ 1-5 million PKR □ More than 5 million PKR
34.	What is your profit margin percentage?	□ Less than 5% □ 5-10% □ 11-20% □ More than 20%
35.	How was the initial investment for your facility funded?	□ Own capital □ Bank loan □ Investors □ Government support □ Other (specify): ___________
36.	How would you rate your access to additional financing on a scale of 1 to 5?	□ 1 (Very Difficult) □ 2 (Difficult) □ 3 (Neutral) □ 4 (Easy) □ 5 (Very Easy)
37.	What are the main financial challenges you face in your operations?	□ Lack of capital □ Difficulty accessing loans □ High operational costs □ Other (specify): ___________
Environmental & Social Impact		
38.	Do you hold any environmental permits for your operations?	□ Yes □ No
39.	What methods do you use to treat wastewater generated during recycling?	□ Reuse □ Treatment plant □ Other (specify): ___________
40.	What is your energy consumption per ton of plastic processed?	□ Less than 5 kWh □ 5-10 kWh □ 11-20 kWh □ More than 20 kWh
41.	What is the percentage of waste generated during your recycling process?	□ Less than 5% □ 6-15% □ 16-30% □ More than 30%
42.	Do you have an environmental management system in place?	□ Yes □ No
43.	If yes, please enlist.	
44.	Have you implemented any energy efficiency measures in your operations?	□ Yes □ No
45.	If yes, please enlist.	
46.	Do you practice water conservation in your operations?	□ Yes □ No
47.	If yes, please enlist.	

48.	How do you engage with the local community?	□ Job creation □ Community programs □ Awareness campaigns □ Other (specify): ___________
49.	What community feedback mechanisms are in place?	□ Surveys □ Feedback forms □ Meetings □ Other (specify): ___________
50.	How many local jobs have been created by your operations?	□ Less than 10 □ 10-50 □ 51-100 □ More than 100
51.	Have you received and resolved community complaints?	□ Yes □ No
52.	Do you offer training programs for your employees?	□ Yes □ No
53.	What is your employee retention rate?	□ Less than 50% □ 51-75% □ 76-90% □ More than 90%
54.	What is the ratio of local vs. non-local employees in your organization?	□ More locals □ Equal locals and non-locals □ More non-locals
55.	Do you have any worker welfare programs in place?	□ Yes □ No
56.	If yes, please enlist.	
Regulations & Support		
57.	Are you aware of government policies on plastic waste recycling?	□ Yes □ No
58.	If yes, please enlist.	
59.	What government support would help you improve your recycling process?	□ Subsidies □ Tax breaks □ Access to grants □ Infrastructure support □ Other
Future Outlook		
60.	Do you have any plans for capacity expansion in your recycling operations?	□ Yes □ No
61.	If no, why?	
62.	Are you considering any new technologies for your operations?	□ Yes □ No
63.	If yes, please enlist.	
64.	Are you planning to manufacture any additional products in the future?	□ Yes □ No
65.	If yes, please enlist.	
66.	What type of support would benefit your business most? (Rank 1-5)	___Technical assistance ___Financial support ___Market access ___Policy support ___Training and capacity building
67.	What are the main barriers to expanding your recycling operations?	□ Financial constraints □ Regulatory hurdles □ Lack of skilled labor □ Market demand □ Other (specify): ___________

68.	What challenges do you face in maintaining the economic sustainability of your business?	□ High operational costs □ Lack of market access □ Price fluctuations □ Regulatory burdens □ Other (specify): ____________
Additional Comments		
69.	Please provide any additional information or suggestions that could help improve plastic recycling practices in Pakistan:	

Annex 02 – List of Stakeholders Engaged

Sr. #	Name	Designation	Organization
1.	Ali Naqvi	Chief Executive Officer	Concept Loop
2.	Angel Imdad	Founder	Irverde
3.	Muhammad Raza Khemji	Founder	Bigger Brick
4.	Shabee-ul-Husnain	HSE & Sustainability Consultant	Envirogreen Training & Consulting
5.	Noor Ulyen	Sustainability Coordinator	Zephyr Waste Solutions
6.	Salman Tariq	Co-founder & CEO	DAVAAM Life
7.	Babar Aziz Bhatti	Managing Director	Green Earth Recycling
8.	Mustafa Ahmed	General Manager Sustainability & ESG	Artistic Milliners

Annex 05 – Survey Pictures







Multi
Surface
Cleaner


Unilever
Refill Station
REDUCE
RE-USE
RECYCLE
Powerful Antibacterial
Multi-Surface Cleaner.
Lemon freshness
Can be used for floor
and other surfaces
DAVAAM
life

Annex 04 – Life Cycle Assessment (LCA) on Feasibility of Plastic Waste Recycling Technologies in Pakistan