Technology Prioritization for Waste Sector

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1. INTRODUCTION

The waste sector in Pakistan suffers from several problems related to the management of municipal solid waste (MSW), plastic waste and agricultural waste. Pakistan produces an estimated 49.6 million tons of SW per annum, and a projected growth rate of 2.4% per year[1]. Around 60%[2] of the generated MSW is collected from where the majority of it is disposed of through open dumps or burning therefore significantly affecting the environment and human health. Plastic waste constitutes nearly 65% of the overall mismanaged waste which leads to water pollution[3]. In Pakistan 36 million tons per year total agricultural waste is produced, which is typically openly incinerated thus releasing toxic pollutants into the atmosphere[4]. Insufficient recycling systems, the informal structure of waste management sector and insufficient legislation are some of the main challenges of waste management in Pakistan. The inefficiencies mentioned above do not only degrade the quality of environment through polluting soils and water, but also negatively impact health of the population and inhibit economic development. If the challenges to efficient waste management are dealt with, Pakistan would possibly save around $200 -$500million[5], from recycling, energy recovery and reduction of environmental health costs thus improving economic growth and environmental conservation.

To address these challenges, the Ministry of Climate Change and Environmental Coordination (MoCC&EC), in collaboration with the Climate Technology Centre and Network (CTCN), is developing a **Technology Roadmap** for the **waste and water sectors**. This roadmap aims to strategically plan the deployment of technologies to meet Pakistan's climate and development targets, aligning with the country's commitment to enhancing climate resilience and sustainable development.

The purpose of this report is to prioritize the technologies that will be included in the Technology Roadmap for the waste sector. It critically examines the challenges mentioned above, aiming to contribute to the discourse on sustainable water management in Pakistan through technological interventions. By identifying existing and emerging technologies, the report focuses on those that have the potential to significantly impact waste management, enhance climate resilience, and contribute to sustainable development in Pakistan. The report supports the objectives of Pakistan's NDCs by identifying technologies that enhance both climate adaptation and mitigation capabilities. Prioritizing specific technologies ensures that the most effective and feasible solutions are integrated into national plans, thereby accelerating the implementation of Pakistan's climate commitments.

[1] https://www.switch-asia.eu/site/assets/files/3378/waste_management_in_pakistan_final.pdf
[2] https://www.epa.gov/facts-and-figures-about-materials-waste-and-recycling/national-overview-facts-and-figures-materials
[3] https://www.undp.org/pakistan/publications/baseline-study-current-scenario-plastic-waste-management-rahim-yar-khan
[4] https://pakobserver.net/sustainable-solution-to-pakistans-smog-crisis/
[5] https://vuir.vu.edu.au/42515/1/SHAIKH_Salsabil-thesis_nosignature.pdf

2. PROCESS FOR TECHNOLOGY SELECTION AND PRIORITIZATION

The figure 1 below guides the steps on how the roadmap would ultimately be developed. For the continuous feedback and ownership from government, three committees were formulated to support the project namely: 1) Water Technical Committee, 2) Waste Technical Committee and 3) Technology Roadmap Committee as highlighted in **Annex-I.**

	Planning and Preparation	Sector Prioritizatoin	Roadmap Development Process
Activities	Kick off Workshop	Sector level assessment and Technology Prioritization	Committee Verification of Sector Level Technology Prioritizatoin
	Stakeholder Sensitization	Gender and Social Assessment	
	Committees Established	Committee Meetings and Feedback	Roadmap Development
	Desk Review and Baseline		
Outcomes	Sub - Listing	Prioritization of 5 Technologies	Roadmap Developed

Figure 1: Roadmap development process

The activity began with a **kick-off workshop** in February, where stakeholders gathered to highlight priority waste sub-sectors based on the challenges identified with waste sector including health risks, contamination of water, deteriorating municipal functions and public health issues. Based on these municipal solid waste, agricultural waste and plastic waste were selected among others (construction, Industrial (hazardous), Hospital (Hazardous) E-Waste (Hazardous) and Water waste) were selected. Secondly, potential technology options within the waste sector were also identified. This initial meeting set the stage for further detailed assessments by establishing the key focus areas

Figure 2: Snippets from kick-off workshop

In March 2024, the **1st stakeholder feedback waste & water technical committee meeting** took place, where a list of technologies was identified through stakeholder sensitization and desk reviews. Long list of technologies is attached in **AnnexII**. This meeting involved engaging stakeholders to gather on-ground insights and conducting comprehensive literature reviews, which helped in voting and subsequently narrowing down the list of potential technologies to three each in all the three subsectors, consisting of 2 existing and 1 emerging technology. Selected technologies are: Aerobic Windrow Composting, Waste Segregation, Engineered Landfill Technology and Waste Valorization (Emerging) in Municipal Solid waste subsector 2. Refuse-derived Fuel, Downcycling and Non-Biodegradable Plastic Pyrolysis (Emerging) from plastic waste subsector and 3. Advanced Agro-Residue Livestock Feeding, Vermicomposting and Integrated Biomass Gasification / pyrolysis for syngas and biochar (Emerging) from agricultural waste subsector.

Subsequently, the **First Technology Roadmap Committee Meeting** was held in April 2024 to finalize the scoring criteria for evaluating the shortlisted technologies. During this meeting, the committee developed and agreed on objective criteria to assess each technology, ensuring that they reflect the priorities and needs identified earlier. List of waste technical committee members is provided in **Annex III.**

The **prioritization** of technologies was decided to be gauged on the basis of three categories, namely: **Legal, Regulatory, and Financial Landscape; Economic and Technical Feasibility; and Inclusive Development and Climate Impacts** for the technology. Each category further divided into specific metrics to gauge the points scored by the particular technology in that metric, which shall be explained in more detail in section 4 of this report. Participants from various provinces, involved in waste management, voted on existing and emerging technologies for solid, agriculture and plastic waste sub-sectors. The prioritization of technologies was guided by stakeholder discussion on relevance to Pakistan's local context, potential climate impact, community resilience, and technological feasibility. Participants from various provinces voted on technologies based on their applicability to Pakistan's waste management challenges, with a focus on those that could significantly improve practices, enhance resource recovery, and promote sustainability. For example, technologies like waste segregation and composting were prioritized for their impact and feasibility, reflecting their alignment with local needs and conditions. The technologies receiving the highest votes were identified as priorities. The process was facilitated through interactive platforms like Zoom and Mentimeter, ensuring a collaborative approach to decision-making.

The **Second Waste Technical Committee Meeting** then focused on gathering feedback from stakeholders on the shortlisted technologies, discussing financial challenges and opportunities, and considering GESI (Gender Equality and Social Inclusion) aspects for each technology. This meeting aimed to ensure that the final selection of technologies is informed by detailed stakeholder input, financial viability, and inclusive development considerations. List of all the members is attached in **Annex IV.**

Taking the lead from the kick-off workshop, followed by waste committee meetings, and technology roadmap meetings to highlight the **Priority sub-sectors, Shortlist technologies, and scoring criteria for the waste sector**, this document takes a step forward as it aims to assess the technologies identified through stakeholder consultations for the **waste** sector and **prioritize 4 existing and 1 emerging technology** to develop a technology roadmap for Pakistan.

3. SUB-SECTOR BASELINING IN PAKISTAN

3.1 Municipal solid waste

Pakistan is grappling with severe challenges in solid and agricultural waste management, resulting in significant environmental and public health issues. The country generates approximately 49.6[6] million tons of solid waste annually, with a major portion consisting of plastic waste. According to UNDP, Pakistan generates 6.41 million tons of plastic waste annually and alarmingly only 30% of this waste ends up in dumpsites or landfills while the rest 70% remains mismanaged[7]. This situation makes Pakistan among the countries with highest percentages of unmanaged plastic waste in South Asia leading to environmental and health issues. According to Pakistan's Environmental Protection Agency (EPA) 55 billion disposable plastic bags are consumed annually[8] . Plastic waste accounts for 65%[9] of beach litter. Pakistan's Indus River is ranked as the second most plastic-polluted river globally carrying 164,332 tonnes of plastic waste per year.[10]The World Bank estimates that MSW in Pakistan will increase to 42 million tonnes in 2030 and over 66 million tonnes in 2050, based on current urbanization and population growth rates[11]. However, the lack of proper waste management infrastructure exacerbates the problem (Table 1).

Settlement Area	Waste Quantity					
	Generated		Collected	Transported	Treated	Dispose of
	Daily (Kg per Capita per day)			Yearly (million metric tons per year)		(% of waste generated)
Large cities (11)	0.55	9.44	80	80	20	80 -100²
Medium-sized and small cities^b	0.42	4.44	50 - 70	50 - 70	10	90 - 100
Rural communities	0.33	13.72	20	20	20	80 - 100
Total		**27.58**				

Table 1: Solid Waste Generation, Treatment and Disposal Estimates, Pakistan[12]

In Pakistan, urban waste is primarily disposed of in landfills through open dumping and burning, resulting in the release of GHG emissions. Estimated GHG emissions are presented in Table 2.

[6] https://www.switch-asia.eu/site/assets/files/3378/waste_management_in_pakistan_final.pdf

[7] https://www.undp.org/pakistan/publications/baseline-study-current-scenario-plastic-waste-management-rahim-yar-khan

[8] https://www.sciencedirect.com/science/article/abs/pii/S0045653523016053#preview-section-introduction

[9] http://www.sacep.org/pdf/Reports-Technical/2018.01.31-Pakistan-Marine-Litter-Action-Plan-Status-Report.pdf

[10] https://www.ecohubmap.com/hot-spot/pollution-of-indus-river-pakistan/2iv01kljlwmnyc#:~:text=The%20Indus%20River%20was%20proclaimed%20as%20the%20second,estimated%20164%2C332%20tons%20of%20plastic%20waste%20per%20year.

[11] https://documents1.worldbank.org/cuduserated/en/651571618988128529/pdf/Pakistan-Sustainable-Solid-Waste-Management-in-Mountain-Areas.pdf?_gl=1*16oynd2*_gcl_au*NTMyMDM2MzEuMTcyMzc5ODM1OA

[12] https://www.adb.org/sites/default/files/publication/784421/solid-waste-management-pakistan-road-map.pdf

Source Category	CO^2	CH^4	N_2O	Total
Waste Open burning	0.0001	0.0003	0.0001	0.092
Solid waste disposal	-	10.23	-	10.23

Table 2: Summary of GHG Emissions from Waste Incineration & Open Burning (Mt of CO2e)[13]

3.2. Agricultural waste

As an agrarian economy, Pakistan generates a large amount of agricultural waste. Pakistan's agriculture sector, consuming about 91.6% of the country's total annual water use, is central to the economy, with 60% of the population engaged in agriculture and livestock. However, the sector generates substantial agricultural waste, and mismanagement has led to harmful practices like crop burning, which significantly degrades air quality. Farmers frequently burn agricultural residues from crops like sugarcane, wheat, and rice due to limited alternatives and lack of awareness of sustainable practices. These burning releases harmful pollutants that contribute to smog formation, severely impacting air quality and public health.[14] Agricultural waste burning accounts for an increase in GHG emission to about 40%[15] predominantly in the province of Punjab and Sindh which highlights the critical need for agriculture waste management (AWM) technology.

The technologies selected for agriculture waste management for this roadmap aim to address these issues by significantly reducing emissions. For instance, livestock feeding can reduce methane emissions by up to 80%, vermicomposting can cut NOx emissions by 40%, and syngas production from integrated biomass gasification fuel cells can reduce carbon emissions by 83-100%[16]. These reductions highlight the potential of these technologies to curb the environmental impact of current waste disposal practices.

3.3 Provincial Situation for Waste Sector in Pakistan

The existing situation in Pakistan varies from province to province, due to the differences in topography and resources. According to Pakistan’s NDCs, waste is ranked lowest emitting sector in Pakistan that contributed **21.72 MT $CO2_e$** to total GHG emissions in 2018. Methane is the major component with a share of **19.2 MT $CO2_e$**.[17] The provincial data for three sub-sectors **(Municipal Waste, Plastic Waste, and Agriculture Waste)** prioritized at the kick-off meeting is as follows:

3.3.1. Municipal Waste

The updated **NDCs of Pakistan (2021)** focus on **strengthening municipal service delivery** by the **local governments**, which includes a composite index of five pillars i.e. water, sanitation, hygiene, solid waste management, and plantation[18].

[13] https://www.adb.org/sites/default/files/publication/784421/solid-waste-management-pakistan-road-map.pdf
[14] https://pakobserver.net/sustainable-solution-to-pakistans-smog-crisis/
[15] https://www.sciencedirect.com/science/article/abs/pii/S135223101930202X
[16] https://www.sciencedirect.com/science/article/pii/S2589014X2100270X
[17] https://unfccc.int/sites/default/files/NDC/2022-06/Pakistan%20Updated%20NDC%202021.pdf
[18] https://unfccc.int/sites/default/files/NDC/2022-06/Pakistan%20Updated%20NDC%202021.pdf

Cities	Faisalabad	Lahore	Karachi	Hyderabad	Peshawar	Quetta
Plastic & Rubber	4.8	9.8	6.4	3.6	3.7	8.2
Metals	0.2	0.1	0.75	0.75	0.3	0.2
Paper	2.1	2.8	4.1	1.5	1.9	1.3
Cardboard	1.6	1.0	2.4	1.5	1.9	1.3
Rags	5.2	6.9	8.4	4.7	4.3	5.1
Glass	1.3	0.7	1.5	1.6	1.3	1.5
Food/vegetable	33.6	63	38	40	35	26
Wood	0.7	0.15	2.25	2.25	0.6	1.5
Fines	43	-	29.7	38.9	42	44
Stones	4.6	-	3.5	3	7.3	7.8

Table 3: % composition of solid waste in major cities of Pakistan[19], [20]

PUNJAB:

In Punjab, **15,841.5 tons** of municipal solid waste are produced daily, with Lahore generating 29% of this waste[21] while other cities like Rawalpindi, Multan, Kasur, and Faisalabad contribute varying percentages[22]. Despite the existence of policies such as the **Punjab Sanitation Policy 2015, Punjab State Solid Waste Management Policy 2018, Punjab Environmental Policy 2015**, and the draft **Punjab Climate Change Policy 2017**, Punjab lacks controlled disposal facilities and formal recycling systems, heavily relying on the informal sector. This results in overfilled landfills, environmental pollution, and threats to public health, increasing economic burdens[23].

No formal sectors are available for **waste recycling** , with much of the dry inorganic waste recovered for recycling through the informal sector. This sector includes housewives and domestic workers sorting waste at the source, scavengers collecting materials at dump sites, and local scrap dealers involved in resale. Organic waste recycling is minimal, with cow dung commonly used as fertilizer in rural areas. Sahiwal recently inaugurated a waste sorting, recycling, and composting plant with a capacity of 200 tons per day, still in trial operation. The informal sector plays a crucial role in managing recyclable waste, mostly at the collection stage or dumping sites. However, this process lacks institutionalization, with no formal record-keeping, resulting in inefficiencies and lost opportunities for structured waste management[24].

[19] https://environment.gov.pk/SiteImage/Misc/files/Downloads/interventions/environmentalissues/BriefSWMPak.pdf
[20] https://journals.sagepub.com/doi/10.1177/0734242X14545373
[21] https://epd.punjab.gov.pk/system/files/230403%20SOE%20Report%202022-Website_.pdf
[22] https://epd.punjab.gov.pk/system/files/230403%20SOE%20Report%202022-Website_.pdf
[23] http://pbit.gop.pk/system/files/Waste%20Management.pdf
[24] https://www.adb.org/sites/default/files/publication/784421/solid-waste-management-pakistan-road-map.pdf

Additionally, there is a gap in the tariff structure, as municipal services exist with associated charges, but the lack of clarity and accessibility hinders transparency in cost details. For instance, Albayrak a waste management company- has struggled to collect waste citywide, leading to reliance on local collectors, or 'Koreywalas,' who charge households Rs. 200-300 per month[25].

Furthermore, no properly engineered landfill sites are available in Pakistan. Mehmood Booti, one of Lahore's main dumping grounds, is oversaturated, exacerbating the waste management crisis. Although the Lahore Energy Department has developed a waste-to-energy project targeting 50MW of electricity generation from solid waste, this project is still in the permitting stage and is not expected to be operational until 2027[26].

SINDH:

Sindh, with Karachi as the major contributor, generates **16,500 tons** of daily waste[27]. The **Sindh SolidWaste Management Act 2021** governs the province, but despite having three designated landfill sites, Karachi's disposal capacity falls short, leading to inadequate sewage systems and sanitation challenges for 40% of its residents[28]. This unmanaged waste pollutes land and water bodies, impacting millions and contributing to air pollution, which affects respiratory health[29]. In **Karachi**, approximately 9% of waste is recycled at the source and sold to local scrap dealers. The rest is taken to empty plots, with 50%-60% of it collected by the municipal council and transported to landfills. **Karachi** also receives support for recycling and biogas production under **World Bank and ADB programs.**[30] Moreover, Sindh developed a **Sindh Waste to Energy Policy 2021** which aims to facilitate and promote the use of Sindh's MSW for energy recovery and electricity generation at affordable costs in a sustainable way, contributing to Pakistan's overall sustainable development.[31],[32] At institutional level Pakistan's Sui Southern Gas Company - Alternate Energy (SSGC-AE) have entered into a Memorandum-of-Understanding (MoU) with Green Waste Energy Pakistan. The MoU outlines that Green Waste Energy (Pvt.) Limited will produce biogas/biomethane from waste materials and generate renewable natural gas through biogas plants. This eco-friendly gas will then be purchased by SSGC-AE, who will manage its local distribution to third-party entities[33].

KPK:

Peshawar, the capital of Khyber Pakhtunkhwa (KPK) produces **600-700 tons** of municipal solid waste daily.[34] Governed by the **Khyber Pakhtunkhwa Environmental Protection Act 2014**, less than 30% of the waste is collected, leading to environmental damage, air pollution, and health risks.[35] The absence of large-scale, properly engineered sanitary landfills exacerbates these issues, with collected waste often ending up in unsuitable locations. In **KPK**, city-level waste sorting, recycling, refuse-derived fuel (RDF), biogas, and composting plants

[25] https://www.researchgate.net/publication/381086113_Assessment_of_Municipal_Solid_Waste_Management_Practices_in_Urban_Centers_of_Pakistan_A_Comprehensive_Review
[26] https://energy.punjab.gov.pk/WtE_Project_LHR
[27] https://www.trade.gov/country-commercial-guides/pakistan-waste-management
[28] https://www.pakistantoday.com.pk/2022/07/09/sindh-solid-waste-management-board/
[29] https://link.springer.com/article/10.1007/s11356-022-22331-2
[30] https://www.adb.org/sites/default/files/publication/784421/solid-waste-management-pakistan-road-map.pdf
[31] https://sindhenergy.gov.pk/directorate-of-alternate-energy/
[32] https://www.adb.org/sites/default/files/publication/784421/solid-waste-management-pakistan-road-map.pdf
[33] https://www.ssgc.com.pk/web/?p=114201
[34] https://documents1.worldbank.org/curated/en/651571618988128529/pdf/Pakistan-Sustainable-Solid-Waste-Management-in-Mountain-Areas.pdf
[35] https://www.adb.org/sites/default/files/linked-documents/51036-002-ea.pdf

are being designed under the **ADB-financed** Khyber Pakhtunkhwa Cities Improvement Projects. Small-scale private operators and NGOs also collect and reprocess waste into various products.

BALOCHISTAN:

Balochistan generates over **450,000 tons** of municipal solid waste annually.[36] Governed by the Balochistan Environment Protection Act 2012, only 35% of the daily waste is collected, leading to unsanitary conditions.[37] Open dumping and landfill practices contribute to soil and water contamination, with valuable resources in the waste stream being lost. Investment in improved collection systems, sanitary landfills, and waste-to-energy initiatives is crucial for Balochistan. At present no formal sectors are present for waste recycling.

GILGIT-BALTISTAN (GB):

GB, covering an area of approximately 72,971 square kilometers[38] is home to an estimated population of 1.4 million. Gilgit city is the fastest-growing urban settlement in the province that generates 42.5 tonnes of waste per day. [39] Skardu generates almost the same with the rate of 0.43 kg/capita/day and is being limited to traditional waste collection methods.[40] The province faces a growing waste management challenge due to its vibrant tourism industry[41]. Waste management is under the jurisdiction of the Solid Waste - Gilgit-Baltistan – Environmental Protection Agency, complemented by the Gilgit-Baltistan Climate Change Strategy and Action Plan 2017. Prioritizing sustainable waste management is essential to protect the environment and the region's tourism industry.

AZAD JAMMU AND KASHMIR (AJ&K):

AJK has an average **residential waste generation** of **0.282 kilograms per person per day**, with a waste composition of 62.04% organic, 25.88% combustible, and 24.08% recyclable[42]. Governed by the **AJK Climate Change Policy 2017**, addressing these waste streams can contribute to effective waste management in the region.

Region	Waste generation	Key issues	Policies/projects
Punjab	• 15,841.5 tons/day (municipal) 42,000 tons/day (solid waste) • Lahore: 6407 tons/day is solid waste out of which 4548 tons/day is municipal [43]	• Lack of controlled disposal facilities, overfilled landfills, heavy reliance on informal sector. Overfilled landfills, lack of formal recycling systems	• Punjab Sanitation Policy 2015, Punjab State Solid Waste Management Policy 2018, Punjab Environmental Policy 2015, draft Punjab Climate Change Policy 2017, Waste-to-energy project in development, expected operational in 2027

[36] https://www.adb.org/sites/default/files/linked-documents/51036-002-ea.pdf
[37] https://scientificeminencegroup.com/articles/Review-of-Solid-Waste-Management.pdf
[38] https://www.travelertrails.com/gilgit-baltistan#:~:text=The%20area%20of%20Gilgit%20Baltistan,is%20about%2072%2C971%20sq%20km.
[39] https://www.researchgate.net/publication/283310172_Municipal_Solid_Waste_Quantity_Composition_and_Current_Management_Practices_in_Gilgit_City_Gilgit-Baltistan_Pakistan
[40] https://ppaspk.org/index.php/PPAS-B/article/view/1176
[41-42] https://www.researchgate.net/publication/283310172_Municipal_Solid_Waste_Quantity_Composition_and_Current_Management_Practices_in_Gilgit_City_Gilgit-Baltistan_Pakistan
[43] https://www.mdpi.com/2071-1050/14/23/16234

Region	Waste generation	Key issues	Policies/projects
Sindh	• 16,500 tons/day (Karachi) (municipal)	• Inadequate landfill capacity, sanitation issues, pollution. 9% recycling rate, significant reliance on informal sector	• Sindh Solid Waste Management Act 2021, Sindh Waste to Energy Policy 2021, World Bank and ADB support for recycling and biogas production
Balochistan	• 450,000 tons annually 1047 tons/day (Quetta District, more than 50% in Quetta city) (municipal) [44]	• 35% collection rate, open dumping, soil and water contamination	• Balochistan Environment Protection Act 2012, need for improved collection systems, sanitary landfills, and waste-to-energy initiatives.
Khyber Pakhtunkhwa	• 600-700 tons/ day(Peshawar) (municipal)	• Less than 30% waste collection, lack of engineered landfills	• Khyber Pakhtunkhwa Environmental Protection Act 2014, city-level waste sorting, recycling, RDF, biogas, and composting plants under ADB-financed Khyber Pakhtunkhwa Cities Improvement Projects.
Gilgit Baltistan	• 40 tons/day (Gilgit)	• Growing waste management challenges due to tourism	• Gilgit-Baltistan Climate Change Strategy and Action Plan 2017, emphasis on sustainable waste management
AJ&K	• 1229 tons/day -0.282 kg/ person/day (residential waste only)	• High organic waste percentage, need for effective waste stream management	• AJ&K Climate Change Policy 2017

Table 4. Comparative analysis of Municipal Waste Management practices across Pakistan

3.3.2 Plastic Waste

Plastic pollution in Pakistan poses serious environmental and health threats. Similar to other developing countries, Pakistan lacks a comprehensive waste management system, with inadequate disposal and post-use treatment of plastics, leading to significant environmental issues. Plastic degradation can result in the release of chemical, such as bisphenol A (BPA), phthalates, and brominated flame retardants, which disrupt human reproductive and nervous systems. Additionally, microplastics from garment fibers persist in sewage sludge, which is often used as fertilizer, leading to significant soil contamination[45].

[44] https://www.researchgate.net/publication/363738441_Estimation_of_the_Total_Generation_of_Municipal_Solid_Waste_in_Quetta_city_and_its_Sustainable_Management_ABDUL_REHMAN_NAZIMA_YOUSAF_KHAN_AJAB_KHAN_TAREENEstimation_of_the_Total_Generation_of_Municipa
[45] https://www.wwfpak.org/issues/plastic_pollution/scoping_study_for_pet_waste_management_in_pakistan/

In Pakistan, waste management companies primarily handle the collection, transportation, and disposal of waste. The collected waste is neither sorted nor recycled by these companies. However, **PET plastic recycling** is effectively managed by informal waste pickers who collect nearly all PET waste after disposal. These comprise of scavengers, junk dealers and recyclers. This informal recycling system operates without government financial support and is the only large-scale recycling mechanism in the country, playing a crucial role in PET plastic recycling[46]. Due to the lack of a legal framework for sustainable PET bottle recycling, most recycling units operate informally, often using low-grade equipment and child labor while ignoring health and safety standards. PET bottles are crushed into flakes, which are then either exported to China, sold to the textile industry, or converted into low-quality plastic, sometimes mislabeled as food-grade, posing health risks.

PUNJAB:

In Punjab, a specific strategy for plastic waste management is outlined in the P**lastic Management Strategy, Punjab 2023**. This strategy complements existing environmental policies, such as the **Punjab Environmental Policy 2015**, to address the challenges posed by plastic waste and promote sustainable practices within the province. In Sindh, the regulation of plastic waste is outlined in the **Sindh Solid Waste Management Act, 2021**. Meanwhile, **Khyber Pakhtunkhwa (KPK) follows the Khyber Pakhtunkhwa Environmental Protection Act 2014**, and Balochistan adheres to the **Balochistan Environment Protection Act - 2012**. Gilgit-Baltistan has established the **Solid Waste - Gilgit-Baltistan – Environmental Protection Agency**, along with the Gilgit-Baltistan Climate Change Strategy and Action Plan 2017. AJK focuses on plastic waste management through **the AJK Climate Change Policy 2017**. The **updated NDCs of Pakistan(2021)** note that **banning single-use plastic** was a beneficial initiative for Pakistan, as it promotes reuse and source reduction of waste. [47]

Punjab generates 1.22 million tons of plastic waste annually, with only 19.2% undergoing recycling.[48] In major cities like Lahore, Islamabad, and Bahawalpur, 9% to 13% of municipal solid waste consists of plastic.[49] Unmanaged plastic contributes to ecological and aesthetic threats as it accumulates in landfills and litter streets. Open burning of plastic releases harmful toxins, causing air pollution, respiratory diseases, and potential metabolism and neurological disorders.

Despite the presence of policies like the Punjab Plastic Management Strategy (2023) and the ban on single-use plastics across Pakistan, the **on-ground situation** remains troubling. Enforcement is weak, especially in smaller cities and rural areas, where plastic bags are still widely used. Public resistance, coupled with limited availability of affordable alternatives, hinders the transition. The informal sector continues to dominate recycling efforts without government oversight or safety standards. As a result, plastic waste accumulates in landfills, waterways, and coastal regions, worsening pollution levels despite regulatory measures.

[46] https://www.wwfpak.org/issues/plastic_pollution/scoping_study_for_pet_waste_management_in_pakistan/
[47] https://unfccc.int/sites/default/files/NDC/2022-06/Pakistan%20Updated%20NDC%202021.pdf
[48] https://punjabcode.punjab.gov.pk/uploads/articles/the-plastic-management-strategy-punjab-pdf.pdf
[49] https://www.globalplasticaction.org/case-study-details/plastic-landscape-analysis:-pakistan/aJY68000000CaSyGAK

SINDH:

Sindh faces a critical threat from plastic waste, particularly in Karachi which is a major contributor. About 30% of Pakistan's plastic waste originates from Sindh, with over 90% of sampled plastic in the Upper Indus Basin ending up in waterways like the Indus River thus severely impacting aquatic life and surrounding communities., Nearly 10,000 tonnes of this plastic reach the Indus River's mouth annually, threatening coastal and marine ecosystems. This pollution clogs drains, exacerbates urban flooding during monsoons, and leads to the accumulation of microplastics in water bodies and food sources, posing significant health risks[50]. Low-density polyethylene (LDPE) prevalent in single-use plastics, dominates pollution, accounting for 43% of detected plastic. [51] Beyond environmental impacts, plastic debris endangers public health, harms coastal and marine life, affecting livelihoods and tourism in Sindh's coastal areas.

KHYBER PAKHTUNKHWA (KPK):

Khyber Pakhtunkhwa (KPK) confronts a significant challenge in managing plastic waste. Peshawar, the largest city, generates 1,050 tons of plastic waste daily, constituting 70% of its overall municipal waste.[52] Despite KPK's 7% share in Pakistan's plastic production, unmanaged plastic pollutes waterways, harms wildlife, disrupts ecosystems, and hinders agricultural productivity.[53] Improper plastic burning releases toxic fumes, contributing to air pollution and harming public health.

BALOCHISTAN:

Balochistan has banned plastic bags, but coastal areas of Gwadar and Lasbela still face plastic pollution, impacting local fishermen. Inadequate plastic waste management and burning add to the issue. The province has established a biodegradable plastic factory.[54]

GILGIT-BALTISTAN:

Gilgit-Baltistan, known for its natural beauty, confronts plastic pollution with an estimated consumption of 11 tons per month in Gilgit alone. [55] This translates to approximately 20.4 million discarded plastic objects annually.[56] The region's plastic pollution poses threats to wildlife, drainage systems, and air quality. Burning plastic releases harmful toxins, impacting respiratory health and contributing to climate change. Contaminated soil and water jeopardize biodiversity and pose potential health risks for humans and animals. Immediate and strategic action is crucial to mitigate these environmental and human health impacts.

Region	Waste generation	Key issues	Relevant Policies
Punjab	• 3342 tons/day (1.22 million tons annually)	• Unmanaged plastic, open burning, air pollution, health risks	• Plastic Management Strategy, Punjab 2023; Punjab Environmental Policy 2015

[50] https://thefridaytimes.com/29-Nov-2023/pakistan-s-plastic-waste-management-crisis#:~:text=Shah%20said%20his%20team%27s%20research,%25%20and%20Baluchistan%20generates%203%25.
[51] https://blogs.worldbank.org/endpovertyinsouthasia/whats-waste-plastics-threaten-pakistans-mighty-indus
[52] https://tribune.com.pk/story/2391859/plastic-waste-a-threat-to-marine-life
[53] https://thefridaytimes.com/29-Nov-2023/pakistan-s-plastic-waste-management-crisis
[54] https://tribune.com.pk/story/1385156/balochistan-bans-use-plastic-bags
[55] https://thefridaytimes.com/31-Jan-2023/gilgit-baltistan-s-plastic-crisis-threatens-the-mountain-ecosystem
[56] https://thefridaytimes.com/31-Jan-2023/gilgit-baltistan-s-plastic-crisis-threatens-the-mountain-ecosystem

Region	Waste generation	Key issues	Relevant Policies
Sindh	• Significant, 30% of Pakistan's total annually	• Plastic pollution in Indus River, urban flooding, impact on marine life	• Sindh Solid Waste Management Act 2021; Sindh Waste to Energy Policy 2021
Balochistan	• 3% of Pakistan's total annually	• Coastal pollution, inadequate management, impact on fisheries	• Balochistan Environment Protection Act 2012
Khyber Pakhtunkhwa	• Balochistan Environment Protection Act 2012	• Waterway pollution, ecosystem disruption, toxic fumes from burning	• Khyber Pakhtunkhwa Environmental Protection Act 2014
Gilgit Baltistan	• 11 tons/month (approx. 20.4 million objects/year)	• Pollution affecting wildlife and drainage, health risks from burning plastic	• Gilgit-Baltistan Climate Change Strategy and Action Plan 2017
AJ&K	• 1229 tons/day -0.282 kg/ person/day (residential waste only)	• High organic waste percentage, need for effective waste stream management	• AJ&K Climate Change Policy 2017

Table 5. Comparative overview of plastic waste management across Pakistan's provinces

3.3.3 Agricultural Waste

PUNJAB:

Agriculture contributes **19% to Pakistan's GDP and drives 80% of export** earnings in Punjab. [57] With over **5 million farms cultivating 16.68 million hectares**, the traditional practice of burning rice residue for wheat cultivation poses a major threat.[58] This widespread burning results in severe air pollution, reducing life expectancy and leading to the loss of valuable organic matter crucial for soil fertility. Additionally, the released smoke contributes to GHG emissions, exacerbating climate change concerns. [59] Provincial policies and departments for the agriculture waste sub-sector in Punjab include the **Punjab Agriculture Policy 2018 and Punjab Environmental Policy 2015**.

SINDH:

Sindh, a cornerstone of Pakistan's economy with over 50 million inhabitants, faces a critical challenge in managing its agricultural waste. Responsible for 90% of Pakistan's banana production,[60] Sindh generates tons of residue per harvest, and alarmingly, 100% of this waste is simply burned in the fields. [61] This practice extends beyond bananas to include the burning of leftover residue from rice and wheat production in 2022, releasing harmful air pollutants like particulate matter and volatile organic compounds. [62] Sindh is guided by the

[57] https://www.agripunjab.gov.pk/overview#:~:text=Punjab%27s%20total%20cropped%20area%20was,the%20Punjab%27s%20total%20cropped%20area.
[58] http://www.sandeeonline.org/uploads/documents/publication/1018_PUB_Policy_Brief_71_Tanvir.pdf
[59] https://unfccc.int/sites/default/files/NDC/2022-06/Pakistan%20Updated%20NDC%202021.pdf
[60] https://eprints.whiterose.ac.uk/98565/1/1%20CO%201%202
[61] https://eprints.whiterose.ac.uk/98565/1/1%20CO%201%202
[62] http://www.amis.pk/agristatistics/Data/HTML%20Final/Wheat/Production.html

Sindh Agriculture Policy 2018-2030, complemented by the **Sindh Environmental Protection Agency**. Despite irrigated agriculture forming the backbone of its rural economy, unsustainable practices pose a significant threat overall.

GILGIT-BALTISTAN:

Only 1% of Gilgit's population directly works in agriculture. [63] Women in Gilgit are primarily engaged in agricultural work or household duties. The total cultivated land in Gilgit is just 22 square kilometers, yet it produces 63,000 metric tons of wheat, maize, barley, potato, vegetables, and fruits annually [64]. Gilgit-Baltistan is overseen **by the Environmental Protection Agency.** Inadequate marketing and packaging infrastructure lead to substantial wastage of Gilgit's agricultural output. Decomposing food waste in landfills generates methane, a potent GHG contributing to climate change. Wasted food represents wasted resources like water, land, and energy used in its production and transportation.

AJ&K:

Around 13% (194,592 hectares) of the AJ&K territory is dedicated to agriculture.[65] Approximately 42.63% (0.567 million hectares) of the land is under the Forest Department's control.[66] 66.8% (0.379 million hectares) of the forested area is considered productive.[67] The remaining 33.2% (0.188 million hectares) are non-productive forests.[68] AJK emphasizes agriculture waste management through the **AJK Statistical Year Book 2020 and the AJK Climate Change Policy 2017.**

In conclusion, the gap between waste generation and management infrastructure is significant. Punjab and Sindh face critical gaps due to high waste production. KPK and Balochistan have limited collection systems and Balochistan still has no agriculture waste management policy. Gilgit-Baltistan needs better infrastructure for tourism-related waste, while AJK requires enhanced collection and recycling. Targeted interventions are needed to improve recycling, adopt sustainable practices, and reduce environmental and health risks. In Pakistan, there is no formal sector for agricultural waste management; the responsibility typically falls on the farmers or those generating the waste. This waste is often burned on-site by the farmers themselves. In some cases, agricultural waste is burned in the fields to clear the ground for the next growing season. Even if collected by waste handlers, it is ultimately either openly burned or dumped in unmanaged sites.

Region	Relevant Policies	Current practices	Challenges
Punjab	• Punjab Agriculture Policy 2018, Punjab Environmental Policy 2015	• Burning of rice residue, leading to air pollution and loss of soil fertility	• Severe air pollution, smog formation, GHG emissions, soil degradation

[63] https://www.commissiemer.nl/docs/mer/diversen/pos722-sea-masterplan-gilgitcity.pdf
[64] https://www.commissiemer.nl/docs/mer/diversen/pos722-sea-masterplan-gilgitcity.pdf
[65] https://www.commissiemer.nl/docs/mer/diversen/pos722-sea-masterplan-gilgitcity.pdf
[66] https://www.commissiemer.nl/docs/mer/diversen/pos722-sea-masterplan-gilgitcity.pdf
[67] https://www.commissiemer.nl/docs/mer/diversen/pos722-sea-masterplan-gilgitcity.pdf
[68] https://www.commissiemer.nl/docs/mer/diversen/pos722-sea-masterplan-gilgitcity.pdf

Region	Relevant Policies	Current practices	Challenges
Sindh	• Sindh Agriculture Policy 2018-2030, Sindh Environmental Protection Agency	• 100% of agricultural waste burned in the fields, contributing to air pollution	• Air pollutants, unsustainable burning practices
Balochistan	• No specific agriculture waste management policy	• Insufficient data	• Insufficient data
Khyber Pakhtunkhwa	• Khyber Pakhtunkhwa Environmental Protection Act 2014	• Waste is often burned, leading to air pollution and loss of organic matter	• Limited collection systems, environmental and health impacts
Gilgit Baltistan	• Overseen by Environmental Protection Agency, Gilgit-Baltistan Climate Change Strategy and Action Plan 2017	• Inadequate marketing and packaging lead to substantial wastage	• Lack of infrastructure, food waste contributes to methane emissions
AJ&K	• AJ&K Climate Change Policy 2017	• Agriculture waste management is minimal	• Limited collection and recycling, inadequate infrastructure

Table 6. key aspects of Agricultural Waste Management across different provinces of Pakistan

3.4 Legal and Policy Framework

The 18th Constitutional Amendment of 2010 significantly restructured Pakistan's governance, devolving many federal responsibilities to provincial governments. Environmental management was a key area affected. The Pakistan Environmental Protection Agency (Pak-EPA) assumed environmental oversight in Islamabad, while Provincial Environmental Protection Agencies took charge of their respective provinces. Subsequently, the federal Ministry of Environment was transformed into the Ministry of Climate Change in 2012, focusing on national-level environmental challenges and international agreements[69]. **Table 7** provides a comprehensive overview of key legal frameworks and policies related to SWM in Pakistan

1983	**Pakistan Environment Protection Ordinance (PEPO)** marked the beginning of environmental legislation in Pakistan. Its main objective was to establish institutions (e.g., PEPC).
1992	**National Conservation Strategy (NCS)** emerged after almost a decade of discussions and analyses, providing a broad framework for addressing environmental concerns in the country.
1993	**National Environmental Quality Standards (NEQS)** controlled industrial pollution by creating limits for industrial effluents and emissions, as well as municipal discharges from wastewater systems, but did not consider pollution caused by improper disposal of MSW.
1997	**Pakistan Environmental Protection Act (PEPA)** replaced the earlier PEPO to bridge gaps in the law.

[69] Pakistan-Sustainable-Solid-Waste-Management-in-Mountain-Areas.pdf

2001	**National Environmental Action Plan (NEAP)** was approved to follow the strategy of the NCS, which narrows the government's policy focus on the environment to four core programs: clean air, clean water, waste management, and ecosystem management.
2005	**National Environmental Policy (NEP)** aimed to protect, conserve, and restore Pakistan's environment to improve quality of life of citizens through sustainable development, and addressed different sectoral issues, including waste management.
2013	**Local Government Acts (LGAs)** are passed by each province. These Acts contain provisions for integrated solid waste management (ISWM) systems and other municipal services that district councils will review.

Table 7: key legal frameworks and policies related to SWM in Pakistan

Nationally, the federal government has introduced the **National Hazardous Waste Management Policy 2022**[70], which supports waste reduction through the 3Rs (Reduce, Reuse, and Recycle). This policy aims to improve the efficiency of waste management across the country. On the other hand, no direct policies for managing agricultural waste currently exist in Pakistan. However, the Punjab Smog Policy provides guidelines for handling municipal waste and crop residue to address smog issues. The policy outlines that the Agriculture Department should promote environmentally friendly disposal methods for crop residue[71].

At the **provincial level**, several policies promote the 3Rs and seek to enhance waste management efficiency. These include the Punjab Sanitation Policy 2015, Plastic Management Strategy **Punjab 2023, Sindh Solid Waste Management Act 2021, Balochistan Environment Protection Act 2012, Khyber Pakhtunkhwa Environmental Protection Act 2014, and AJK Climate Change Policy 2017.**

3.5 Institutional Framework:

Traditionally, local governments in Pakistan handled solid waste management (SWM). However, the increasing volume of waste and growing awareness about sustainable waste practices have led to a broader involvement of government agencies. Now, departments such as city mayor's offices, environmental protection agencies, housing and urban development authorities, and the Ministry of Climate Change and Environmental Coordination are also playing key roles in various stages of waste management[72]. Overall framework is presented in Table 8.

1975	**Ministry of Climate Change and Environmental Coordination MoCC&EC** (earlier Ministry of Environment) established. Following the Stockholm Declaration of 1972, it proposed and drafted the first consolidated environmental law in Pakistan.
1983	**Pakistan Environmental Protection Agency (Pak-EPA)** administers and implements the provisions of PEPO at the federal level; it also provides technical support to the MoCC&EC.
1984	**Pakistan Environment Protection Council (PEPC)** is the main environmental policy-making body in the country, responsible for pollution control and preservation of the living environment.

[70] https://mocc.gov.pk/SiteImage/Policy/National%20Hazardous%20Waste%20Management%20Policy%202022.pdf
[71] https://epd.punjab.gov.pk/system/files/Policy%20on%20Controlling%20Smog%20%28Final%29_0.pdf
[72] Pakistan-Sustainable-Solid-Waste-Management-in-Mountain-Areas.pdf

1987	**Four Provincial Environmental Protection Agencies (EPAs)** at the provincial level, planned in 1984 but established three years later, to administer and implement the provisions of PEPO.
2001	**Local Government Acts (LGAs)**, passed individually by each province, based on the premise that locally managed basic services would improve responsiveness to local needs and facilitate improved service delivery.

Table 8: Institutional framework of SWM in Pakistan

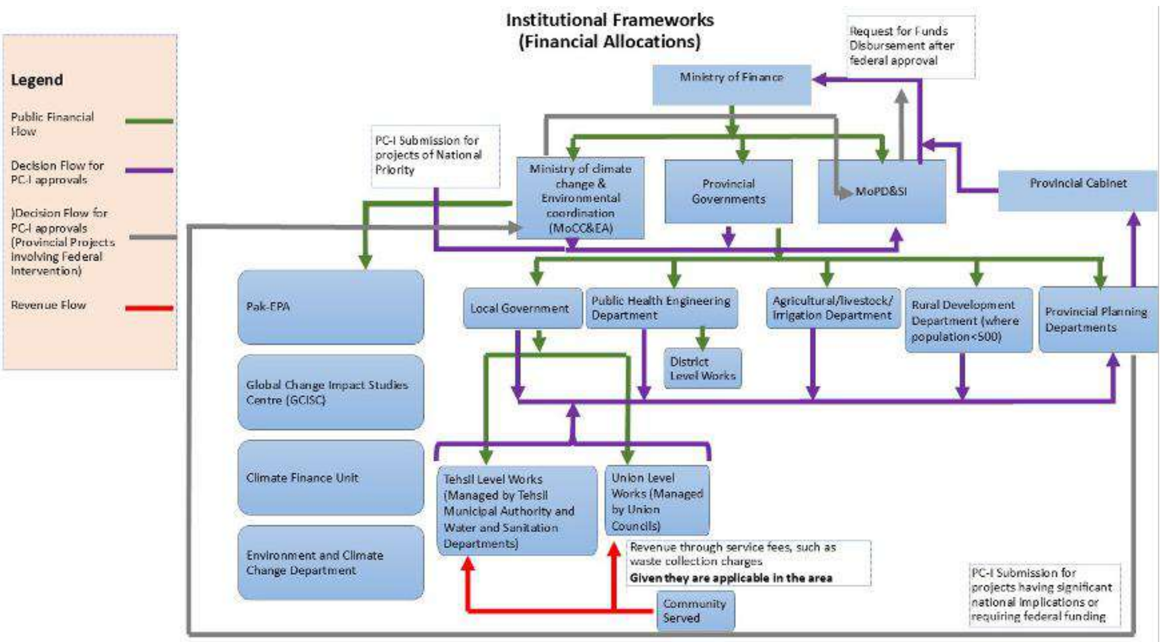

Figure 3. Institutional framework for financial allocations in Pakistan's waste management sector

The above diagram (Figure 3) illustrates the institutional framework for financial allocations in Pakistan's waste management sector. It outlines the decision-making processes, key players, and funding flows involved in waste management sector. The diagram shows the flow of funds represented by green arrows, from the Ministry of Finance (MoF) down to Union, Tehsil, and District levels, ensuring allocations align with each institution's responsibilities. Project proposals (PC-I documents) follow a bottom-up approach represented by purple arrows, where local entities, tehsils and union submit them to relevant provincial departments for review. After approval, these proposals proceed to the provincial cabinet and then to the MoF. The PC-Is for the projects particularly in the domain of the provincial departments are drafted and forwarded directly by these departments to the provincial planning department. This path is followed by all provincial projects unless they involve energy sectors or have national implications that require federal funding. Subsequently, national departments submit PC-Is for national priority projects for scrutiny to the MoPD&SI for presenting the case to MoF.

Provincial projects requiring federal intervention are reviewed by the MoCC&EC and MoPD&SI before MoF consideration. Local governments (Union Councils, Tehsil Municipal Authorities) generate revenue through service fees for waste management. Revenue generation through service fees, such as waste collection charges, is typically limited. In many cases, these fees are only sufficient to cover basic operational costs like the salaries of sanitary workers and fuel expenses for waste collection vehicles. However, the revenue generated is generally inadequate to fund larger waste management initiatives or infrastructure development projects.

SWM services are delivered by a mix of government agencies, quasi-government entities, private companies, NGOs, and others including community groups, households, and businesses. These services encompass waste collection, transportation, and disposal. While data on waste sorting is unavailable, the recovery of recyclable materials primarily occurs within the informal sector. They are presented below[73]

Water Service	Government	Quasi-government	Private Sector	NGOs	Others (e.g, CBOs, informal sector)
Collection	Yes	Yes	Yes	Yes	Yes
Trasnportation	Yes	Yes	Yes	Yes	Yes
Sorting	No data Available	No data Available	No data Available	No data Available	No data Available
Recycling/ Recovery	No data Available	No data Available	Yes	Yes	Yes
Disposal	Yes	Yes	Yes	Yes	No
Financing	Yes	Yes	Yes	No	Yes

Figure 4. Stakeholders providing ancillary SWM services

3.6 SWM financing in Pakistan

SWM in Pakistan is funded through a combination of **government** and **private** sources. Provincial governments, empowered by the 18th Constitutional Amendment, allocate funds to local government and community development departments for SWM services in their respective areas. These funds are distributed based on factors like population, urban/rural classification, and political priorities[74]as shown previously in Fig 3.

The **armed forces** also manage SWM in cantonment areas and military housing societies, with partial government subsidies. Cantonment boards collect service charges from residents in some areas.

Private housing societies, typically upscale gated communities, rely on fees collected from residents to contract private waste management services.

Plastic recycling is majorly taken up by the private sector that is currently struggling as an industry and looking for incentives and exemptions such as in taxes in compensation for being an environmentally friendly company. Some collaborations like the CoreAlliance is a collaboration of key industry players, NGOs that are working towards a circular economy by addressing plastic packaging concerns.[75]

Overall, the financing landscape for SWM in Pakistan is fragmented, with varying levels of government involvement and private sector participation.

[73] https://documents.worldbank.org/en/publication/documents-reports/documentdetail/651571618988128529/pakistan-sustainable-solid-waste-management-in-mountain-areas
[74] https://documents.worldbank.org/en/publication/documents-reports/documentdetail/651571618988128529/pakistan-sustainable-solid-waste-management-in-mountain-areas f
[75] https://corealliance.org.pk/

3.7 SWM systems

Waste management at the provincial level is overseen by **local government departments**. In large cities, public sector **waste management companies** have taken over this responsibility following institutional reforms. Punjab, for instance, has eight waste management companies, Khyber Pakhtunkhwa has seven water and sanitation services companies, and Sindh has established the Sindh SWM Board to enhance technical and professional capacity[76]. One such example is **The Albayrak Group**, expanding from Turkey, who have been a key player in Pakistan's waste management since 2005, operating in major cities such as Karachi, Lahore, Islamabad, Rawalpindi, and Faisalabad. Their efforts complement both formal and informal waste management systems, aiming to improve waste collection, processing, and public engagement[77]. Apart from that Pakistan's informal sector plays a crucial role in managing recyclable waste. This sector, primarily composed of individual workers and small businesses, collects and sorts recyclable materials (Fig 4). While there's no official definition for this group, their importance in the recycling process is widely recognized[78].

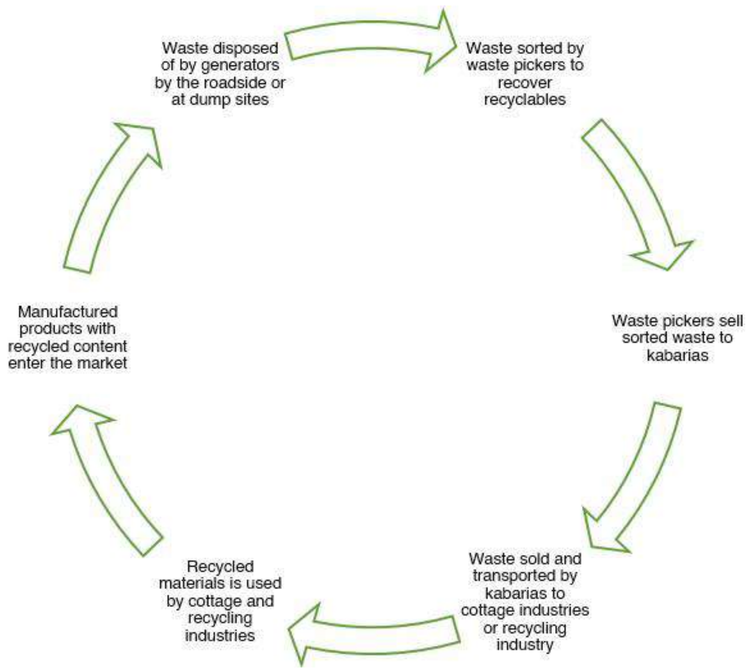

Figure 5. Schematic representation of the informal sector in Pakistan

The collected plastic waste by this informal sector is transferred to the recycling industries: a business opportunity majorly taken up by the private sector in Pakistan. Multan Waste Management Company is ranked among the top recyclers with a revenue of $393.9 M.[79] Green Earth Recycling in Lahore is another major player that builds garden furniture out of recycled plastics and is working towards developing their own collection system in the city.[80]

[76] https://www.adb.org/sites/default/files/publication/784421/solid-waste-management-pakistan-road-map.pdf
[77] https://albayrak.com.pk/
[78] Pakistan-Sustainable-Solid-Waste-Management-in-Mountain-Areas.pdf
[79] https://www.zoominfo.com/top-lists/top-10-companies-from-energy-environment-industry-in-PK-by-revenue
[80] https://greenearthrecycling.com/

3.8 International Development Support for SWM in Pakistan

SWM initiatives in Pakistan are supported by several **funded projects** across different provinces. In Punjab, the **World Bank** is supporting the Urban Unit to reform waste management practices, with outsourced services in Lahore. **ADB** is funding the Sindh Cities Improvement Investment Program with $400 million for improved waste management in 20 secondary cities. KPK plans to build a sanitary landfill under **WSSP**. In Balochistan, no significant infrastructure exists. Additionally, **UNEP**, **JICA**, and other organizations are involved in various waste management projects across the country.[81] WWF Pakistan in collaboration with international donors like Coca Cola Foundation are actively involved in plastic waste reduction initiatives such as No Plastic in Future.[82] **UNDP, GEF and IUCN are some other players to achieve this goal.**

3.9 Agriculture Waste Management Financing in Pakistan

Several entities are working directly or indirectly towards improving agricultural practices in Pakistan. This includes waste management in this subsector which poses numerous hazards due to harmful management practices. Pakistan Agricultural Research Council (PARC) is a responsible for financing solutions in collaboration with federal and provincial institutions.[83] Pakistan Science Foundation (PSF) and Higher Education Commission (HEC) are entities that provide funds for research and innovation to research Institutions for developing new technologies for agriculture waste management.

3.10 Agriculture Waste Management System

Agriculture waste is predominantly subjected to open burning.[84] However, there are some projects like Lahore Compost LCL that also qualified for climate finance[85] that utilize agricultural waste in their composting process.[86] The product of this process can be used as a soil amendment that can substantially improve soil organic matter of the deteriorating soils of Pakistan.[87] Several studies propose the utilization of agricultural waste for the generation of renewable energy which is the objective of Alternative Energy Development Board (AEDB).[88] Circular economy and its implementation in cement industry: A case point in Pakistan is another study that suggests utilization of crop residues like rice husk, wheat straws[89] and bagasse in energy generation e.g. in cement industry.[90]

[81] https://unfccc.int/sites/default/files/resource/Pakistan%E2%80%99s%20First%20Biennial%20Update%20Report%20%28BUR-1%29%20-%202022.pdf

[82] https://www.worldwildlife.org/pages/no-plastic-in-nature

[83] https://www.parc.gov.pk/Detail/NzJlZmQxOWUtYTdhOC00ZmU2LWIwZTAtMDkwMzI4NWNjODVI

[84] https://www.theigc.org/blogs/climate-priorities-developing-countries/crop-residue-burning-pakistan-systems-approach#:~:text=A%20major%20contributor%20to%20air%20pollution%20is%20crop,plant%20wheat.%20Resultant%20fires%20exacerbate%20Punjab%E2%80%99s%20winter%20smog.

[85] https://collaboration.worldbank.org/content/sites/collaboration-for-development/en/groups/results-based-financing/groups/results-based-financing-for-climate/documents.entry.html/2017/02/21/lahore_compost-carbo-ug6W.html

[86] https://collaboration.worldbank.org/content/usergenerated/asi/cloud/attachments/sites/collaboration-for-development/en/groups/results-based-financing/groups/results-based-financing-for-climate/documents/_jcr_content/content/primary/blog/lahore_compost-carbo-ug6W/Good%20Practices%20in%20City%20Energy%20Efficiency%20ESMAP.pdf

[87] https://onlinelibrary.wiley.com/doi/10.1155/2022/5831832

[88] https://www.frontiersin.org/journals/energy-research/articles/10.3389/fenrg.2019.00024/full

[89] https://www.sciencedirect.com/science/article/abs/pii/S0301479719316421

[90] https://www.sciencedirect.com/science/article/abs/pii/S0048969723042286

3.11 International Development Support for Agriculture Waste Management in Pakistan

Funding organizations such as the Asian Development Bank are indirectly working towards sustainable management of agricultural waste or building up the enabling environment for it. ADB has developed guidelines titled Solid Waste Management Sector in Pakistan: A Reform Roadmap for Policy Makers that emphasize the sustainable management of agricultural waste.[91] Moreover, it also stresses on the need to manage this waste to achieve NDC targets.[92] The Acumen Climate Action Pakistan Fund by Green Climate Fund aims to promote a commercially viable business model throughout the agriculture sector in Pakistan which could potentially include circulating waste back into the economy for monetary returns.[93] Another project titled Transforming the Indus Basin with Climate Resilient Agriculture and Water Management[94] by the same agency is focused on building skills, knowledge and technological capacities of the farmers which indirectly address this goal. Pakistan Agricultural Technology Transfer Activity[95] by USAID, financing by Nestle and Engro Corporation, International Fund for Agricultural Development are some of the other examples of international development support in the field of agriculture waste management.

4. TECHNOLOGY SCREENING AND PRIORITIZATION

This report assesses five technologies—four existing and one emerging—selected from a prioritized list discussed during the initial meeting. The evaluation focuses on analyzing the technical, financial, market, and gender feasibility of each technology. To achieve this, a scoring framework was developed through desk research for three waste sub-sectors and the respective waste management technologies. The assessment is structured around three main criteria: Economic and Technical Feasibility, Inclusive Development and Climate Impacts, and Legal, Regulatory, and Financial Landscape. The entire evaluation process is summarized in Table 9.

For financial analysis we conducted cost-benefit analysis (CBA) . To conduct a CBA for waste and water technology projects, we follow a systematic approach using data from similar projects in Pakistan, adjusted for inflation and uncertainties. We begin with data collection, updating financial metrics to present value using an inflation index and including a contingency factor for risks. The analysis calculates key financial indicators like Net Present Value (NPV), Internal Rate of Return (IRR), and payback period, along with visual tools to highlight cash flow dynamics. Sensitivity analysis is performed by varying key variables such as discount rates and capital costs, providing insights into the project's financial resilience. For emerging technologies lacking local data, we incorporate findings from similar projects in other developing countries, ensuring our analysis remains relevant and comprehensive despite potential data gaps. While the analysis suggests favorable outcomes, it's conducted with caution due to assumptions based on past data that may not fully reflect future complexities

Additionally, the evaluation considers the legal, regulatory, and economic landscapes relevant to each technology, as well as their social benefits, which were assessed through a gender-based framework focusing on quality-of-life improvements, inclusive development, potential harmful impacts, and gender-specific needs based on criteria derived from the Pakistan Social & Living Standard Measurement (PSLM 2020-21) report.

[91] https://www.adb.org/sites/default/files/publication/784421/solid-waste-management-pakistan-road-map.pdf
[92] https://www.adb.org/publications/waste-sector-inclusion-revised-ndcs-pakistan
[93] https://www.greenclimate.fund/project/fp229
[94] https://www.greenclimate.fund/project/fp108
[95] https://www.cnfa.org/program/pakistan-agricultural-technology-transfer-activity/

Major Group	Group Score	Criteria	Scoring for each criterion	Criteria Weightage	Technologies
Legal, Regulatory, and Financial Landscape	15	Are there any clear guidelines or regulations for this technology?	Individual score (scale of 1-5)	5%	Score Weighted Score
		Do existing financial structures exist to invest in this technology in Pakistan? (i.e. Existing bankable projects? PPP? Targeted financing facilities?)	Individual score (scale of 1-5)	5%	Score Weighted Score
		Is there an opportunity for private sector investment in this technology?	Individual score (scale of 1-5)	5%	Score Weighted Score
Economic and Technical Feasibility	30	Does this technology efficiently minimize the use of energy and other resources?	Individual score (scale of 1-5)	5%	Score Weighted Score
		Does this technology promote efficiency in the management and delivery of the waste sector?	Individual score (scale of 1-5)	5%	Score Weighted Score
		Is this technology affordable?	Individual score (scale of 1-5)	5%	Score Weighted Score
		Is this technology successfully in use in Pakistan? or there is a potential for a pilot?	Individual score (scale of 1-5)	5%	Score Weighted Score
		Do the skills to implement and operate this technology exist in Pakistan?	Individual score (scale of 1-5)	5%	Score Weighted Score
		Does Pakistan have the capacity to inculcate skills training for this technology through its research and technology institutions?	Individual score (scale of 1-5)	5%	Score Weighted Score
Inclusive Development and Climate Impacts	30	Does this technology possess emission reduction potential?	Individual score (scale of 1-5)	5%	Score Weighted Score
		Does this technology contribute to building resilience and adaptive capacity in Pakistan?	Individual score (scale of 1-5)	5%	Score Weighted Score
		Does this technology enhance the quality of life in target communities?	Individual score (scale of 1-5)	5%	Score Weighted Score
		Does this technology contribute to inclusive development and just transition?	Individual score (scale of 1-5)	5%	Score Weighted Score
		Does this technology have any negative/positive impacts on women and/or minorities or youth and children?	Individual score (scale of 1-5)	5%	Score Weighted Score
		Does this technology address gender specific needs and promote social equality?	Individual score (scale of 1-5)	5%	Score Weighted Score

Table 9: Scoring criteria developed for technology prioritization

The table above outlines a comprehensive assessment framework for evaluating a specific technology across three major categories: **Legal, Regulatory, and Financial Landscape; Economic and Technical Feasibility**; and **Inclusive Development and Climate Impacts**. Each category has a specific metric, with individual scoring (on a scale of 1-5) and a weightage of 5% per metric. For instance, a technology scores 3 in any of the metric, its weightage would be 3% in that particular metric. The total weight would be 75% out of which each technology would be assessed for ranking.

5. Analysis

The analysis of the shortlisted technologies (Table 10) focuses on the main components of the scoring criteria; legal, regulatory, and financial landscape, economic and technical feasibility, and inclusive development and climate impacts. Keeping in view the needs of the provinces, the technologies were prioritized as per their strengths and weaknesses.

Sub Sector	Shortlisted Technologies
Municipal Solid Waste	1. Aerobic Windrow Composting 2. Waste Segregation 3. Engineered Landfill Technology 4. Waste Valorization **(Emerging)**
Plastic Waste	1. Refuse-derived Fuel 2. Downcycling 3. Non-Biodegradable Plastic Pyrolysis **(Emerging)**
Agriculture Waste	1. Advanced Agro-Residue Livestock Feeding 2. Vermicomposting 3. Integrated Biomass Gasification / pyrolysis for syngas and biochar **(Emerging)**

Table 10. list of shortlisted technologies for prioritized waste sub-sectors

5.1 Definition of waste sub-sectors

Municipal solid waste MSW	MSW—more commonly known as trash or garbage—consists of everyday items we use and then throw away, such as product packaging, grass clippings furniture, clothing, bottles, food scraps, newspapers, appliances, paint, and batteries. This comes from our homes, schools, hospitals, and businesses[96]
Agriculture waste	Agricultural waste is defined as waste left over after cultivating and processing agricultural products like fruits, vegetables, dairy and grains, as well as meat, poultry and crops[97].
Plastic waste	Plastic waste refers to discarded or unwanted plastic materials, typically in the form of packaging, containers, bottles, bags, and other plastic products, that have reached the end of their useful life. It includes both single-use and durable plastics that are improperly disposed of, recycled, or managed, often contributing to environmental pollution if not adequately handled[98].

[96] https://archive.epa.gov/epawaste/nonhaz/municipal/web/html/index.html
[97] https://www.sciencedirect.com/topics/earth-and-planetary-sciences/agricultural-waste
[98] https://www.nationalgeographic.com/environment/article/plastic-pollution

5.2 Definition of Technologies

Aerobic Windrow Composting	Aerobic Windrow Composting is the controlled, biological decomposition of organic materials by microorganisms in the presence of oxygen to form compost. Organic (carbon-based) materials include grass clippings, leaves, yard and tree trimmings, food scraps, crop residues, animal manure and biosolids[99]
Waste Segregation	Waste segregation is defined as the separation of waste into different types. This can include separating organic waste from your recyclable waste. It ensures that waste is sent to the correct place for disposal[100]
Engineered Landfill Technology	Engineered landfills Technology is an advanced waste disposal method that involves the design and operation of landfills with engineered systems, including liners, leachate collection, gas management, and monitoring, to safely contain waste, prevent environmental contamination, and control pollution.[101]
Waste Valorization	Waste valorization is defined as reusing, recycling or conversion of waste materials into resources. These include materials, chemicals, fuels or other sources of energy[102]
Refuse-derived Fuel (RDF)	RDF is a fuel generated from MSW that contains combustible ingredients. This waste, sourced from industrial or commercial sectors, sustains the processes of shredding, drying, and baling, and then is burned to generate electric energy. RDF acts as a renewable energy source, preventing waste from being disposed of in landfills and maximizes its utilization[103]
Downcycling	Downcycling is the term used for practicing of recycling waste which results in the material of lesser quality than the original product.[104]
Non-Biodegradable Plastic Pyrolysis	Non-biodegradable plastic pyrolysis is defined as the thermal decomposition of plastic waste that cannot be broken down naturally by biological means, in the absence of oxygen, to produce valuable products such as fuels, oils, and carbon-rich materials. [105]
Livestock Feeding	Livestock feeding refers to the practice of providing animals, typically those raised for agricultural purposes such as cattle, sheep, goats, pigs, and poultry, with the necessary food and nutrients required for their growth, maintenance, reproduction, and production of animal products like meat, milk, and eggs. Recovering food waste for animal feeding (ReFeed) is a viable option that has the potential to simultaneously address waste management[106]
Vermicomposting	Vermicomposting is a biological process that utilizes earthworms and microorganisms to convert organic waste into a nutrient-rich soil amendment, enhancing soil quality and providing a natural source of plant nutrients[107].
Integrated Biomass Gasification / pyrolysis for syngas and biochar	Integrated Biomass Gasification Fuel Cell is a complex thermochemical process that converts biomass into syngas (combustible gas) through gasification and biochar. The syngas is then used in a fuel cell to generate electricity[108]. Biochar captures carbon that is then beneficial for soil and is used as a fuel. The proportion of outputs is based on technologies applied; biochar production is optimized in absence of oxygen.

[99] https://www.sciencedirect.com/topics/agricultural-and-biological-sciences/windrow-composting

[100] https://www.greenatlanta.com/what-is-waste-segregation-and-its-importance/#:~:text=Waste%20segregation%20is%20the%20process%20of%20separating%20your,is%20sent%20to%20the%20correct%20place%20for%20disposal.

[101] https://www.epa.gov/landfills/basic-information-about-landfills

[102] https://www.aiche.org/topics/energy/waste-valorization

[103] https://energytheory.com/what-is-refuse-derived-fuel-rdf/

[104] https://www.greenmatters.com/p/what-is-downcycling

[105] https://www.sciencedirect.com/science/article/pii/S240584401935858X#:~:text=Pyrolysis%20of%20waste%20non-biodegradable%20polymer%20materials%20involves%20controlled,range%20of%20products%20from%20hydrogen%2C%20hydrocarbons%20to%20coke.

[106] https://www.sciencedirect.com/science/article/pii/S2211912417301384

[107] https://www.indianjournals.com/ijor.aspx?target=ijor:ijset1&volume=2&issue=12&article=015

[108] https://pubs.rsc.org/en/content/articlehtml/2016/ee/c6ee00935b

5.3 Municipal Solid Waste

5.3.1 Aerobic windrow Composting

Aerobic windrow composting involves sorting, shredding, and moistening organic materials before piling them into long rows. These piles, or windrows, are regularly turned to introduce oxygen, essential for the breakdown of organic matter by microorganisms. As decomposition progresses over several weeks, the compost is screened to remove contaminants, resulting in a nutrient-rich end product suitable for soil improvement.

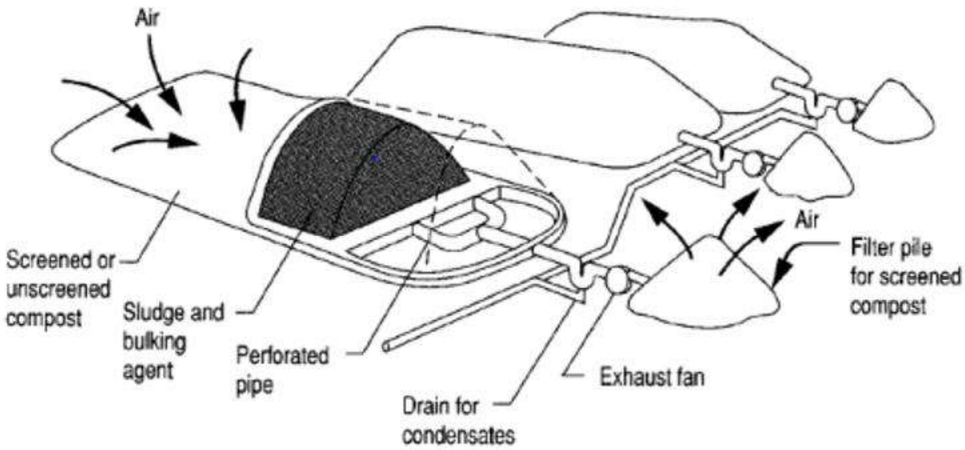

Figure 5. Schematic representation of the aerobic windrow composting

i. Legal, Regulatory, and Economic Landscape

Composting initiatives in Pakistan are bolstered by existing guidelines outlined in the **Draft Guidelines for Solid Waste Management in Pakistan 2005** by the Environmental Protection Agency (EPA). **Existing projects** for composting are discussed in the **solid waste management brief by switch-Asia (2022)**, and the **Solid Waste Sector Reform Roadmap by ADB (2022)**, which shows that composting is practiced in Lahore, and Karachi at a small scale. [109][110] These guidelines provide a regulatory framework for composting activities, through comprehensive nationwide policies specifically addressing MSW composting, which is not a common practice. Despite the presence of guidelines, the implementation of composting projects faces challenges, particularly due to the lack of research on the cost-savings or the environmental benefits and the absence of a well-defined monitoring and evaluation framework. Furthermore, while composting offers economic benefits such as cost savings on landfill disposal, the upfront investment required for infrastructure development, including composting facilities and monitoring systems, poses financial barriers. The limited availability of targeted financing mechanisms and private sector investment opportunities further constrains the financial landscape for composting initiatives in Pakistan.

ii. Socio-Economic Feasibility

Composting demonstrates economic and technical feasibility in Pakistan, offering a sustainable waste management solution with significant environmental benefits. Composting diverts a significant portion of organic waste from landfills, **cutting down the landfill cost** on average of up to **USD 49.76 per ton of waste.** Composting technology is well-established and

[109] https://www.switch-asia.eu/site/assets/files/3378/waste_management_in_pakistan_final.pdf
[110] https://www.adb.org/sites/default/files/publication/784421/solid-waste-management-pakistan-road-map.pdf
[111] https://composting.ces.ncsu.edu/large-scale-composting/

can **be implemented at various scales**, from backyard bins to large-scale municipal facilities. [111] Composting can manage the waste of a household for **USD 25** saving up to **USD 60**, whereas normal waste management cost will be **USD 85. Existing projects** for composting are discussed in the **solid waste management brief by switch-Asia (2022)**, and the **Solid Waste Sector Reform Roadmap by ADB (2022)**, which shows that composting is practiced in Lahore, and Karachi at a small scale selling the compost at a **bulk rate of Rs.80/kg and an individual rate of Rs. 100/kg.** However, challenges such as variability in compost quality and limited expertise in environmental monitoring hinder the technology's effectiveness. Despite the presence of well-established composting technology and guidelines, the lack of comprehensive skills training and capacity-building initiatives poses barriers to implementation. Initiatives like the **Better Cotton Initiative 2021** exist which include training farmers in techniques such as composting, and making **skills locally available** in Pakistan. On the contrary, composts may **lack uniformity** among different raw materials and batches, leading to variability in quality, and composting **can attract unwanted pests** and wildlife, which can create public health risks and damage property. Additionally, negative public perception about composting due to **odor** or **lack of awareness** can hinder participation, highlighting the need for targeted awareness campaigns and community engagement efforts.

To delve into the economic analysis a project[112] of 2006 is taken as a base, where Lahore Compost Limited (LCL) initiated a composting project in Lahore, aiming to process up to **1,000 tons per day[113]** (TPD) of municipal solid waste (MSW). Located at the **Mehmood Booti dumpsite**, this project sought to address open dumping issues and reduce emissions by **4.5 million tCO2e from 2008 to 2026**. Initially processing 300 TPD[91], the plant scaled up to **1,000 TPD**[91] by April 2009, with a target of 1,500[91] TPD. The compost produced is a high-quality, 100%[91] organic fertilizer beneficial for soil conditioning. Financial analysis, adjusted for inflation to 2024, estimated the total initial investment at **USD 37.16 million**, with running costs at 20% of this amount. Projected annual revenue from compost sales was **USD 15.77**[91] **million**, with an additional **USD 1.77**[91] **million** from carbon credits, totaling USD **17.54**[91] **million** per year. Despite initial financial challenges, including delays in carbon payments and market development, the project demonstrated strong economic viability. The Net Present Value (NPV) of **USD 138.8 million[114]** achieved at a **3%**[92] discount rate, along with an Internal Rate of Return (IRR) of **27%**[92] and a payback period of **3.7 years** represents the actual financial performance of the investment, demonstrating substantial profitability and rapid investment recovery.

A sensitivity analysis showed the project's resilience, with NPV ranging from USD 80.6 million to USD **185.9 million**[92], IRR from **26% to 38%**[92], and payback periods between **2.7 and 4 years**[92]. These results highlight the project's robustness and long-term financial sustainability, despite inherent uncertainties from assumptions made for 2024 conditions. Overall, the Lahore composting project showcases a promising waste management solution with significant economic and environmental benefits.

Overall aerobic windrow composting is an environmentally friendly and cost-effective waste management option. It significantly reduces emissions, saves money compared to traditional waste management, requires a moderate initial investment, and has a reasonable operational cost as reflected in the table 11 below:

[91] https://www.adb.org/sites/default/files/publication/784421/solid-waste-management-pakistan-road-map.pdf

[92] https://www.adb.org/publications/waste-sector-inclusion-revised-ndcs-pakistan

[112] https://collaboration.worldbank.org/content/usergenerated/asi/cloud/attachments/sites/collaboration-for-development/en/groups/results-based-financing/groups/results-based-financing-for-climate/documents/jcr:content/content/primary/blog/lahore_compost-carbo-ug6W/Good%20Practices%20in%20City%20Energy%20Efficiency%20ESMAP.pdf

[113] Ibid.

[114] Authors calcuations

Emissions Reduction/ Resource Conservation	Other Benefits/ Cost Savings	Capital Cost/ Total Investment	Operational cost	Social Benefits
50% emissions reduction	Manage the waste of a household for 25 USD saving up to USD 60, whereas usual waste management cost will be 85 USD	Based on Mehmood Booti Landfill, Lahore Composting Limited (LCL) Cost: USD 37.16 + 20% running cost for 1500 TPD capacity Discount Rate: 3% NPV: USD 138.8 million IRR: 27% and a Payback period: 3.7 years This project would lead to emissions reductions of 160,714.29 tCO2e per year	40% for Mehmood Booti but 20% of total cost taken for analysis	Reduced exposure to the pollutants as it reduces the GHG emissions by over 50%.[115]. Carbon sequestration will lead to a more congenial environment for the communities (especially women who tend to stay at home) living in the vicinity of the composting site. Sustainable solution with reference to job creation or startup business for women Easy and sustainable solution for soil fertility by replacing it with harmful artificial fertilizers.

Table 11: Socio-economic benefits of Aerobic Windrow Composting in Pakistan

iii. Inclusive Development and Climate Impacts

Composting initiatives in Pakistan present opportunities for inclusive development and climate mitigation. By diverting organic waste from landfills, composting reduces greenhouse gas emissions, with **potential reductions of over 50% per million metric tons of decomposed waste**. On the other hand, Composts from municipal solid waste and **biosolids may contain heavy metals**, posing environmental and **health risks**, although leaching to the environment is usually minimal. Government-led campaigns and collaborations with private-sector stakeholders can promote awareness about the benefits of composting and incentivize community participation. Composting facilities can create new jobs, as composting creates at least **twice as many jobs as landfills and four times as many jobs as incineration facilities.** [116] However, challenges such as limited market demand for compost products and the presence of heavy metals in compost from MSW and biosolids pose environmental and **health risks**.

[115] https://drawdown.org/solutions/composting#:~:text=Composting%E2%80%94the%20conversion%20of%20such,by%20more%20than%2050%20percent
[116] https://ecocycle.org/learn-about-zero-waste/jobs-and-economic-benefits/

According to a **survey**, **51% of the surveyed women showed low interest in composting** for various reasons with a recurring reason of the male head of their house not allowing them to do so. Addressing these challenges requires comprehensive policies and regulations, technical innovations, and capacity-building initiatives to ensure sustainable waste management practices and inclusive development in Pakistan.

SWOT Analysis (Summary)

Composting is essential for managing Pakistan's organic waste, reducing landfill use, and cutting greenhouse gas emissions. It's a proven, low-cost technology that creates jobs and improves soil health. Despite challenges like public awareness and cost, expanding composting through education, market incentives, and government support can enhance waste management and sustainability as shown in Table 12.

Strengths	Weaknesses
S1. Composting diverts a significant portion of organic waste from landfills, **cutting down the landfill** cost on average of up to USD **49.76 per ton of waste**. **S2**. Composting **reduces greenhouse gas emissions by over 50%**, mitigating the release of **469 metric tons of CO2** equivalent per million metric tons of organic waste decomposed.[117] **S3**. Initiatives like the **Better Cotton Initiative 2021** exist which include training farmers in techniques such as composting, and making **skills locally available** in Pakistan. **S4**. Composting technology is well-established and can **be implemented at various scales**, from backyard bins to large-scale municipal facilities.[118] **S5**. Composting offers a relatively simple technology with **low energy requirements**. **S6**. Composting facilities can create new jobs, as composting creates at least **twice as many jobs as landfills and four times as many jobs as incineration facilities**.[119] **S7**. **Composts have been produced locally** in Pakistan by organizations such as the Saif Group in LCL composting at the Mehmood Booti site. **S8**. There **exist guidelines on composting** in Pakistan which are included in the Draft Guidelines for **Solid Waste Management in Pakistan 2005** by the EPA.	**W1**. A well-defined **M&E framework** for composting projects **is not widely established** in Pakistan as of yet, as there are only a **few examples** where environmental monitoring has been considered such as LCL Composting in Mehmood Booti. **W2**. Negative public perception about composting due to **odor** or **lack of awareness** can hinder participation. **W3**. Improperly matured composts can exhibit **phytotoxicity**, **potentially harming plants**. **W4**. Composts may **lack uniformity** among different raw materials and batches, leading to variability in quality. **W5**. Composting **can attract unwanted pests** and wildlife, which can create public health risks and damage property. **W6**. According to a **survey**, **51% of the surveyed women showed low interest in composting** for various reasons with a recurring reason of the male head of their house not allowing them to do so. **W7**. The capital cost of installing a composting facility is of 1500 tons per day **USD 37.16 and 20% running cost.**

[117] https://drawdown.org/solutions/composting#:~:text=Composting%E2%80%94the%20conversion%20of%20such,by%20more%20than%2050%20percent.
[118] https://composting.ces.ncsu.edu/large-scale-composting/
[119] https://ecocycle.org/learn-about-zero-waste/jobs-and-economic-benefits/

Strengths	Weaknesses
S9. Existing projects for composting are discussed in the **solid waste management brief by switch-Asia (2022), and the Solid Waste Sector Reform Roadmap by ADB (2022)**, which shows that composting is practiced in Lahore, and Karachi at a small scale selling the compost at a **bulk rate of Rs.80/kg and an individual rate of Rs. 100/kg.**[120] [121] **S10**. Composting can manage the waste of a household for **USD 25** saving up to **USD 60**, whereas normal waste management cost will be **USD 85**.	

Opportunities	Threats
O1. Educating the public about the benefits of composting and proper sorting practices can **increase participation** and reduce contamination risks. **O2**. Advancements in composting technologies, such as **in-vessel composting**, can offer more **efficient** and controlled processes with **reduced odor and emissions**. **O3**. Integrating composting into existing waste collection systems can streamline MSW management and **increase diversion rates**. **O4**. Developing a **strong market** for compost products like soil amendments and potting mixes can incentivize composting initiatives. **O5**. Government support **through subsidies, regulations**, and **infrastructure development** can promote large-scale composting adoption.	T1. Established landfill infrastructure and **lower disposal costs** can pose a challenge to widespread composting adoption. T2. Fluctuations in **demand for compost** products can impact the economic viability of composting facilities.[122] T3. **Extreme weather** events associated with climate change **can disrupt** the composting process and require adaptation strategies.[123] T4. A limited market for compost products can impact the economic viability of composting facilities.[124] T5. Composts from municipal solid waste and **biosolids may contain heavy metals**, posing environmental and **health risks**.

Table 11: SWOT analysis of Aerobic Windrow Composting in Pakistan

[120] https://www.switch-asia.eu/site/assets/files/3378/waste_management_in_pakistan_final.pdf
[121] https://www.adb.org/sites/default/files/publication/784421/solid-waste-management-pakistan-road-map.pdf
[122] https://blog.cabi.org/2022/06/13/using-compost-to-grow-better-cotton-in-pakistan-a-farmers-story/
[123] https://www.mdpi.com/2225-1154/11/10/202
[124] https://energypedia.info/images/6/67/Solid_Waste_Composting_in_Pakistan.pdf

5.3.2 Engineered Landfill Technology

Engineered landfills are waste dumping sites designed with liners and gas collection systems to capture methane gas produced by decomposing organic waste. This methane can then be used for various purposes like electricity generation or heat production[125].

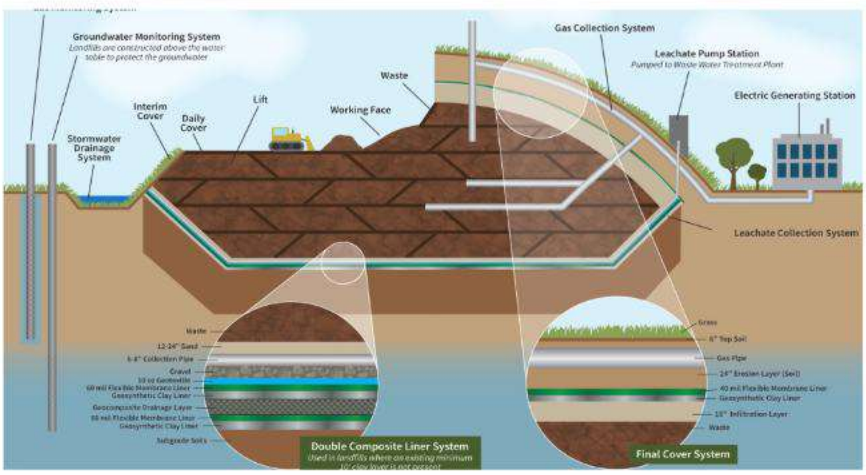

Figure 6. Schematic representation of the engineered landfill technology

i. Legal, Regulatory, and Economic Landscape

Engineered landfill technology in Pakistan benefits from regulatory support outlined in the **National Hazardous Waste Management Policy of Pakistan 2022** and the **Asian Development Bank's reform roadmap 2022**. However, while policies exist, their implementation remains a challenge, as highlighted by the lack of properly managed engineered landfill sites. There exists the **Lakhodair landfill site designed and constructed by Turkish companies**, with only **2 cells completed** which is a bankable project and has a lot of potential for private sector investment. The absence of targeted financing mechanisms and limited expertise complicates the financial landscape, hindering investment opportunities and scalability for the private sector. Additionally, **engineered landfills require ongoing monitoring** and maintenance to ensure their effectiveness, which makes the **lack of a monitoring and evaluation framework in Pakistan** a big challenge.[126]

ii. Socio-Economic Feasibility

Engineered landfill technology demonstrates economic and technical feasibility in Pakistan but with certain limitations. Methane gas produced by decomposing waste in engineered landfills can be captured and **used for energy generation, reducing reliance on fossil fuels**.[127] Methane gas produced by decomposing waste in engineered landfills can be captured and **used for energy generation, reducing reliance on fossil fuels**.[128] Despite challenges such as high infrastructure costs, ongoing maintenance requirements, and negative public perceptions, engineered landfills offer a controlled waste management solution with reduced environmental impacts. However, the limited expertise in landfill design and management poses technical challenges, necessitating capacity-building efforts. Moreover, community resistance and site selection difficulties underscore the need for comprehensive planning and stakeholder engagement to ensure successful implementation.

[125] https://sh.itjust.works/pictrs/image/07662afa-f1ce-472c-a3f8-1ed933d2ce0f.webp
[126] https://www.sciencedirect.com/topics/earth-and-planetary-sciences/landfill-management
[127] https://www.mdpi.com/2071-1050/15/20/14782
[128] https://www.mdpi.com/2071-1050/15/20/14782

To understand the economic viability Lakhodair landfill project [129] in Lahore is taken as a base, which began operations in 2016, and aims to manage **2,000**[130] tons of municipal solid waste (MSW) per day for 10 years. The initial phase, **costing PKR 1.3 million[111]**, includes leachate collection systems across LOT-1 (4.7 hectares) and LOT-2 (5 hectares). The project aims to reduce greenhouse gas emissions and harness methane for energy. After adjusting for inflation and a 10% contingency, the total capital cost is estimated at PKR 3,065,332 (**USD 11,036**[131]). Adding 50%[112] of this cost for methane-to-electricity conversion (**USD 5,518**[112]) brings the total to USD 16,554, with an additional 10% for operation and maintenance costs (**USD 1,655.4[112]**). Using the daily MSW of **2,000** tons and a 25% methane recovery rate, the landfill can generate 14.581 MWh of electricity daily. At the national average tariff of **PKR 29.78/kWh**, this yields a daily revenue of PKR 434,222[112] and an annual revenue of PKR 158,491,096[112] (**USD 571,193[112]**).

The project shows strong financial viability with a Net Present Value (NPV) of **USD 7.08 million[112]** at a 5% discount rate, an Internal Rate of Return (**IRR**) of **34%[112]**, and an exceptionally short payback period of 0.02 years[112]. Sensitivity analysis confirms the project's resilience, with NPV ranging from **USD 4.83** million to **USD 10.26 million[112]** and IRR from **29%** to **43%[112]**, even under variable conditions. Despite the favorable outcomes, the analysis relies on assumptions about electricity sales and methane recovery rates. Therefore, while the project demonstrates promising financial metrics, these findings should be interpreted cautiously.

The overall information on engineered landfills indicates that they are highly effective in reducing emissions by capturing methane for energy, significantly lower waste management costs compared to traditional methods, and have a moderate operational cost as presented in below table 13.

Emissions Reduction/ Resource Conservation	Other Benefits/ Cost Savings	Capital Cost/ Total Investment	Operational cost	Social Benefits
88.07% reduction in emissions based on a Chinese model (System Dynamics - Logarithmic Mean Divisia Index model) Economic development, population scale, and emission intensity were driving forces that induced GHG emissions	Normal Waste Excavation or clean fill/management costs around USD 400,000, but in engineered landfills the cost is reduced to USD 117,720	Based on: Lakhodair Landfill Project Cost about USD 11,036 managing up to 2000-2500 tons of waste daily 50% cost of methane-to-electricity+10% O&M Discount Rate: 5% NPV: USD 7.08 million IRR: 34% Payback period: 0.02 years	10% of total cost	Engineered landfills can reduce health risks associated with open dumps, which often contaminate water sources and air quality. This can lead to better health outcomes for everyone, including women and children who may be more susceptible.

[112] https://collaboration.worldbank.org/content/usergenerated/asi/cloud/attachments/sites/collaboration-for-development/en/groups/results-based-financing/groups/results-based-financing-for-climate/documents/jcr:content/content/primary/blog/lahore_compost-carbo-ug6W/Good%20Practices%20in%20City%20Energy%20Efficiency%20ESMAP.pdf
[129] https://urbanunit.gov.pk/Download/publications/Files/11/2021/Lakhodair%20Landfill%20Site.pdf
[130] ibid
[131] Authors calculations

Emissions Reduction/ Resource Conservation	Other Benefits/ Cost Savings	Capital Cost/ Total Investment	Operational cost	Social Benefits
				Engineered landfills are typically fenced and controlled environments, redu cing the risk of accidents or exposure to harmful materials. This can improve safety for women who may be involved in waste collection or sorting in the informal settings.

Table 13: Socio-economic benefits of Engineered Landfill technology in Pakistan

iii. Inclusive Development and Climate Impacts

Engineered landfills present opportunities for inclusive development and climate mitigation in Pakistan, yet several considerations must be addressed. **Landfill gas utilization leads to an 88.07% reduction in emissions**, from the business-as-usual scenario, based on a System Dynamics (SD-LDPI) model developed for Shanghai (China). Further, **rising temperatures and extreme weather** events associated with climate change **can accelerate the decomposition of waste** in landfills, leading to increased methane emissions, a potent greenhouse gas.[132] Additionally, the availability of data regarding **women's involvement** in the value chain is **non-existent** for this technology. Government initiatives and public-private partnerships can attract funding and foster infrastructure development, promoting inclusivity and economic growth. Collaboration with international waste management experts can enhance technical capabilities and best practices, contributing to resilience and adaptive capacity. However, threats such as mismanagement of waste input, mixed waste streams, and environmental hazards from natural disasters highlight the importance of robust engineering safeguards and climate adaptation strategies. Addressing these challenges requires a holistic approach that integrates social, economic, and environmental considerations to ensure sustainable waste management practices in Pakistan.

[132] https://www.sciencedirect.com/science/article/pii/S004896972307016X

SWOT Analysis (Summary)

Engineered Landfills are controlled systems that reduce environmental pollution and capture methane for energy, offering cost-effective waste management. However, high initial costs, limited expertise, and local resistance are key challenges (Table 14). Government support, international collaborations, and carbon credit opportunities can enhance adoption. Careful planning is needed to manage capacity limits and climate-related risks.

Strengths	Weaknesses
S1. Compared to traditional landfills, **engineered landfills have stricter controls on methane gas emissions**, minimizing environmental pollution of soil, water, and air.[133]	**W1.** Constructing and maintaining engineered landfills **requires significant upfront costs** for infrastructure, liners, leachate collection systems, and gas capture mechanisms. The LCL Lakhodair **first phase (Cell-1 & Cell-2) cost about PKR 1.3 Million.[140]**
S2. Landfill gas utilization leads to an 88.07% reduction in emissions, from the business-as-usual scenario, based on a System Dynamics (SD-LDPI) model developed for Shanghai (China).[134]	**W2.** Implementation and operation of engineered landfills **requires expertise in landfill** design, construction, and management, which is limited in Pakistan, as there are no properly managed engineered landfill sites.[141]
S3. Methane gas produced by decomposing waste in engineered landfills can be captured and **used for energy generation, reducing reliance on fossil fuels.** [135]	**W3.** Local communities resist the establishment of engineered landfills near their residences due to concerns **about potential odor, pollution, and property value depreciation**. [142]
S4. Engineered landfills can be integrated with **waste-to-energy facilities, further reducing waste volume and generating renewable energy**.[136]	**W4.** Finding suitable land for engineered landfills near populated areas can be difficult due to competition for land use and concerns about potential environmental impact.[143]
S5. There exists an engineered landfill gas recovery site in Lakhodair, Punjab (Pakistan) expanding up to **52 hectares of land, managing up to 2000-2500 tons of waste daily**, and mitigating the emissions linked with that waste.[137]	**W5.** Engineered landfills require ongoing monitoring and maintenance to ensure their effectiveness.[144]
S6. Engineered landfill technical guidelines are available in the **National Hazardous Waste Management Policy of Pakistan 2022**, and the **ADB reform roadmap for the solid waste sector 2022**, also mentions engineered landfills as a sustainable waste solution.[138] [139]	**W6. Brief/Guidelines exist in Pakistan**, made publicly available by the Pakistan EPA, but are not being implemented.[145]
S7. Normal Waste Excavation or clean fill/ management costs around **USD 400,000**, but in engineered landfills the cost is reduced to **USD 117,720**.	W7. The availability of data regarding **women's involvement** in the value chain is **non-existent** for this technology.
S8. The operational cost for managing waste in a landfill is **USD 11 per ton of waste** (~ **PKR 3,060**).	

[133] https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8440080/
[134] https://www.sciencedirect.com/science/article/abs/pii/S0956053X20306115#:~:text=Scenario%20analysis%20further%20revealed%20that,as%2Dusual%20scenario%20in%202050.
[135] https://www.mdpi.com/2071-1050/15/20/14782
[136] https://winnoenergy.com/waste-to-energy-turning-trash-into-power/
[137] https://www.lwmc.com.pk/lwmc-sanitary-landfill.php
[138] https://www.dra.gov.pk/news_updates/press_releases/national-hazardous-waste-management-policy-2022/
[139] https://www.adb.org/sites/default/files/publication/784421/solid-waste-management-pakistan-road-map.pdf
[140] https://www.hindawi.com/journals/jeph/2021/6921607/
[141] https://www.adb.org/sites/default/files/publication/784421/solid-waste-management-pakistan-road-map.pdf
[142] https://www.semanticscholar.org/paper/A-SWOT-Analysis-of-Landfill-Management-System%3A-Case-Koderi-Suyadi/33f543ed053f83b11bca94220af4e9d3b5433cf1
[143] https://www.sciencedirect.com/science/article/pii/S2667010021002225
[144] https://www.sciencedirect.com/topics/earth-and-planetary-sciences/landfill-management
[145] https://environment.gov.pk/SiteImage/Misc/files/Downloads/interventions/environmentalissues/DevelopmentLandfillSites.pdf

Opportunities	Threats
01. Government initiatives and public-private partnerships can attract funding for developing engineered landfills across Pakistan. [146] 02. Collaboration with international waste management experts can help establish best practices and address technical limitations.[147] 03. Landfills can cater to the high interest of the public community in educational tourism[148] O4. Pakistan can leverage carbon credit programs by capturing and utilizing landfill gas for energy production, drawing inspiration from successful initiatives such as the Gorai Landfill Closure and Gas Capture Project in Mumbai[149], India, and the auction of over 800 thousand carbon credits by São Paulo (Brazil) Municipality in 2007, priced at a minimum of 12.79 euros per ton.[150] O5. 50% of waste in Pakistan is picked up for segregation and recycling by the informal sector, including women and children, and landfills provide an alternative to that.[151]	T1. An increase in input waste amount to landfill can lead to mismanagement of the waste. [152] T2. Mixed waste streams can reduce landfill efficiency and methane capture from the landfill site. [153] T2. Low budget or financial support for operational facilities can lead to shutdown of the site, posing several challenges.[154] T4. Floods and earthquakes can damage landfill infrastructure, causing environmental hazards if not build with proper engineering safeguards.[155] T5. Rising temperatures and extreme weather events associated with climate change can accelerate the decomposition of waste in landfills, leading to increased methane emissions, a potent greenhouse gas.[156] T6. Even engineered landfills have a finite capacity. Pakistan's growing population and waste generation rates could outpace the development of new landfills.[157]

Table 14: SWOT analysis of Engineered landfill technologies in Pakistan

[146] https://www.semanticscholar.org/paper/A-SWOT-Analysis-of-Landfill-Management-System%3A-Case-Koderi-Suyadi/33f543ed053f83b11bca94220af4e9d3b5433cf1
[147] https://www.wsp.com/en-gl/services/waste-management-and-landfill
[148] https://www.semanticscholar.org/paper/A-SWOT-Analysis-of-Landfill-Management-System%3A-Case-Koderi-Suyadi/33f543ed053f83b11bca94220af4e9d3b5433cf1
[149] https://www.adb.org/publications/improving-financing-and-sustainability-landfill-closure-project
[150] https://www.gnpw.com.br/en/energy/how-do-landfills-generate-carbon-credit/
[151] https://www.dandc.eu/en/article/pakistan-informal-waste-pickers-manage-about-50-municipal-waste
[152] https://www.semanticscholar.org/paper/A-SWOT-Analysis-of-Landfill-Management-System%3A-Case-Koderi-Suyadi/33f543ed053f83b11bca94220af4e9d3b5433cf1
[153] https://www.semanticscholar.org/paper/A-SWOT-Analysis-of-Landfill-Management-System%3A-Case-Koderi-Suyadi/33f543ed053f83b11bca94220af4e9d3b5433cf1
[154] https://www.semanticscholar.org/paper/A-SWOT-Analysis-of-Landfill-Management-System%3A-Case-Koderi-Suyadi/33f543ed053f83b11bca94220af4e9d3b5433cf1
[155] https://www.adb.org/sites/default/files/institutional-document/32193/country-environment-analysis.pdf
[156] https://www.sciencedirect.com/science/article/pii/S004896972307016X
[157] https://www.roadrunnerwm.com/blog/landfills-were-running-out-of-space

5.3.3 Waste Segregation (Conveyor belts)

Waste Segregation involves separating waste into different categories (organics, paper, plastic, etc.) at the source for efficient recycling, composting, or disposal. Waste Segregation programs are being implemented in Pakistan, such as the "Clean Ambassadors Programme" in Punjab by the Lahore Waste Management Company focused on Students in Schools and Colleges. While some pilot projects exist to promote source separation, widespread segregation at the household level is a challenge due to a lack of awareness and infrastructure for the collection of sorted waste streams.

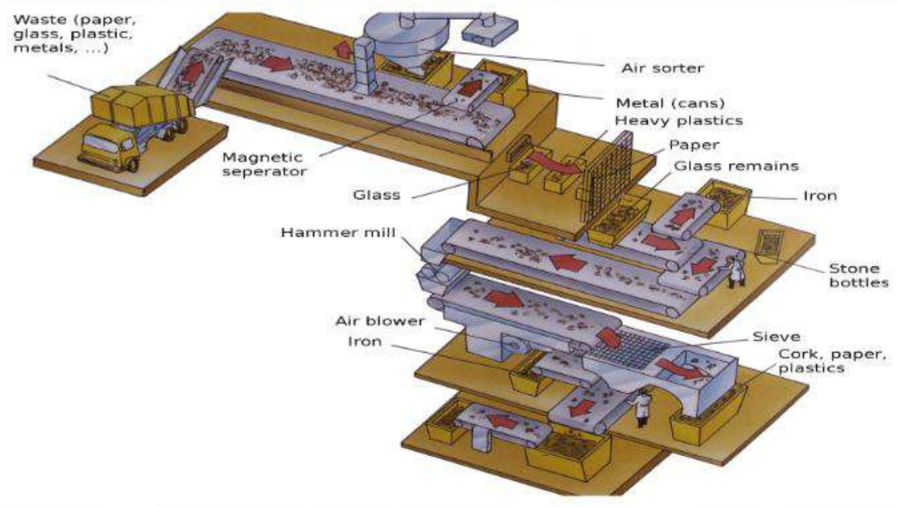

Figure 7. Schematic representation of the waste segregation system

i. Legal, Regulatory, and Economic Landscape

Waste segregation at source benefits from regulatory acknowledgment in Pakistan, with guidelines incorporated into the **Draft Solid Waste Management Guidelines in Pakistan 2005 by the Environmental Protection Agency (EPA)**. However, the lack of proper implementation hampers its effectiveness, as highlighted by the absence of supportive infrastructure and enforcement mechanisms. Financial constraints pose challenges to infrastructure development, particularly in densely populated areas where space limitations exacerbate logistical complexities. The **National Hazardous Waste Management Policy of Pakistan 2022** and the **Asian Development Bank's reform roadmap 2022** mention waste segregation, emphasizing its importance. However, there is a notable lack of comprehensive implementation of these policies, hindering the advancement of waste segregation initiatives. Waste Segregation is carried out by the **informal sector in Pakistan**, and there exists a lot of potential for private-sector investment in this area of work.[158] The **lack of proper collection infrastructure** for segregated waste streams can hinder the effectiveness of the program.[159]

ii. Socio-Economic Feasibility

Waste segregation at source demonstrates economic and technical feasibility in Pakistan, offering potential cost savings for municipalities and significant environmental benefits,

[158] https://www.mdpi.com/2071-1050/13/21/11717
[159] https://www.mdpi.com/2071-1050/13/5/2717

but with certain constraints. There also exist challenges such as the lack of proper collection infrastructure and informal waste collection practices that hinder its effectiveness. A large **informal waste collection sector in Pakistan might resist changes** that could disrupt their livelihood, requiring cooperation and integration strategies.[160] In densely populated areas, **households may have limited space** for multiple waste bins, creating logistical challenges for segregation.[161] **Improper sorting by residents** can lead to contamination of recyclable materials, reducing their value and requiring additional processing.[162] **Operating and maintaining** conveyor belt systems necessitate **specialized technical knowledge** for troubleshooting, repairs, and ensuring optimal performance, and Pakistan lacks these skills.[163] Moreover, weak enforcement of waste segregation regulations further undermines the program's efficiency, necessitating comprehensive capacity-building efforts and enhanced enforcement mechanisms to ensure successful implementation.

For the economic analysis examination of a case study from Jordan titled "**A Techno-Economic Analysis of Sustainable Material Recovery Facilities: The Case of Al-Karak Solid Waste Sorting Plant, Jordan**.[164]" Is taken into consideration. This study assesses the technical and economic performance of the Al-Karak solid waste sorting plant, aiming for financial sustainability. The plant processes commercial solid waste (CSW) using a bale presser, a conveyor belt, a plastics shredder, a forklift, and waste collection trucks. It operates on municipally owned land, and the study proposes a new design involving capital costs for new equipment.

The new design includes a ballistic separator, an Near Infra-Red (NIR) belt, and a conveyor belt, with a total capital cost of **USD 555,712**[165]. The economic analysis reveals promising financial metrics, with a Net Present Value (NPV) of **USD 1.7 million**[166]. at a **10%** discount rate, indicating significant value generation. The payback period is 1.4 years, and the Internal Rate of Return (IRR) is **56%**[167]., highlighting high profitability and attractiveness to investors.

While the original design shows strong financial metrics, opting for a simpler design with only conveyor belts would reduce initial capital costs and potentially improve financial viability, albeit with compromised efficiency. Jordan's waste sorting plant design offers valuable insights for Pakistan. By balancing advanced sorting technologies and cost-effective solutions, Pakistan can enhance the financial viability and efficiency of its waste management systems.

Overall waste segregation is highly effective in reducing emissions by 85.48% through improved waste categorization as shown in table 15 . It has a moderate capital cost with a capacity of 50-100 kg per foot, however, lacks data on operational costs and specific savings.

[160] https://www.mdpi.com/2071-1050/13/21/11717
[161] https://www.ncbi.nlm.nih.gov/pmc/articles/PMC9224205/
[162] https://www.sciencedirect.com/science/article/abs/pii/S0956053X19307135
[163] https://bistaterubber.com/elevator-conveyor-belt-maintenance-essential-best-practices/
[164] https://www.mdpi.com/2071-1050/13/23/13043
[165] Authors calculation based on the case study
[166] Authors calculation based on the case study
[167] Authors calculation based on the case study

Emissions Reduction/ Resource Conservation	Other Benefits/ Cost Savings	Capital Cost/ Total Investment	Operational cost	Social Benefits
85.48% emissions reduction based on a Chinese model (System Dynamics - Logarithmic Mean Divisia Index model) Economic development, population scale, and emission intensity were driving forces that induced GHG emissions	Simpler models can be explored for cost saving e.g. conveyor belts only	Based on study: A Techno-Economic Analysis of Sustainable Material Recovery Facilities: The Case of Al-Karak Solid Waste Sorting Plant, Jordan Discount Rate: 10% Cost: USD 555,712 NPV: USD 1.7 million IRR: 56% Payback period is 1.4 years,	48% of total cost	Improves public health by reducing exposure to hazardous waste and promotes community involvement in producing compost and organic fertilizers

Table 15. Socio-economic benefits of Waste Segregation in Pakistan

iii. Inclusive Development and Climate Impacts

Waste segregation at source presents opportunities for inclusive development and climate mitigation in Pakistan. Moreover, waste segregation demonstrates significant mitigation potential, as evidenced by **studies showing an 85.48% reduction in emissions** compared to business-as-usual scenarios. Government-led campaigns, collaboration with private waste management companies, and community outreach programs can accelerate infrastructure development and promote community engagement. Affordability concerns for **low-income households and logistical challenges** in densely populated areas require equitable solutions and targeted interventions. Promoting small-scale composting initiatives or buy-back programs for recyclables can incentivize waste segregation and create **economic opportunities for marginalized communities**. Addressing these threats and challenges requires a holistic approach that integrates social, economic, and environmental considerations to ensure sustainable waste management practices and inclusive development in Pakistan. **Women and children** belonging to the informal waste sector can play a crucial role in waste segregation, offering opportunities for increased job opportunities and economic empowerment if properly integrated into formal waste management systems.

SWOT Analysis (Summary)

Waste Segregation at source simplifies processing and reduces waste management costs, leading to significant emissions reduction and better recycling outcomes. However, challenges include inadequate infrastructure, resistance from informal collectors, and logistical issues in densely populated areas. Opportunities for improvement include government campaigns, collaboration with private companies, and community incentives (Table 16). Addressing skill gaps and regulatory enforcement is crucial for effective implementation

Strengths	Weaknesses
S1. Segregating waste at source **simplifies sorting and processing**, potentially leading to lower overall waste management costs for municipalities.[168]	**W1**. The **lack of proper collection infrastructure** for segregated waste streams can hinder the effectiveness of the program.[174]
S2. Waste Segregation has an 85.48% emissions reduction from the business-as-usual scenario, based on a System Dynamics (SD-LDPI) model developed for Shanghai (China).[169]	**W2**. A large **informal waste collection sector in Pakistan might resist changes** that could disrupt their livelihood, requiring cooperation and integration strategies.[175]
S3. Separating recyclables like paper, plastic, and metal from **organic waste allows for more efficient** recycling processes and the production of higher-quality recycled materials.[170]	**W3**. In densely populated areas, **households may have limited space** for multiple waste bins, creating logistical challenges for segregation.[176]
S4. Segregation diverts recyclables and organics from landfills, **extending their lifespan** and reducing environmental impact.[171]	**W4**. Improper sorting by residents can lead to contamination of recyclable materials, reducing their value and requiring additional processing.[177]
S5. Organic waste segregation **facilitates composting**, creating valuable fertilizer for agriculture and reducing reliance on chemical fertilizers.[172]	**W5**. The **National Hazardous Waste Policy of Pakistan 2022** only mentions waste segregation as well as the **ADB reform roadmap for the solid waste sector in Pakistan 202**2, but there is a lack of implementation. [178] [179]
S6. Segregated waste streams can be efficiently processed to **recover valuable resources for use in new products**. [173]	**W6**. Women and children belonging to the informal sector, which is mainly responsible for waste picking and segregation, can play a crucial role in waste segregation, leading to increased job opportunities.
S7. The guidelines for waste segregation have been incorporated and made available in the draft **Solid Waste Management in Pakistan 2005** by the EPA.	**W7**. Waste Sorting conveyor belt systems can cost up to **PKR 500,000 per belt** (**IndiaMART**).

[168] https://www.nature.com/articles/s41599-023-01982-7
[169] https://www.sciencedirect.com/science/article/abs/pii/S0956053X20306115
[170] https://recyclinginside.com/recycling-technology/separation-and-sorting-technology/
[171] https://rekart.co.in/blog/The-Impact-of-Waste-Segregation
[172] https://www.mdpi.com/2073-4395/10/11/1838
[173] https://www.commercialwastequotes.co.uk/blog/waste-segregation/
[174] https://www.mdpi.com/2071-1050/13/5/2717
[175] https://www.mdpi.com/2071-1050/13/21/11717
[176] https://www.ncbi.nlm.nih.gov/pmc/articles/PMC9224205/
[177] https://www.sciencedirect.com/science/article/abs/pii/S0956053X19307135
[178] https://www.dra.gov.pk/news_updates/press_releases/national-hazardous-waste-management-policy-2022/
[179] https://www.adb.org/sites/default/files/publication/784421/solid-waste-management-pakistan-road-map.pdf

Opportunities	Threats
O1. Government-led campaigns can **educate the public on the importance and methods** of waste segregation at source.[180] **O2. Collaboration between government and private waste management companies can accelerate infrastructure development** for segregated waste collection.[181] **O3**. Community **outreach programs and incentive schemes** can encourage participation and overcome initial challenges.[182] **O4**. Promoting **small-scale composting initiatives or buy-back programs for recyclables** can incentivize waste segregation and create economic opportunities.[183]	**T1. Operating and maintaining** conveyor belt systems necessitate **specialized technical knowledge** for troubleshooting, repairs, and ensuring optimal performance, and Pakistan lacks these skills.[184] **T2. Weak enforcement of waste segregation regulations/Policies** hinders the effectiveness of the program. **T3. Integrating conveyor belt systems with existing, potentially informal,** waste collection systems in Pakistan can be complex.[185] **T4**. Providing separate bins or collection services for segregated waste might be **unaffordable** for low-income households, requiring consideration of equitable solutions. [186]

Table 16: SWOT analysis of waste segregation in Pakistan

[180] https://www.sciencedirect.com/science/article/abs/pii/S0921344905000996

[181] https://www.undp.org/sites/g/files/zskgke326/files/2023-09/undp-harnessing-the-role-of-private-sector-in-waste-management-through-south-south-and-triangular-cooperation-for-inclusive-urbanization.pdf

[182] https://www3.uwsp.edu/cnr-ap/clue/Documents/publicProcesses/Enhancing_Involvement_Community_Planning_Using_Incentives.pdf

[183] https://www.sciencedirect.com/science/article/pii/S2405844024003633

[184] https://bistaterubber.com/elevator-conveyor-belt-maintenance-essential-best-practices/

[185] https://www.urbanunit.gov.pk/Download/publications/Files/8/2021/KOICA-World%20Bank%20Joint%20Study%20on%20Solid%20Waste%20Management%20in%20Punjab,%20Pakistan.pdf

[186] https://www.ncbi.nlm.nih.gov/pmc/articles/PMC9224205/

5.3.4 Waste Valorization (Emerging)

Organic Municipal Waste Valorization is an Advanced technology for processing organic waste into valuable products like bio-fuels, compost, or soil amendments. As this is an emerging technology, there is no such implementation in Pakistan as of yet, and the research conducted on this technology is also limited.

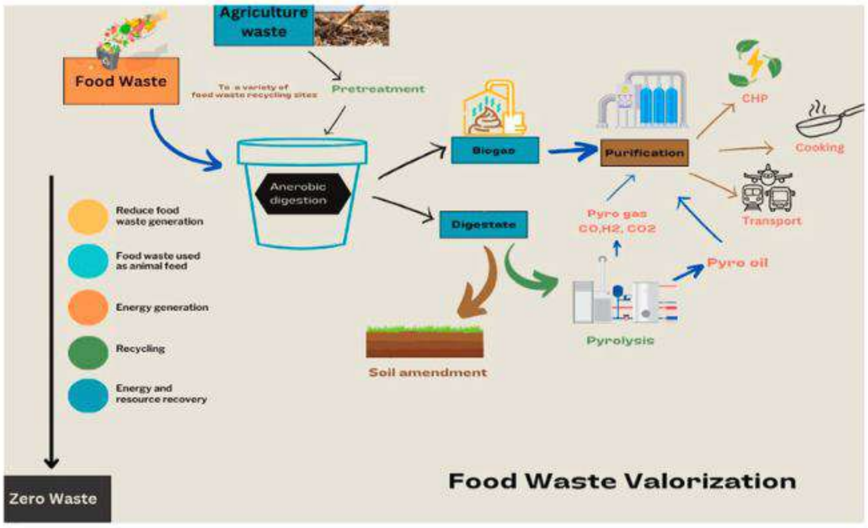

Figure 8. Schematic representation of the waste valorization technology

i. Legal, Regulatory, and Economic Landscape

Waste valorization in Pakistan operates in a regulatory environment **lacking comprehensive nationwide policies or guidelines specifically tailored for this technology**. While valorization aligns with the principles of a circular economy, the **absence of regulatory frameworks presents challenges** for its widespread adoption. Scaling up some valorization technologies from pilot to large-scale operations can be complex and **require significant investment**.[187] These challenges hinder private-sector investment in this technology.

ii. Socio-Economic Feasibility

Waste valorization demonstrates economic and technical feasibility in Pakistan, offering diverse opportunities to create new resources such as energy, fuels, compost, or recycled materials. Certain valorization methods r**equire specialized technology and infrastructure**, which is not readily available or affordable in all regions of Pakistan.[188] The efficiency and effectiveness of valorization processes can be highly dependent on the **quality and consistency of the waste feedstock**.[189] Further, the **market demand for some valorization products may be limited**, impacting the economic viability of these processes.[190] Additionally, public concerns about potential environmental or health risks associated with certain valorization technologies can impede their adoption. Despite these challenges, waste valorization presents opportunities for creating new job opportunities, particularly for women and youth, in waste collection, processing, and valorization facilities.

[187] https://www.kewaunee.in/blog/scaling-up-from-pilot-plants-to-large-scale-production/
[188] https://academic.oup.com/qje/article/132/3/1101/3064351
[189] https://link.springer.com/chapter/10.1007/978-3-031-55665-4_9
[190] https://www.sciencedirect.com/science/article/pii/S0022030214000903

To understand the economic feasibility in detail, the report "**Towards the Valorization of Solid Waste in Latin America and the Caribbean: Basic Concepts, Feasibility, and Public Policy**, [191]" is made based on evaluating waste segregation, treatment, and valorization techniques, providing a feasibility analysis to guide municipalities in selecting suitable waste recovery technologies. Techniques for waste treatment, reuse, recycling, and recovery are categorized into mechanical, biological, and thermal valorization methods. For mechanical treatment, investment ranges from **USD 70-75 per ton** per year[192] (TPY), with annual operation and management costs of **USD 35-38** per ton[180]. Biological treatment through anaerobic digestion requires an investment of **USD 140-250**[180] per TPY, with annual costs between **USD 20-60** per ton[180]. Composting demands an investment of **USD 75-80**[180] per TPY, with annual costs of USD 40-45180 per ton. Intensive heat treatment involves an investment of **USD 282.50** per TPY[180] and high annual costs of **USD 1,000-2,500[180]** per ton.

Mechanical biological treatment combines mechanical and biological processes, with an investment of **USD 65-150[180]** per TPY and annual costs of **USD 32-45[180]** per ton. Thermal treatment methods, including incineration, require an investment of **USD 500-700** per[180] TPY and annual costs of **USD 65-90[180]** per ton. Gasification also requires an investment of **USD 500-700[180]** per TPY, with annual costs of **USD 45-180** per ton[180]. Co-processing in cement kilns involves lower investments of **USD 10-30** per TPY[180] and annual costs of **USD 10-25** per ton[180]. Capturing and valorizing biogas requires an investment of **USD 400,000[180]** for every **300kW** installed. The cost-benefit ratios for waste valorization technologies in Colombia show that incineration is viable only for large-scale operations, while composting and anaerobic digestion are effective across all scales, with the highest ratios for small-scale operations.

Biogas extraction and power generation are viable for large and medium scales. For Pakistan, authorities need to consider local waste generation rates, composition, infrastructure, cultural acceptance, climate, economic factors, regulatory environment, and market demand for end products. Pilot projects and capacity building initiatives are recommended to ensure the successful adaptation of these technologies in Pakistan.

The cost-benefit analysis on organic municipal waste valorization reflects that it reduces emissions by 25% and conserves 15% of water by converting organic waste into valuable products through multiple processes (Table 17). The combined capital cost for these processes totals approximately PKR 40.7 million.

[180] https://www.sciencedirect.com/science/article/abs/pii/S0921344905000996
[191] https://publications.iadb.org/publications/english/document/Towards-the-Valorization-of-Solid-Waste-in-Latin-America-and-the-Caribbean-Basic-Concepts-Feasibility-Analysis-and-Public-Policy-Recommendations.pdf
[192] ibid

Emissions Reduction/ Resource Conservation	Other Benefits/ Cost Savings	Capital Cost/ Total Investment	Operational cost	Social Benefits
25% emissions reduction, 15% water conservation	Composting and anaerobic digestion are effective across all scales, with the highest ratios for small-scale operations. Biogas extraction and power generation are viable for large and medium scales.	Based on study Mechanical with capacity 1, 500 TPY or less (manual) 1, 500 TPY – 40, 000 TPY (semi-mechanized) 40,000 TPY or more (mechanized):USD 70/TPY[193] – USD 75/TPY Biological Anaerobic with capacity 20,000 TPY – 240, 000 TPY: USD 140/TPY – USD 250/TPY Biological Composting with capacity 1,000 TPY – 200, 000 TPY: USD75/TPY – USD 80/TPY Biological Intensive Heat Treatment with capacity 36 TPY – 602 TPY : USD 282.50/TPY Mechanical Biological with capacity 20,000 TPY – 500,000 TPY : USD 65/TPY – USD 150/ TPY Thermal Incineration with capacity 50,000 TPY/ line – 3,50,000 TPY /line: USD 500/ TPY – USD 700/TPY Thermal Gasification with capacity 250 tons/day – 500 tons/ day : USD 500/TPY – USD 700/TPY Coprocessing in Cement kilns with capacity 50,000 TPY approximately.: USD 10/TPY – USD 30/TPY Biogas Ideal for sanitary landfill with more than 500,000 tons of waste disposed off: USD 400,000 for every 300kW installed.	Mechanical: USD 35/ton – USD 38/ ton Biological Anaerobic: USD 20/ ton – USD 60/ton Biological Composting: USD 40/ton – USD 45/ ton Biological Intensive Heat Treatment: USD 1,000/ton – USD 2,500/ton (per year for equipment that treats 500 kg of waste per cycle). Mechanical Biological: USD 32/ ton – USD 45/ton Thermal Incineration: USD 500/TPY – USD 700/TPY Thermal Gasification: USD 45/ton – USD 180/ ton Coprocessing in Cement kilns: USD 10/ton – USD 25/ton Biogas: No data	Generates extra income by converting plastic waste into valuable products for the fashion industry, especially involving women throughout the value chain and helping to alleviate emotional stress

Table 17: Socio-economic benefits of Waste Volarization in Pakistan

[193] Per ton of waste produced annually.

iii. Inclusive Development and Climate Impacts

Waste valorization has significant emission reduction potential, with studies indicating **reductions of up to 25% from business-as-usual scenarios and water conservation by up to 15%**. However, threats such as public opposition, investor hesitation, and the lack of advanced infrastructure and expertise pose challenges to the widespread adoption of waste valorization technologies in Pakistan. Addressing these challenges requires concerted efforts to build regulatory frameworks, promote innovation, and raise public awareness to realize the full potential of waste valorization for sustainable development and climate mitigation. Valorization **can create new job opportunities, especially for women and youth**, in waste collection, processing, and valorization facilities, potentially **boosting the local economy.**[194] Waste valorization encompasses various technologies and approaches, **allowing for adaptation to different types of waste** and local contexts.[195]Government policies promoting waste valorization through regulations, subsidies, and tax breaks can encourage investment and innovation, while ongoing research and development can improve efficiency and reduce costs. Public awareness campaigns can educate communities about the benefits of waste valorization and address concerns about potential environmental or health impacts. Collaboration between government, industry, and research institutions can accelerate the development and adoption of innovative waste valorization solutions.

SWOT Analysis (Summary)

Waste Valorization diverts waste from landfills and incineration, minimizing emissions and resource strain, and supports a circular economy by creating valuable new resources. It also generates job opportunities and reduces waste management costs. However, challenges include the need for specialized technology, market demand issues, and high costs. Opportunities lie in supportive government policies, ongoing R&D, and public awareness campaigns (Table 18). Addressing infrastructure gaps and public concerns will be crucial for broader adoption.

Strengths	Weaknesses
S1. Valorization **diverts waste from landfills and incineration, minimizing greenhouse gas emissions**, pollution, and strain on resources.[196]	**W1**. Certain valorization methods **require specialized technology and infrastructure**, which is **not readily available** or affordable in all regions of Pakistan.[201]
S2. Waste valorization **offers a way to create new resources like energy, fuels, compost, or recycled materials**, reducing reliance on virgin resource extraction.[197]	**W2.** The efficiency and effectiveness of valorization processes can be highly dependent on the **quality and consistency of the waste feedstock**.[202]
S3. Waste valorization **aligns with the principles of a circular economy by keeping materials in use for longer** and minimizing waste generation.[198]	**W3.** The **market demand for some valorization products may be limited**, impacting the economic viability of these processes.[203]

[194] https://www.degruyter.com/document/doi/10.1515/opag-2017-0020/pdf
[195] https://www.sciencedirect.com/science/article/pii/S1110062118301375
[196] https://www.sciencedirect.com/science/article/pii/S1110062118301375
[197] https://www.mdpi.com/2313-4321/8/4/61
[198] https://www.sciencedirect.com/science/article/pii/S2949750723000408
[199] https://www.degruyter.com/document/doi/10.1515/opag-2017-0020/pdf
[201] https://academic.oup.com/qje/article/132/3/1101/3064351
[202] https://link.springer.com/chapter/10.1007/978-3-031-55665-4_9
[203] https://www.sciencedirect.com/science/article/pii/S0022030214000903

Strengths	Weaknesses
S4. Valorization can **create new job opportunities, especially for women and youth**, in waste collection, processing, and valorization facilities, potentially **boosting the local economy**.[199] **S5.** Waste valorization encompasses various technologies and approaches, **allowing for adaptation to different types of waste** and local contexts.[200] **S6**. Waste Valorization has an **emission reduction potential of up to 25%** from a Business-as-usual scenario and leads to **water conservation by up to 15%.** **S7**. Waste Valorization significantly **reduces the costs** involved in managing organic waste.	**W4**. Scaling up some valorization technologies from pilot to large-scale operations can be complex and **require significant investment**.[204] **W5. Public concerns** about potential environmental or health risks associated with certain valorization technologies can hinder their adoption.[205] **W6**. There is **no nationwide policy/regulation** or any guideline available for waste valorization in Pakistan, and there is only some research going on in this domain. **W7**. Combined cost for valorization can be calculated by adding the capital cost of several technologies involved in the process i.e., PKR 18.7M (Composting) + PKR 0.5M (Segregation) + PKR 21.5M (Pyrolysis), **which comes out to be PKR 40.7M**, which makes it a bit costly.

Opportunities	Threats
O1. Government policies promoting waste valorization through regulations, subsidies, and tax breaks can **encourage investment** and innovation.[206] **O2. Ongoing research and development** in waste valorization technologies **can improve efficiency, reduce costs, and broaden the range** of feasible valorization options.[207] **O3**. Public awareness campaigns can **educate communities about the benefits of waste valorization** and address concerns about potential environmental or health impacts.[208] **O4**. **Collaboration between government, industry**, and **research institutions** can accelerate the development and adoption of innovative waste valorization solutions.[209] **O5**. Integrating waste valorization into existing waste management systems can **optimize waste collection, sorting, and processing for maximum resource recovery**.[210]	**T1**. Established waste disposal methods like landfills and incineration can be cheaper in the short term, hindering the adoption of valorization.[211] **T2**. Concerns about potential environmental or health risks associated with certain valorization facilities can lead to public opposition.[212] **T3**. The novelty of some valorization technologies in Pakistan can lead to investor hesitation due to perceived risks or uncertainties about long-term profitability.[213] **T4**. Many waste valorization technologies require advanced infrastructure and expertise which is lacking in Pakistan. [214] **T5**. The economic viability of some valorization technologies can be sensitive to fluctuating market prices for recovered resources or energy products.[215]

Table 18: SWOT analysis of Waste Volarization in Pakistan

[199] https://www.degruyter.com/document/doi/10.1515/opag-2017-0020/pdf
[200] https://www.sciencedirect.com/science/article/pii/S1110062118301375
[204] https://www.kewaunee.in/blog/scaling-up-from-pilot-plants-to-large-scale-production/
[205] https://www.researchgate.net/publication/327509028_Factors_affecting_sustainable_process_technology_adoption_A_systematic_literature_review
[206] https://www.ncbi.nlm.nih.gov/pmc/articles/PMC10073629/
[207] https://www.mdpi.com/2071-1050/15/7/6281
[208] https://www.mdpi.com/2071-1050/13/20/11423
[209] https://www.mdpi.com/2071-1050/15/7/6281
[210] https://www.researchgate.net/publication/338124321_INTEGRATION_OF_RESOURCE_RECOVERY_INTO_CURRENT_WASTE_MANAGEMENT_THROUGH_ENHANCED_LANDFILL_MINING
[211] https://www.sciencedirect.com/science/article/pii/S1110062118301375
[212] https://www.sciencedirect.com/science/article/abs/pii/S0956053X15301847
[213] https://www.researchgate.net/publication/228140099_How_Do_Investors_Judge_the_Risk_of_Financial_Items
[214] https://www.mdpi.com/2071-1050/15/7/6281
[215] https://www.sciencedirect.com/science/article/abs/pii/S0013935122012841?dgcid=rss_sd_all

5.4 Plastic Waste

5.4.1 Refuse-Derived Fuel

Refused Derived Fuel (RDF) is a process that converts non-recyclable plastic waste into a fuel source. The plastic is shredded, washed, and processed into a uniform fuel that can be burned for energy in industrial furnaces or power plants.

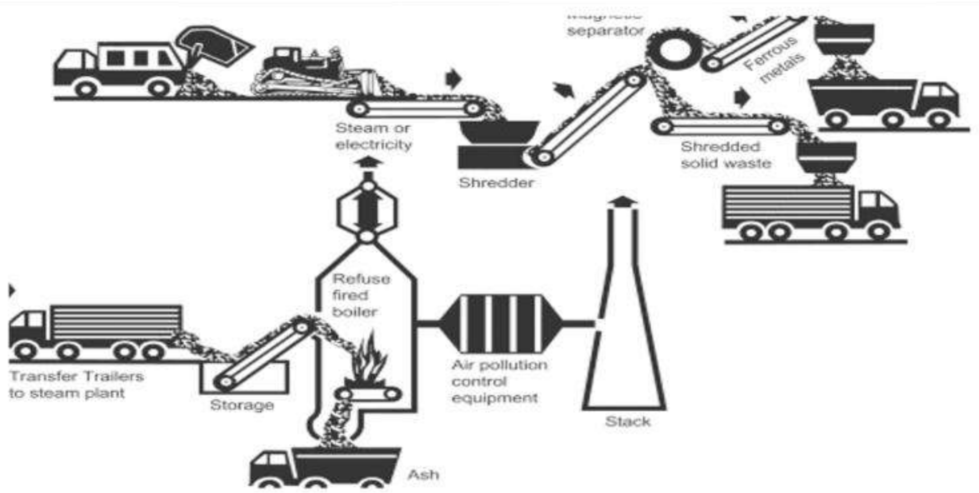

Figure 9. Schematic representation of the RDF preparation process

i. Legal, Regulatory, and Economic Landscape

RDF utilization in Pakistan benefits from **existing guidelines formulated in 2012 for its use in the cement industry**, indicating regulatory support for this alternative energy source. However, the absence of nationwide policies or regulations specifically addressing plastic waste RDF production poses challenges for its widespread adoption. Moreover, the financial landscape presents hurdles, with challenges such as meeting cement fuel requirements, requiring upgrades in cement plant infrastructure, and additional drying processes to improve RDF quality, which increases production costs. Despite these challenges, RDF offers significant potential for reducing fossil fuel consumption and CO_2 emissions, particularly in the cement sector, where demand for RDF is high. There is a lot of potential for private-sector investment in this technology, as seen from the previously running plants in Pakistan, **Fauji Cement, in 2008**, was the first to install an RDF facility in their **3700 TPD cement Plant**, and several others such as **DG Khan Cement** have also followed their positive move, showing that there exists private investment potential **for RDF in the cement sector of Pakistan.**[216]

[216] http://www.cement.pk/wp-content/uploads/2019/06/Alternative-Fuel-Pakistan-Cement-Industry.pdf

ii. Socio-Economic Feasibility

RDF demonstrates economic and technical feasibility in Pakistan, serving as an alternate energy source for cement plants and contributing to the reduction of CO_2 emissions. The **RDF process does not leave any residue behind**, which needs to be landfilled, conserving natural resources and energy.[217] The **skills for RDF production** and use **are locally available in Pakistan**, as there are many plants constructed and operated in various cement plants all over the country. RDF provides **energy recovery efficiency by up to 80%**, which increases its potential applications.[218] However, challenges such as efficient plastic waste segregation, meeting cement fuel requirements, and ensuring RDF quality pose technical barriers to its effectiveness. Effective RDF production from plastic waste **requires separation** from other waste materials, and Pakistan's waste collection system lacks the infrastructure and capacity for efficient plastic waste segregation at the source.[219] Additionally, concerns regarding **incomplete combustion leading to emissions of pollutants like dioxins and furans** raise air quality concerns. [220] Despite these challenges, the skills for RDF production and use are locally available in Pakistan, with many plants constructed and operated in various cement plants across the country.

To delve into the economic analysis case study of the Fauji Cement Company RDF (Refuse-Derived Fuel) processing plant[221] in Pakistan with a capacity of 12 tons per hour[222] is taken here. By 2015, the company operated a 3,700-tons per day[214] cement plant in Jang Bahtar, Punjab, later expanding with a new 7,200 tons per day production line. Our economic analysis of RDF is based on a UNFCCC project design report, updated for 2024.

The RDF project investment is estimated at PKR 7,249,132,249 (**USD 26,104,185**[214]), with annual electricity production of **54,696 MWh**[214]. The unit cost of grid electricity is **PKR 29,780 per MWh**, while WHR (Waste Heat Recovery) electricity costs **PKR 5,250**[214] per MWh. Over 25 years, the project is projected to generate income or savings of **PKR 1,628,846,880** (USD 5,865,491[214]) from electricity, with WHR generation costs of **PKR 287,154,000** (USD 1,034,044[214]). The feasibility study indicates economic viability with a **3%** O&M cost and **10%** discount rate, showing an NPV of **USD 10.6 million**[223], an IRR of **15%[215]**, and a **6.4[215]**-year payback period. Sensitivity analysis under different scenarios, including discount rates of **6%** and **14%[215]** and variations in costs and WHR electricity prices demonstrates positive outcomes. The NPV ranges from **USD 1.7 million** to **USD 13.2 million[215]**, the IRR from 13% to 17%, and the payback period from **6.1** to **7.1 years[215]**.

[214] https://www.mdpi.com/2071-1050/15/7/6281
[215] https://www.sciencedirect.com/science/article/abs/pii/S0013935122012841?dgcid=rss_sd_all
[217] https://www.researchgate.net/publication/373537115_Solid_waste_management_by_RDF_production_from_landfilled_waste_to_renewable_fuel_of_Nonthaburi
[218] https://www.mdpi.com/1996-1073/16/18/6695
[219] https://www.sciencedirect.com/science/article/abs/pii/S0045653523016053
[220] https://iopscience.iop.org/article/10.1088/1748-9326/abae9f;
[221] https://www.cement.pk/wp-content/uploads/2019/06/Alternative-Fuel-Pakistan-Cement-Industry.pdf
[222] ibid
[223] Authors calculation

A study titled "**Techno-economic analysis of a hybrid heat recovery-renewable energy system for enhancing power reliability in cement factories in Pakistan**[224]" proposes a hybrid power system integrating solar thermal power, waste heat recovery, and wind turbines. Simulated for a cement factory in Kalar Kahar, Pakistan, this system can meet **40%**[225] of the factory's electricity demand, generating 109.2[217] GWh annually. It has an NPV of USD **25.69**[217] million reduces the annual electricity bill by **USD 19.66**[217] million, and cuts CO_2 emissions by **52.7 thousand**[217] tCO_2e/year. These findings underscore the economic feasibility and environmental benefits of integrating RDF projects and hybrid renewable energy systems in Pakistan's industrial sector, contributing significantly to sustainable energy solutions and waste management practices.

Overall Refuse Derived Fuel (RDF) is effective in reducing CO2e emissions by 54.8% and converts non-recyclable plastic waste into a fuel suitable for industrial use. The capital investment is PKR 300 million with a capacity of 12 tons per hour, and it replaces 170 tons of coal daily. The operational cost is approximately PKR 16,000 per ton/day as depicted in the table 19.

Emissions Reduction/ Resource Conservation	Other Benefits/ Cost Savings	Capital Cost/ Total Investment	Operational cost	Social Benefits
54.8% CO2e emissions reduction	RDF cost was told to be PKR 1/kg (LWMC) 1kg of Coal is around PKR 250[226]	Based on study: Fauji Cement Company RDF (Refuse-Derived Fuel) processing plant, Pakistan Discount Rate: 10% Cost: USD 26,104,185 NPV: USD 10.6 million IRR: 15%, Payback Period: 6.4-year	3% O&M of total cost	Reduces reliance on firewood, which can positively impact households by decreasing the time spent on wood collection and allowing more opportunities for education and other activities

Table 19. Socio-economic benefits of Refuse Derived Fuel in Pakistan

iii. Inclusive Development and Climate Impacts

RDF presents opportunities for inclusive development and climate mitigation in Pakistan. RDF reduces up to **54.8% of CO2e emissions from the BAU scenario**, which was proved in a case study of Thailand. Stricter landfill regulations and bans drive demand for alternative waste disposal methods, creating opportunities for RDF uptake. **Waste plants can sign contracts with cement plants for a continuous supply of RDF** for a specific period to secure an alternative source of regular income.[227] Furthermore, **cement plants can reduce their (non-biogenic) CO2 emissions** and **may generate carbon credits**, allowing them to earn additional income.[228]

[224] https://www.sciencedirect.com/science/article/abs/pii/S0045653523016053
[225] ibid
[226] https://www.daraz.pk/products/koyla-charcoal-1-kg-i191224233.html
[227] https://iopscience.iop.org/article/10.1088/1748-9326/abae9f;
[228] https://iopscience.iop.org/article/10.1088/1748-9326/abae9f;

However, **challenges such as chlorine content concerns**, reduced availability of materials for RDF production due to waste recycling goals, and shifts towards renewable energy sources like hydrogen could impact RDF uptake. [229] Moreover, **women are found at the lowest strata in the value chain**, on the role of segregation and collection, and the technology does not involve women in other important roles. Addressing these challenges requires collaboration between government, industry, and research institutions to develop comprehensive policies, regulations, and technical innovations to ensure sustainable RDF production and inclusive development in Pakistan.

SWOT Analysis (Summary)

Refuse-Derived Fuel (RDF) offers a crucial alternative energy source for cement plants, significantly reducing reliance on fossil fuels and cutting CO2 emissions. Despite challenges such as waste segregation issues and quality control concerns, RDF's high energy recovery efficiency and the existing local expertise make it a viable option (Table 20). The technology's potential to provide a steady income stream through contracts with cement plants and contribute to reducing landfill use highlights its importance. Even with threats like equipment damage and competition from renewable energy, RDF's benefits in reducing environmental impact and supporting local industry underscore its need and value.

Strengths	Weaknesses
S1. RDF is an **alternate energy source for factories, mainly cement plants**, contributing to the reduction of fossil fuel consumption.[230]	**W1**. Effective RDF production from plastic waste **requires separation** from other waste materials, and Pakistan's waste collection system lacks the infrastructure and capacity for efficient plastic waste segregation at the source.[237]
S2. RDF reduces up to 54.8% of CO2e emissions from the BAU scenario, which was proved in a case study of Thailand.[231]	**W2**. It is **challenging to meet cement fuel requirements** in areas such as grain size, NCV, and moisture content.[238]
S3. The **RDF process does not leave any residue behind**, which needs to be landfilled, conserving natural resources and energy.[232]	**W3. Requires upgrades and investment in the cement plant reception**, storage, dosing, and firing system.[239]
S4. High **demand for RDF in the cement sector of Pakistan**.[233]	**W4. Additional drying may be required to improve RDF quality**, which increases the costs of producing RDF.[240]
S5. RDF provides **energy recovery efficiency by up to 80%**, which increases its potential applications.[234]	**W5. Changes in waste composition** may affect RDF quality leading to economic losses.[241]
S6. Guidelines exist in Pakistan for the use of RDF in the Cement Industry that were formulated in the year 2012.[235]	

[229] https://iopscience.iop.org/article/10.1088/1748-9326/abae9f;
[230] https://www.eib.org/attachments/lucalli/20230376_managing_refuse_derived_and_solid_recovered_fuels_en.pdf
[231] SOURCE
[232] https://www.researchgate.net/publication/373537115_Solid_waste_management_by_RDF_production_from_landfilled_waste_to_renewable_fuel_of_Nonthaburi
[233] http://www.cement.pk/wp-content/uploads/2019/06/Alternative-Fuel-Pakistan-Cement-Industry.pdf
[234] https://www.mdpi.com/1996-1073/16/18/6695
[235] https://docplayer.net/21468864-Guidelines-for-processing-and-using-refuse-derived-fuel-rdf-in-cement-industry.html
[236] https://docplayer.net/21468864-Guidelines-for-processing-and-using-refuse-derived-fuel-rdf-in-cement-industry.html
[237] https://www.sciencedirect.com/science/article/abs/pii/S0045653523016053
[238] https://www.sciencedirect.com/science/article/abs/pii/S0045653523016053
[239] https://www.sciencedirect.com/science/article/abs/pii/S0045653523016053
[240] https://www.sciencedirect.com/science/article/abs/pii/S0045653523016053
[241] https://www.sciencedirect.com/science/article/abs/pii/S0045653523016053

Strengths	Weaknesses
S7. The **skills for RDF production and use are locally available in Pakistan**, as there are many plants constructed and operated in various cement plants all over the country. [236] **S8**. Automatic RDF Plants can cost up to PKR 300M with a Capacity of 12 TPH and replace 170 tons of coal/day, which makes the technology not very costly.	**W6**. Incomplete combustion of RDF in power plants can lead to emissions of pollutants like dioxins and furans, raising air quality concerns.[242] **W7**. There exists **no nationwide policy** for plastic waste RDF production, but there is mention in the **ADB reform roadmap for the waste sector in Pakistan 2022**. [243] **W8. Women are found at the lowest strata in the value chain**, on the role of segregation and collection, and the technology does not involve women in other important roles.

Opportunities	Threats
O1. Stricter landfill regulations and bans are driving demand for alternative waste disposal methods, **creating opportunities for RDF uptake**.[244] **O2**. The **demand for RDF could increase**, provided it aligns with regulatory requirements.[245] **O3**. **Waste plants can sign contracts with cement plants for a continuous supply of RDF** for a specific period to secure an alternative source of regular income.[256] **O4**. **Cement plants can reduce their (non-biogenic) CO_2 emissions and may generate carbon credits**, allowing them to earn additional income.[247]	**T1. Chlorine content is a critical concern due to its potential to cause blockages** and damage in the ducts, as well as harm to cement kiln refractories. [248] **T2**. Waste recycling and circular economy goals could **reduce the availability of materials** for RDF production, thus impacting RDF quality. [249] **T3**. The **shift towards renewable** energy sources such as hydrogen may **impact the demand** for RDF uptake. [250] **T4**. **Reduced gate fees in cement plants result in smaller economic incentives** for cement plants to use RDF. [251]

Table 20: SWOT analysis of Refuse-Derived Fuel in Pakistan

[242] https://iopscience.iop.org/article/10.1088/1748-9326/abae9f;
[243] https://www.adb.org/sites/default/files/publication/784421/solid-waste-management-pakistan-road-map.pdf
[244] https://iopscience.iop.org/article/10.1088/1748-9326/abae9f;
[245] https://iopscience.iop.org/article/10.1088/1748-9326/abae9f;
[246] https://iopscience.iop.org/article/10.1088/1748-9326/abae9f;
[248] https://iopscience.iop.org/article/10.1088/1748-9326/abae9f;
[249] https://iopscience.iop.org/article/10.1088/1748-9326/abae9f;
[250] https://iopscience.iop.org/article/10.1088/1748-9326/abae9f;
[251] https://iopscience.iop.org/article/10.1088/1748-9326/abae9f;

5.4.2 Downcycling

Downcycling means reusing plastic waste to create products of generally lower quality or value compared to the original plastic. Examples include using plastic bottles to make fleece jackets or plastic bags for trash liners. Widely used due to its simplicity and affordability. However, efforts are increasing to promote higher-value plastic recycling processes. Open burning of plastic waste releases harmful chemicals and black carbon, a potent greenhouse gas with significant warming potential. In 2019, plastic production and incineration added 850 million metric tons of greenhouse gases to the atmosphere, potentially rising to 2.8 gigatons by 2050. Establishing a circular economy for plastics—where plastics are reusable, recyclable, or compostable—could reduce ocean plastic pollution by 80%, generate $200 billion in savings, cut greenhouse gas emissions by 25%, and create 700,000 new jobs by 2040, highlighting the critical importance of plastic recycling over incineration[252].

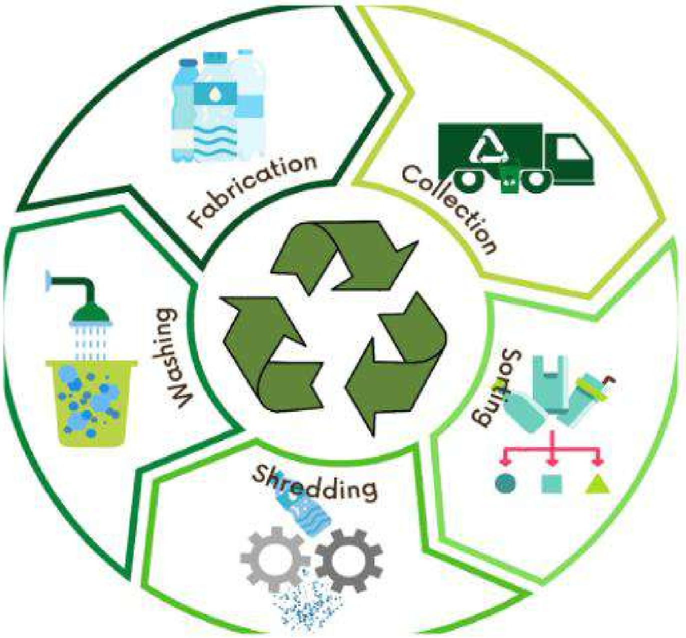

Figure 10. Steps involved in the downcycling process

i. Legal, Regulatory, and Economic Landscape

Downcycling in Pakistan currently operates within the informal sector **without a nationwide legal or regulatory framework specifically addressing this practice**. [253] The absence of formal regulations poses challenges for its formalization and scalability. Although downcycling diverts plastic waste from landfills and incineration, reducing environmental pollution, the lack of regulatory support hinders its widespread adoption. Furthermore, the potential for private investment in downcycling facilities is impeded by **limited market demand** for downcycled products due to their lower quality compared to virgin plastic. However, there are initiatives such as, **Levi's** using plastic waste to make jeans **not only conserve energy and water in manufacturing but also contribute to reducing plastic waste** through downcycling, [254] encourage private-sector investment in this technology.

[252] https://www.weforum.org/agenda/2022/01/plastic-pollution-climate-change-solution/
[253] https://www.pjoes.com/Role-of-the-Informal-Sector-in-Recycling-r-nWaste-in-Eastern-Lahore,89442,0,2.html
[254] https://earth5r.org/plastic-processing-upcycling-recycling-downcycling-and-more/

ii. Socio-Economic Feasibility

Downcycling demonstrates economic and technical feasibility in Pakistan, serving as an alternative to landfilling or incineration for plastic waste disposal. Downcycled products **are generally of lower quality** than those made from virgin plastic, limiting their applications in some cases.[255] Downcycled Plastic finds **applications in various products** such as fleece or carpeting, plastic lumbers, car parts, and textiles, though not all of these can be recycled or downcycled again. [256] The **market demand for downcycled products is limited due to their low quality**, impacting the economic viability of downcycling facilities.[257] **Improper sorting of plastic waste can lead to contamination issues** in downcycled products, affecting their quality and safety.[258] Since virgin plastic is derived from oil, **fluctuating oil prices can affect the economic viability** of both virgin plastic and downcycled products.[259].

An Indian study on "**Waste recovery cost analysis of life-ended PV modules**[260]" reveals the economic viability of recycling discarded photovoltaic (PV) modules. The benefit-cost ratio (BCR) is **1.64**[261], and the NPV is **USD 25.22**[262] million, indicating that solar module recycling is economically feasible. The study highlights the neglect of PV waste management and suggests investing in a structured recycling system for economic benefits and environmental protection. This is particularly relevant for Pakistan as it develops its solar power sector.

Findings from developed countries offer valuable insights for Pakistan. The Dutch study, "**A cost-effectiveness analysis for incineration or recycling of Dutch household plastics**[263]" compares recycling and incineration. It shows that recycling has high costs and minimal CO2 reduction benefits, with an implicit CO2 abatement price of **178[264] Euros per ton**. This suggests that recycling may not always be cost-effective and underscores the need for a careful evaluation of waste management strategies in Pakistan. A Swedish study titled "**Cost-benefit analysis of two possible deposit-refund systems for reuse and recycling of plastic packaging**[265]" evaluates recycling versus reuse scenarios for PET trays. The reuse scenario is more cost-effective, with a **BCR of 1.67**[266], while recycling has a **BCR of 0.73**[267], indicating that reuse systems offer better economic returns.

For Pakistan, these findings suggest exploring reuse-oriented policies and integrating the informal sector into formal waste management systems. Lessons from these studies highlight the importance of government support, infrastructure development, and successful strategies to improve waste management efficiency and sustainability.

The overall cost-benefit analysis of downcycling is summarized in table 21. It shows that downcycling significantly reduces NOx emissions by 62.8% and involves reusing plastic waste to produce lower-value products. The capital cost is USD 550 (~PKR 150,000) with a production capacity of 100-1500 kg/hr. Operational costs are about PKR 600,000, which is four times the initial investment.

[255] https://onlinelibrary.wiley.com/doi/full/10.1111/jiec.13289
[256] https://earth5r.org/plastic-processing-upcycling-recycling-downcycling-and-more/
[257] https://www.sciencedirect.com/science/article/abs/pii/S0956053X20300040
[258] https://www.rubicon.com/blog/recycling-contamination/
[259] https://www.webpilot.ai/writeDetail/9cb6a854-b077-47a6-a50b-87dc7099b64c
[260] https://link.springer.com/article/10.1007/s00542-023-05546-2
[261] https://link.springer.com/article/10.1007/s00542-023-05546-2
[262] https://link.springer.com/article/10.1007/s00542-023-05546-2
[263] A cost-effectiveness analysis for incineration or recycling of Dutch household plastics
[264] A cost-effectiveness analysis for incineration or recycling of Dutch household plastics
[265] A cost-effectiveness analysis for incineration or recycling of Dutch household plastics
[266] A cost-effectiveness analysis for incineration or recycling of Dutch household plastics
[267] A cost-effectiveness analysis for incineration or recycling of Dutch household plastics

Emissions Reduction/ Resource Conservation	Other Benefits/ Cost Savings	Capital Cost/ Total Investment	Operational cost	Social Benefits
62.8% NOx emissions reductions	1 Liter Plastic Bottle can cost up to PKR 45 Shopping bags made by downcycling bottles cost around 1-5 PKR per bag	Based on study: Cost-benefit analysis of two possible deposit-refund systems for reuse and recycling of plastic packaging in Sweden Reuse scenario BCR: 1.67 Recycling scenario BCR : BCR of 0.73 Cost for Pakistan: USD 550, 100-1500 Kg/h production capacity (~ PKR 150,000)	Operational cost is 4 times as capital cost = PKR 600,000 (100-1500 Kg/hr.)	Use of downcycled products in the textile and garment industry enhances the value chain, benefiting a significant portion of the workforce involved in this sector

Table 21: Socio-economic benefits of plastic Downcycling in Pakistan

iii. Inclusive Development and Climate Impacts

Downcycling presents opportunities for inclusive development and climate mitigation in Pakistan. Downcycled and pyrolyzed **LDPE can lead to 62.8% NOx emissions** reductions. On the contrary, some **downcycling processes require significant energy input**, potentially reducing their environmental benefits.[268] Advancements in downcycling technologies can improve product quality, expand application possibilities, and increase efficiency, thereby enhancing market demand and economic viability. For instance, downcycled products find applications in various sectors, such as fleece or carpeting, plastic lumbers, car parts, and textiles. Downcycling facilities **can create new jobs for targeted communities, women, and youth** in the waste processing, and manufacturing of downcycled products.[269] Public awareness campaigns and government incentives can further promote the use of downcycled products, contributing to waste management strategies. Addressing these challenges requires **integrating informal waste sectors into formal downcycling processes**, developing sustainable downcycling technologies, and fostering consumer acceptance through education and incentives.

SWOT Analysis (Summary)

Downcycling is a crucial technology for managing plastic waste, as it effectively diverts plastic materials from landfills and incineration, thus mitigating environmental pollution and conserving resources. Despite its limitations—such as producing lower-quality products and facing market challenges—downcycling helps reduce NOx emissions and can create valuable job opportunities, particularly for targeted communities (Table 22). Initiatives like using downcycled plastic in consumer products demonstrate its potential to contribute to a circular economy and reduce waste, making it a valuable addition to comprehensive waste management strategies.

[268] SOURCE
[269] https://cleanrobotics.com/recycling-strategies-downcycling-and-upcycling-explained/

Strengths	Weaknesses
S1. Downcycling is often confused with recycling, but it results in products of lesser quality compared to recycling, which **preserves the value and life of the material.**[270] **S2**. Downcycling **diverts plastic waste from landfills and incineration**, reducing environmental pollution and strain on these resources.[271] **S3. Downcycled and pyrolyzed LDPE** can lead to **62.8% NOx emissions reductions.** **S4**. Downcycling facilities **can create new jobs for targeted communities, women, and youth** in the waste processing, and manufacturing of downcycled products.[272] **S5**. Downcycled Plastic finds **applications in various products** such as fleece or carpeting, plastic lumbers, car parts, and textiles, though not all of these can be recycled or downcycled again. [273] **S6**. Downcycling conserves energy and water and reduces plastic waste. [274] **S7**. Downcycling comes with a capital cost of USD 550 (~**PKR 150,000**), for a production capacity of 100-1500 Kg/h, which makes it not very costly.	**W1**. Downcycled products **are generally of lower quality** than those made from virgin plastic, limiting their applications in some cases.[275] **W2**. The **market demand for downcycled products is limited due to its low quality**, impacting the economic viability of downcycling facilities.[276] **W3. Improper sorting of plastic waste can lead to contamination issues** in downcycled products, affecting their quality and safety.[277] **W4**. Some **downcycling processes require significant energy input**, potentially reducing their environmental benefits.[278] **W5**. There is **no nationwide existing legal or regulatory framework, policy, or guideline** for downcycling in Pakistan, it is mainly carried out by the informal sector on its own.[279]

[270] https://earth5r.org/plastic-processing-upcycling-recycling-downcycling-and-more/
[271] https://www.oberk.com/packaging-crash-course/downcycling-temp#:~:text=Downcycling%20is%20the%20term%20used,of%20product%20than%20the%20original.
[272] https://cleanrobotics.com/recycling-strategies-downcycling-and-upcycling-explained/
[273-274] https://earth5r.org/plastic-processing-upcycling-recycling-downcycling-and-more/
[275] https://onlinelibrary.wiley.com/doi/full/10.1111/jiec.13289
[276] https://www.sciencedirect.com/science/article/abs/pii/S0956053X20300040
[277] https://www.rubicon.com/blog/recycling-contamination/
[278] SOURCE
[279] https://www.pjoes.com/Role-of-the-Informal-Sector-in-Recycling-r-nWaste-in-Eastern-Lahore,89442,0,2.html

Opportunities	Threats
O1. Advancements in downcycling technologies can improve product quality, expand application possibilities, and increase efficiency.[280] **O2. Promoting the use of downcycled products through public awareness** campaigns and government incentives can increase market demand.[281] **O3. Integrating downcycling into existing waste management and plastic recycling systems** can optimize plastic waste management strategies.[282] **O4. Developing downcycling processes that minimize energy consumption** and environmental impact can enhance the overall sustainability of the approach.	**T1.** Low virgin plastic prices can **make downcycled products less competitive** in the market.[283] **T2.** Since virgin plastic is derived from oil, **fluctuating oil prices can affect the economic viability** of both virgin plastic and downcycled products.[284] **T3. Downcycled products can be of lower quality and have shorter** lifespans compared to virgin plastic products, discouraging consumer adoption.[285] **T4. A large portion of Pakistan's waste collection is handled by the informal sector. Integrating this sector** with formal downcycling processes could be challenging.[286]

Table 22: SWOT Analysis of Plastic Downcycling in Pakistan

[280] https://journals.sagepub.com/doi/10.1177/00405175231210239
[281] https://www.econstor.eu/bitstream/10419/283130/1/DP2024-3.pdf
[282] https://www.sciencedirect.com/science/article/pii/S0921344923004299
[283] https://www.sciencedirect.com/science/article/pii/S0921344923004299
[284] https://www.webpilot.ai/writeDetail/9cb6a854-b077-47a6-a50b-87dc7099b64c
[285] https://www.sciencedirect.com/science/article/pii/S0921344923004299
[286] https://www.mdpi.com/2071-1050/13/21/11717

5.4.3 Non-biodegradable Plastic Pyrolysis Technology (Emerging)

Non-biodegradable plastic Pyrolysis is a thermochemical process that heats non-biodegradable plastic waste in an oxygen-limited environment. This process can convert plastic into various products, such as bio-oil (fuel), syngas (combustible gas), or char (charcoal).

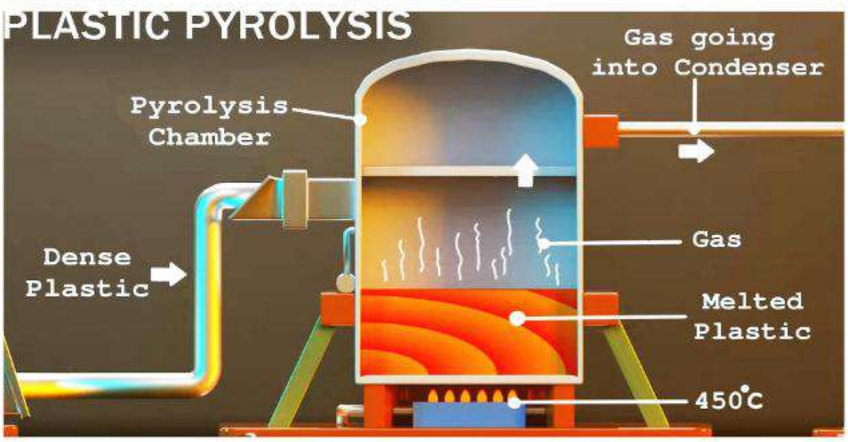

Figure 11. Plastic pyrolysis technology

i. Legal, Regulatory, and Economic Landscape

Non-biodegradable plastic pyrolysis in Pakistan operates within a regulatory framework that lacks comprehensive guidelines, hindering its widespread implementation. **Punjab EPA haddrafted guidelines regarding pyrolysis plants with no cover** and has taken action according to the guidelines in several places like the Margalla Hills, but **they are not being implemented all across Pakistan**, and they do not focus on other non-biodegradable plastic pyrolysis. While pyrolysis diverts plastics from dumping sites, reducing environmental impact, the absence of enforced regulations poses challenges for ensuring safe and responsible operation. Additionally, setting up and running pyrolysis plants requires significant investment, which may be scarce in Pakistan, hindering its feasibility. There is potential for private-sector investment in this technology, as **Pakistan's plastic waste generation is equivalent to two K2-Mountains**[287], which can be pyrolyzed and used for electricity generation as per the success story of Indonesia, and lead to carbon credit trading, and there exist bankable projects in the Margalla hills, that can be run again with new technology.[288]

[287] https://gulfnews.com/world/asia/pakistan/plastic-waste-generated-in-pakistan-so-far-equals-two-k2-mountains-climate-change-minister-1.94814323#:~:text=ISLAMABAD%3A%20The%20total%20mass%20of,of%20Circular%20Economy%20in%20Pakistan.%E2%80%9D
[288] https://www.tyreandrubberrecycling.com/articles/news/guidelines-drafted-to-regularise-pakistan-pyrolysis-plants/

ii. Socio-Economic Feasibility

Non-biodegradable plastic pyrolysis does not demonstrate economic and technical feasibility in Pakistan. Pyrolysis oil can be used for **electricity generation or transportation fuels**, potentially **reducing reliance on imported fossil fuels** in Pakistan, and promoting a just transition. [289] Operating and maintaining pyrolysis plants requires specialized knowledge of the technology and safety protocols. Developing a skilled workforce in Pakistan is necessary, posing skill development challenges.[290] Further, challenges such as the quality variability of pyrolysis oil, incomplete combustion leading to harmful pollutant emissions, and the lack of awareness among waste collectors and technology operators affect its effectiveness. **Pyrolysis can handle a wider range of waste feedstock** compared to some recycling technologies, potentially improving waste management efficiency in Pakistan where segregation rates are low. [291]The **quality of pyrolysis oil can vary depending on feedstock** and technology, **which is a serious issue caused by the lack of awareness of waste collectors** and technology operators.[292]Moreover, navigating complex regulations for air emissions and waste product disposal presents additional hurdles to operational sustainability. Nevertheless, ongoing research and development can improve pyrolysis efficiency, and product quality, and reduce operational costs, making it more competitive.

A study evaluating the conversion of waste plastic into fuel oil using pyrolysis technology in Bahawalpur[293], Pakistan, addresses both plastic waste management and energy shortages. Pakistan generates **20 million**[294] tons of solid waste annually, with a **2%**[295]increase each year, of which **9%**[296] is plastic waste, amounting to **1.32 million**[297] tons. Bahawalpur, Punjab, has the highest population density among provinces, producing 282 tons of waste daily, with **5.6%**[298] being hard plastic and **2.3%** soft plastic.

Pyrolysis is highlighted as a cost-effective alternative to traditional mechanical and thermal recycling methods, which are often costly and environmentally harmful. The feasibility study for a pyrolysis plant in Bahawalpur reveals promising economic indicators. With a total capital investment of USD 0.2 million and an annual production cost of **USD 1.6 million**[299], the plant can generate annual revenues of **USD 8.5 million**[300], resulting in net profits of **USD 4.8 million**[301]. The rate of return is **19.81%**[302], and the payback period is 5 years[303], indicating that the investment will be recovered within this timeframe.

The study concludes that pyrolysis is an economically viable solution for managing plastic waste and producing fuel oil, offering significant economic benefits and addressing both waste management and energy production challenges in Pakistan.

[289] https://www.mdpi.com/2071-1050/13/6/3214
[290] https://www.sciencedirect.com/science/article/pii/S1364032122006049
[291] https://www.mdpi.com/1996-1073/15/2/510
[292] https://www.mdpi.com/1996-1073/15/2/510
[293] https://austinpublishinggroup.com/environmental-sciences/fulltext/aes-v6-id1053.pdf
[294] https://austinpublishinggroup.com/environmental-sciences/fulltext/aes-v6-id1053.pdf
[295] https://austinpublishinggroup.com/environmental-sciences/fulltext/aes-v6-id1053.pdf
[296] https://austinpublishinggroup.com/environmental-sciences/fulltext/aes-v6-id1053.pdf
[297] https://austinpublishinggroup.com/environmental-sciences/fulltext/aes-v6-id1053.pdf
[298] https://austinpublishinggroup.com/environmental-sciences/fulltext/aes-v6-id1053.pdf
[299] https://austinpublishinggroup.com/environmental-sciences/fulltext/aes-v6-id1053.pdf
[300] https://austinpublishinggroup.com/environmental-sciences/fulltext/aes-v6-id1053.pdf
[301] https://austinpublishinggroup.com/environmental-sciences/fulltext/aes-v6-id1053.pdf
[302] https://austinpublishinggroup.com/environmental-sciences/fulltext/aes-v6-id1053.pdf
[303] https://austinpublishinggroup.com/environmental-sciences/fulltext/aes-v6-id1053.pdf

The cost-benefit analysis of non-biodegradable plastic pyrolysis indicates that it offers a moderate reduction in GHG emissions while converting plastic waste into valuable pyrolysis oil. The process has a substantial capital investment with a capacity of 10 tons and incurs notable operational costs. The cost of pyrolysis oil is significantly lower than diesel, highlighting its potential economic benefits(Table 23).

Emissions Reduction/ Resource Conservation	Other Benefits/ Cost Savings	Capital Cost/ Total Investment	Operational cost	Social Benefits
18-23% GHG emissions reduction	Pyrolysis Oil Price is USD 0.4/kg in Pakistan (~ PKR 111/ kg) Diesel price is PKR 282/liter	Based on study: Pyrolysis plant in Bahawalpur, Pakistan Cost: USD 0.2 million for 14 kilotons/year flowrate that produces 10 kilotons/year of fuel Net Profits: USD 4.8 million IRR 19.81% Payback Period: 5 years	Production cost: USD 1.6 million	Using pyrolysis to convert plastic into liquid fuel reduces indoor air pollution from fossil fuels, enhancing health and safety for those who spend considerable time cooking, while also adding value to the socio-economic gains within the textile industry.

Table 23: Socio-economic benefits of Non-biodegradable Plastic Pyrolysis in Pakistan

iii. Inclusive Development and Climate Impacts

Non-biodegradable plastic pyrolysis presents opportunities for inclusive development and climate mitigation in Pakistan. Research reveals that **recycling post-use plastic through pyrolysis** can reduce **GHG emissions by 18-23%. Incomplete combustion during pyrolysis can release harmful pollutants like particulates and dioxins** if not properly controlled with advanced emission control systems.[304] Government incentives and education can boost participation and long-term success, while technological advancements streamline sorting and enhance efficiency. The **participation of women is only in the informal sector was waste collection**, and no participation is there for the value chain, as it is an emerging technology.[305] Addressing the challenges requires concerted efforts to ensure inclusive development and the use of climate-friendly technology in Pakistan.

SWOT Analysis (Summary)

Pyrolysis is a key technology for transforming plastic waste into valuable products like fuel oil, syngas, and biochar. It helps divert plastics from landfills and reduces greenhouse gas emissions, addressing environmental impacts and reducing reliance on fossil fuels. Despite the high initial investment and challenges such as varying product quality and the need for effective emission control, pyrolysis presents a promising solution for improving waste management efficiency, particularly in regions with low waste segregation rates like Pakistan (Table 24). By leveraging government incentives and technological advancements, pyrolysis can contribute significantly to sustainable waste management and energy recovery.

[304] https://www.mdpi.com/2313-4321/8/2/38
[305] https://www.researchgate.net/publication/292983134_Women_in_Pakistan's_Urban_Informal_Economy

Strengths	Weaknesses
S1. Pyrolysis diverts plastics from dumping sites, reducing environmental impact and generating valuable products like fuel oil, syngas, and biochar. [306]	**W1**. Setting up and running pyrolysis plants **requires significant investment of about** USD 0.2 million for 14 kilotons/year flowrate that produces 10 kilotons/year of fuel.
S2. Pyrolysis oil can be used for **electricity generation or transportation fuels**, potentially **reducing reliance on imported fossil fuels** in Pakistan, and promoting a just transition. [307]	**W2**. Challenges in encouraging behavioral change due to habits and lack of awareness. [310]
S3. Research reveals that **recycling post-use plastic through pyrolysis** can **reduce GHG emissions by 18-23%**.[308]	**W3**. The **quality of pyrolysis oil can vary depending on feedstock** and technology, **which is a serious issue caused by the lack of awareness of waste collectors and technology** operators.[311]
S4. Pyrolysis can handle a wider range of waste feedstock compared to some recycling technologies, potentially improving waste management efficiency in Pakistan where segregation rates are low. [309]	**W4. Incomplete combustion during pyrolysis can release harmful pollutants like particulates and dioxins** if not properly controlled with advanced emission control systems.[312]
S5. Pyrolysis Oil Price is USD 0.4/kg in Pakistan (~ **PKR 111/kg**) and the Diesel price is PKR 282/liter, which makes it cost-saving.	**W5. Pakistan EPA had drafted guidelines regarding pyrolysis plants** with no cover and has taken action according to the guidelines in several places like the Margalla Hills, but they are not being implemented all across Pakistan, and they do not focus on another non-biodegradable plastic pyrolysis.[313]

[306] https://www.sciencedirect.com/science/article/abs/pii/S1364032121003610#:~:text=Various%20types%20of%20energy%20in,oil%2C%20biochar%2C%20and%20syngas.

[307] https://www.mdpi.com/2071-1050/13/6/3214

[308] https://www.sciencedaily.com/releases/2023/10/231012161451.htm#:~:text=Research%20reveals%20that%20recycling%20post,waste%20and%20fossil%20resource%20reliance.

[309-311] https://www.mdpi.com/1996-1073/15/2/510

[312] https://www.mdpi.com/2313-4321/8/2/38

[313] https://www.tyreandrubberrecycling.com/articles/news/guidelines-drafted-to-regularise-pakistan-pyrolysis-plants/

Opportunities	Threats
O1. Government incentives for developing and deploying pyrolysis technology can accelerate adoption and overcome initial investment hurdles. [314] **O2**. Technological advancements streamline sorting and enhance efficiency. [315] **O3**. Incentives and education boost participation and long-term success. [316] **O4**. Ongoing research and development can improve pyrolysis efficiency, and product quality, and reduce operational costs, making it more competitive.[317] **O5**. A plastic pyrolysis plant is located in India with a capacity of 50 tons per day, which can be replicated in Pakistan as well.	**T1**. Operating and maintaining pyrolysis plants demands a deep understanding of the technology and strict adherence to safety protocols. Building a skilled workforce in Pakistan is essential, presenting significant challenges in workforce training and skill development [318] **T2**. Strict regulations for air emissions and waste product disposal are crucial for responsible operation, but navigating complex regulations can be challenging. [319] **T3**. Impact on waste pickers' livelihoods if segregation reduces recyclables in mixed Plastic waste. [320] **T4**. Pakistan generates a massive amount of plastic waste, equivalent in volume to two K2-sized mountains[321] This waste can be pyrolyzed and used for electricity generation as per the success story of Indonesia, and lead to carbon credit trading.

Table 24: SWOT Analysis of pyrolysis in Pakistan

[314] https://www.sciencedirect.com/science/article/pii/S1364032122006049
[315-316] https://www.mdpi.com/1996-1073/15/2/510
[317-320] https://www.sciencedirect.com/science/article/pii/S1364032122006049
[321] https://gulfnews.com/world/asia/pakistan/plastic-waste-generated-in-pakistan-so-far-equals-two-k2-mountains-climate-change-minister-

5.5 Agriculture Waste

5.5.1 Advanced Agro-Residue Livestock Feeding Technology

Livestock Feeding utilizes agricultural residues like straw or stover as animal feed after proper processing to improve digestibility. Livestock feeding is one of the most used practices for managing agricultural waste in Pakistan, especially for ruminant animals like cows and buffaloes. The process flow for straw processing involves several key stages designed to convert straw into high-density feed. Initially, straw is unloaded and transferred to a grinder via a conveyor, where it is shredded into smaller particles. The processed waste is then moved to an intermediate holding bin, which balances intake variations and, if required, is dried to a specified moisture content using electric heating coils. From the bin, the waste is either further processed or treated with a solution in a treatment unit, with the addition of the solution being regulated by a band weigher. The treated waste is then processed through a pellet mill, where it is converted into high-density pellets, with the treatment enhancing particle cohesion. The final pellets are cooled and stored, optimizing their use as livestock feed.

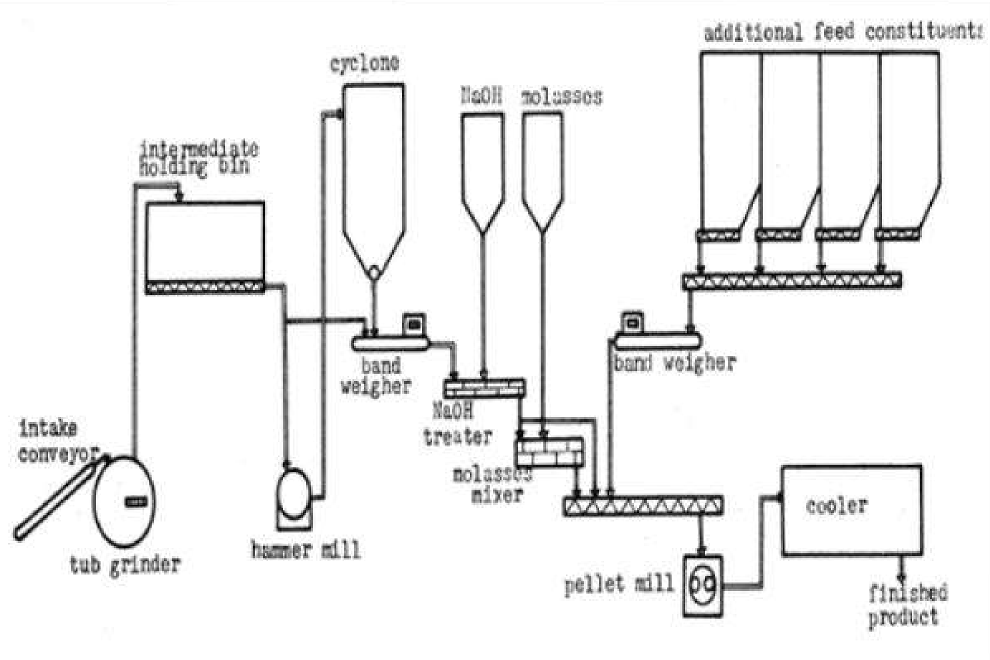

Figure 12. Process flow diagram of pellet formation for livestock feeding using straw[322]

i. Legal, Regulatory, and Economic Landscape

Livestock feeding practices in Pakistan operate without a nationwide policy or regulatory framework, posing challenges for standardized implementation and oversight. The **KPK province has a Livestock Policy 2018**, which mentions Livestock feeding as a good source of nutrition for animals. Other than that, there are **no guidelines in other provinces** on this. Additionally, the lack of subsidies or tax breaks further inhibits widespread adoption. There are **no or limited subsidies or tax breaks** available for waste-reducing feeding technologies in Pakistan.[323] However, opportunities exist for the government to develop clear policies and regulations promoting waste reduction in livestock feeding practices, potentially incentivizing private investment and innovation in this sector.

[322] https://www.fao.org/4/X6510E/X6510E03.html
[323] https://www.adb.org/sites/default/files/publication/784421/solid-waste-management-pakistan-road-map.pdf

ii. Socio-Economic Feasibility

Livestock feeding practices offer economic and technical feasibility in Pakistan, with **locally produced** feed **commonly used in practice**. Animal feed is locally produced and commonly used in practice in Pakistan,[324]but access to financing for implementing new feeding technologies is limited in Pakistan, especially for small-scale farmers.[325] Low costs when coupled with limited access to financing and a lack of subsidies or tax breaks, present barriers to adoption, particularly for small-scale farmers. Some advanced feeding techniques **are not readily available or manufactured** domestically, requiring imports.[326] Further, the **knowledge and skills required** to implement **advanced feeding techniques** are **limited among small-scale** farmers.[327] Training programs for these techniques are insufficient or inaccessible in rural areas, and they need to be focused upon more.[328] All of these challenges need to be addressed to improve the technical and economic feasibility of the technology for Pakistan.

For economic insights, the "**Report on the Cost-Benefit Analysis for Integrating New Forage Technologies in Cattle Production Systems in Kenya and Ethiopia**[329]" compares traditional feeding practices (FP) with improved scenarios (IN) incorporating new forage technologies. The FP scenario relies on local feed resources and crop residues, while the IN scenario includes improved grasses like Brachiaria hybrid cv. Mulato II.

In Ethiopia, the traditional feeding practices, which utilize local resources like backyard grazing and crop residues, yield a daily milk production of **4.75**[330] liters per animal unit. Over the course of a year, this amounts to **724** liters per animal unit[335], with total farm milk production reaching 1,449 liters. The total gross income generated from these practices is **USD 1,024**[335] annually, with **USD 899**[335] coming from milk sales and **USD 86**[335] from weaned calf sales. The total variable cost is **USD 1,118**[335], leading to a net profit of **USD 94.23**[335] per farm per year. The unit cost of milk production stands at USD 0.68 per liter, while the sales price is **USD 0.59**[335] per liter, resulting in a net revenue of **USD 0.09** per liter. The Net Present Value (NPV) for this scenario is **USD 2,066**[335], with an Internal Rate of Return (IRR) of **-17.9%**[335].

In contrast, the improved forage technologies scenario in Ethiopia, which incorporates advanced grasses like Brachiaria hybrid cv. Mulato II, shows increased productivity. Daily milk production rises to **5.28 liters[335]** per animal unit, totaling **1,159[335]** liters annually, with farm-level milk production reaching 2,319 liters. Gross income increases to **USD 1,598[335]**, with milk sales contributing **USD 1,439[335]** and weaned calf sales adding **USD 121[335]**. The total variable cost slightly decreases to USD 1,061, leading to a substantial net profit of **USD 537.32[335]** per farm per year. The unit cost of production drops to USD 0.41 per liter, while the sales price remains at **USD 0.59[335]** per liter, giving a net revenue of **USD 0.18[335]** per liter. The NPV is **USD 1,586[335]**, and the IRR is **26%[335]**, reflecting a more favorable economic outcome.

[324] https://www.dcceew.gov.au/climate-change/emissions-reduction/agricultural-land-sectors/livestock
[325] https://www.mdpi.com/2077-0472/10/12/586
[326] https://openknowledge.fao.org/
[327] https://www.ncbi.nlm.nih.gov/pmc/articles/PMC9819478/
[328] https://www.researchgate.net/publication/260382594_Barriers_to_Training_and_Skills_Development_in_Rural_Areas_Learning_Theme_Executive_Summary
[329] Report on the Cost-Benefit Analysis for Integrating New Forage Technologies in Cattle Production Systems in Kenya and Ethiopia
[330] Ibid.
[335] https://www.researchgate.net/publication/374433555_Impact_of_Cultural_Norms_and_Social_Expectations_for_Shaping_Gender_Disparities_in_Educational_Attainment_in_Pakistan

In Kenya, the traditional feeding practices scenario results in a daily milk production of **7.40[335]** liters per animal unit, summing up to **1,129[335]** liters annually and a total farm production of **2,257[335]** liters. This generates a gross income of **USD 762[335]**, with milk sales contributing **USD 730[335]** and weaned calf sales **USD 320[335]**. Variable costs are USD 1,058[335], leading to a net profit of USD 295.50[335] per farm per year. The unit cost of production is **USD 0.45** per liter, while the sales price is USD 0.32[335] per liter, resulting in a net revenue of **USD 0.13 per[335]** liter. The NPV is **USD 2,044[335]**, but the IRR is indeterminate.

For the improved forage technologies scenario in Kenya, daily milk production increases to **8.10[335]** liters per animal unit, totaling **1,643[335]** liters annually, with farm-level production reaching 3,286 liters. Gross income rises to USD 1,095, with milk sales providing **USD 1,063[335]** and weaned calf sales remaining at USD 32. Variable costs are comparable to the traditional practices at **USD 1,059[335]**, yielding a lower net profit of **USD 36.01[335]** per farm per year. The unit cost of production drops to **USD 0.31[335]** per liter, while the sales price is **USD 0.32[335]** per liter, resulting in a marginal net revenue of **USD 0.01[335]** per liter. The NPV is **USD 226[335]**, and the IRR is 5%[335], reflecting less favorable economic results compared to the FP scenario.

In summary, the improved forage technologies generally offer increased milk production and reduced production costs in Ethiopia but show varied results in Kenya, where the traditional practices scenario provides higher net profits and better NPV. These findings emphasize the importance of adapting feeding technologies to local conditions to optimize economic returns.

The overall cost-benefit analysis of livestock feeding indicates that it significantly reduces methane emissions by 80% and turns agricultural residues into valuable animal feed. It involves a moderate capital investment with a high production capacity. The process is economically viable, with a small profit margin per kilogram of feed, highlighting its efficiency and profitability in agriculture waste management as shown in table 25.

Emissions Reduction/ Resource Conservation	Other Benefits/ Cost Savings	Capital Cost/ Total Investment	Operational cost	Social Benefits
80% methane reduction[331]	The selling cost of feed is PKR 136/kg, and this leads to a profit of PKR 2.5 per Kg	From the study: Improved forage technologies scenario in Kenya NPV: USD 226 IRR is 5%	The unit cost of production drops to USD 0.31 per liter	Improved feed conversion reduces the amount of food needed for livestock, cutting greenhouse gas emissions from both feed crop production and livestock digestion.

Table 25. Socio-economic benefits of Livestock Feeding in Pakistan

[335] https://www.researchgate.net/publication/374433555_Impact_of_Cultural_Norms_and_Social_Expectations_for_Shaping_Gender_Disparities_in_Educational_Attainment_in_Pakistan

iii. Inclusive Development and Climate Impacts

Livestock feeding practices present opportunities for inclusive development and climate mitigation in Pakistan. The livestock sector, which currently employs **approximately 30 million individuals**, including a significant proportion of women, can facilitate employment for the local community. Some feed supplements have been shown to reduce **methane emissions by up to 80%,**, contributing to climate change mitigation efforts. Improved feeding practices can lead to **increased livestock productivity, potentially improving livelihoods in rural communities.**[332] The livestock sector can facilitate employment for the local community, which is currently of the size of **30 million employees, including a major proportion of women.**[333]Further, collaboration with international organizations and research institutions can enhance social equality by facilitating the development and adaptation of cost-effective waste-reduction technologies. However, challenges such as a **lack of political will, economic instability, and cultural norms limiting access** to training and resources must be addressed to ensure inclusive development and climate resilience in the livestock sector.[334][335]

SWOT Analysis (Summary)

Improved livestock feeding practices offer significant benefits, such as reducing methane emissions by up to 80% and enhancing animal health and productivity (Table 26). These practices also promote water conservation and can support the livelihoods of the large workforce engaged in livestock farming, including women. Despite challenges like high costs, limited access to financing, and insufficient training programs, the technology has potential benefits for climate resilience and economic development in rural Pakistan. With supportive policies and targeted financial schemes, these technologies can contribute to sustainable agriculture and improved quality of life.

Strengths	Weaknesses
S1. Some feed supplements that work by inhibiting the animal's digestive system can reduce **methane emissions by up to 80%.**[336] **S2**. Animal feed is **locally produced** and **commonly used in practice in Pakistan.**[337] **S3. Improved feeding practices** can lead to healthier livestock, enhancing resilience to climate change.[338]	W1. Access to financing for implementing new feeding technologies is limited in Pakistan, especially for small-scale farmers.[342] W2. There are **no or limited subsidies or tax breaks** available for waste-reducing feeding technologies in Pakistan.[343] W3. Some advanced feeding techniques **are not readily available or manufactured** domestically, requiring imports.[344]

[332] https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7553850/
[333] https://www.sciencedirect.com/science/article/pii/S2214317316301123
[334] https://library.fes.de/pdf-files/bueros/sarajevo/12465.pdf
[335] https://www.researchgate.net/publication/374433555_Impact_of_Cultural_Norms_and_Social_Expectations_for_Shaping_Gender_Disparities_in_Educational_Attainment_in_Pakistan
[336] https://www.dcceew.gov.au/climate-change/emissions-reduction/agricultural-land-sectors/livestock#:~:text=Research%20has%20shown%20some%20feed,in%20the%20animals'%20digestive%20systems.
[337] https://www.dcceew.gov.au/climate-change/emissions-reduction/agricultural-land-sectors/livestock
[338] https://www.dcceew.gov.au/climate-change/emissions-reduction/agricultural-land-sectors/livestock#:~:text=Research%20has%20shown%20some%20feed,in%20the%20animals'%20digestive%20systems.
[342] https://www.mdpi.com/2077-0472/10/12/586
[343] https://www.adb.org/sites/default/files/publication/784421/solid-waste-management-pakistan-road-map.pdf
[344] https://openknowledge.fao.org/

Strengths	Weaknesses
S4. Using efficient fixtures can promote water conservation by reducing the amount of water used in feed preparation.[339]	W4. The **knowledge and skills required** to implement **advanced feeding techniques** are **limited among small-scale farmers**.[345]
S5. The livestock sector can facilitate employment for the local community, which is currently of the size of **30 million employees, including a major proportion of women**.[340]	**W5.** Training programs for these techniques are insufficient or inaccessible in rural areas, and they need to be focused upon more.[346]
S6. Improved feeding practices can lead to increased livestock productivity, potentially improving livelihoods in rural communities.[341]	**W6.** There is **no nationwide policy/guideline/ regulation** for livestock feeding in Pakistan.
	W7. The capital cost comes up to be USD 5000 (~ **PKR 1.39M**) [MA1] [MOU2] with a production capacity of 3 tons per hour, which is a bit costly.

Opportunities	Threats
O1. The government can develop and implement clear policies and regulations **promoting waste reduction** in livestock feeding practices.	T1. A **lack of political will** or competing priorities can hinder the development of supportive policies and regulations.
O2. **Collaboration** between financial institutions and agricultural development agencies could create targeted financing schemes for waste-reducing technologies.	T2. **Economic instability** or market fluctuations can make financing for new technologies even more challenging.
O3. **Government incentives** like subsidies or tax breaks can encourage investment in these technologies.	T3. The **availability and affordability** of essential resources like energy and water can impact the feasibility of some techniques.
O4. By **promoting gender-inclusive training** and resource allocation, these techniques can further enhance social equality.	T4. **Rapid technological advancements** might render existing equipment obsolete, requiring continuous investment.
O5. The **KPK province has a Livestock Policy 2018**, which mentions Livestock feeding as a good source of nutrition for animals. Following KPK, other provinces can develop their own livestock policies.[347]	T5. Cultural norms or **social inequalities** limit women’s and minorities' access to training and resources.
	T6. A **lack of awareness** about the benefits of these techniques might hinder their adoption by some communities.

Table 26: SWOT Analysis of Advanced Agro-Residue Livestock feeding in Pakistan

[339] https://www.sciencedirect.com/science/article/pii/S1751731117000416
[340] https://www.sciencedirect.com/science/article/pii/S2214317316301123
[341] https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7553850/
[345] https://www.ncbi.nlm.nih.gov/pmc/articles/PMC9819478/
[346] https://www.researchgate.net/publication/260382594_Barriers_to_Training_and_Skills_Development_in_Rural_Areas_Learning_Theme_Executive_Summary
[347] https://faolex.fao.org/docs/pdf/pak191270.pdf

5.5.2 Vermicompost

Vermi Compost Technology utilizes earthworms to convert organic waste (agricultural residues, food scraps) into nutrient-rich vermicompost, a valuable soil amendment. Earthworms efficiently convert organic waste into nutrient-rich vermicompost, a valuable soil amendment that **improves soil fertility and water retention**.[348]

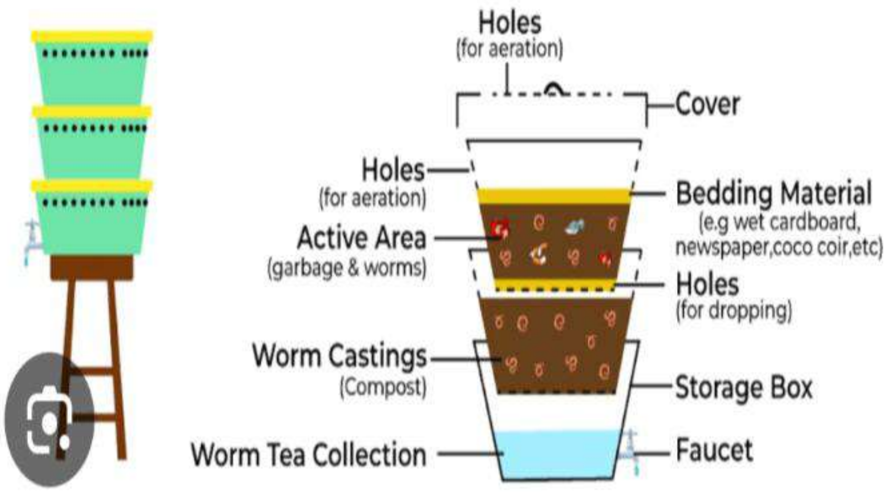

Figure 13. Overview of the components of Vermi Compost Technology

i. Legal, Regulatory, and Economic Landscape

Vermicomposting practices in Pakistan currently operate **without a nationwide policy or regulatory framework**, leading to a lack of awareness and recognition of vermicomposting as a viable waste management technique. **Limited access to financing and credit facilities** further hinders the establishment of larger-scale vermicomposting operations, making **barriers to private investment**. Additionally, the absence of a structured policy or guideline for vermicompost contributes to the challenges faced in this sector.

[348] https://www.researchgate.net/publication/26513646_Vermicomposting_recycling_wastes_into_valuable_organic_fertilizer#:~:text=Vermicomposting%20is%20a%20process%20of,a%20natural%20fertilizer%20for%20plants.

ii. Socio-Economic Feasibility

Vermicomposting offers economic and technical feasibility in Pakistan, with its ability to efficiently convert organic waste into nutrient-rich vermicompost. Earthworms efficiently convert organic waste into nutrient-rich vermicompost, a valuable soil amendment that **improves soil fertility and water retention.**[349] Vermicomposting **requires minimal space and infrastructure**, making it suitable for **small-scale** implementation in homes and farms.[350] However, vermicomposting faces challenges such as, it has a **slower processing** time compared to some industrial composting methods, limiting large-scale organic waste treatment capacity. Further, **maintaining optimal temperature** and moisture conditions within the vermicomposting bin requires some **knowledge** and **management skills**, which are **lacking in Pakistan**. The availability of a consistent supply of organic waste materials is crucial for vermicomposting operations, and **competition from alternative waste disposal methods limits access**. Addressing these challenges is crucial, and integrating vermicomposting with existing waste management systems can **optimize organic waste processing and resource recovery**.
Vermicomposting in Pakistan has shown promise through various studies and initiatives, although comprehensive economic analyses are limited. To understand the economic viability of vermicomposting more comprehensively, we can look at research from neighboring countries, India and Nepal.

In India, a study[351] conducted at the College of Agriculture, Rajendranagar, evaluated the economic feasibility of vermicomposting. The research, carried out at a unit established in 2019, considered various costs including fixed costs (interest on fixed capital and depreciation) and variable costs (organic wastes, electricity, labor, maintenance, nutrient testing, and interest on working capital). The vermicomposting process, using the anaerobic open pit method, took **60 to 75** days[352]. The study found that vermicompost production was economically viable, with benefit-cost ratios (BCR) ranging from **1.4 to 2.54**[353] depending on pricing. Higher market prices significantly increased profitability, demonstrating strong commercial potential for vermicomposting operations.

In Nepal, a similar assessment focused on small-scale farmers in Banke[354]. This study showed that vermicomposting is financially advantageous, with a positive Net Present Value (NPV) of Rs. 313,370[355] and a quick payback period of **1.2**[356] years. The benefit-cost ratio was **1.71**[357], indicating that Rs. **1.71**[358] is earned for every **Rs. 1 spent**[359]. This suggests that vermicomposting is a high-return enterprise for small farmers, offering benefits such as enhanced soil quality, reduced dependence on chemical inputs, and substantial income generation.

[349] https://www.researchgate.net/publication/26513646_Vermicomposting_recycling_wastes_into_valuable_organic_fertilizer#:~:text=Vermicomposting%20is%20a%20process%20of,a%20natural%20fertilizer%20for%20plants.

[350] https://www.sciencedirect.com/science/article/pii/S0956053X15000926

[351] https://www.researchtrend.net/bfij/pdf/The-Budgetary-Analysis-of-Vermicompost-Production-in-College-Farm,-College-of-Agriculture,-Rajendranagar,-PJTSAU-Shreedevi-Jinnur-108.pdf

[352] https://www.researchtrend.net/bfij/pdf/The-Budgetary-Analysis-of-Vermicompost-Production-in-College-Farm,-College-of-Agriculture,-Rajendranagar,-PJTSAU-Shreedevi-Jinnur-108.pdf

[353] https://www.researchtrend.net/bfij/pdf/The-Budgetary-Analysis-of-Vermicompost-Production-in-College-Farm,-College-of-Agriculture,-Rajendranagar,-PJTSAU-Shreedevi-Jinnur-108.pdf

[354-359] file://winfs-uni.top.gwdg.de/hamber$/Downloads/Vermicomposting%20Article.pdf

Overall, vermicomposting emerges as an economically viable and environmentally sustainable practice. It transforms organic waste into valuable agricultural inputs, supports a circular economy, reduces landfill waste, and minimizes greenhouse gas emissions. Additionally, it decreases reliance on chemical fertilizers, enhances soil health, and fosters local employment. The low investment and operational costs, combined with its adaptability from household to industrial scales, make vermicomposting a promising approach for sustainable development and improved waste management in Pakistan.

The cost-benefit analysis of vermicompost technology indicates that it is effective in reducing NOx emissions by 40%. It has a significant capital investment with a high production capacity and is highly profitable, with annual revenue significantly exceeding production costs. The operational cost is reasonable, contributing to its economic viability and efficiency in waste management as shown in the table 27.

Emissions Reduction/ Resource Conservation	Other Benefits/ Cost Savings	Capital Cost/ Total Investment	Operational cost	Social Benefits
NOx emissions by up to 40%	According to a study, the total cost of vermicompost production for a facility was INR 725,805/yr (~ **PKR 24M**) The revenue generated was INR 1,674,000 (~ **PKR 55M**)	Based on study: Assessment focused on small-scale farmers in Banke, Nepal NPV: Rs. 313,370 Payback Period:1.2 years, BCR: 1.71 Cost online: USD 6,108, 6000m3/15 days (~ PKR 1.69M) [MA1] [MOU2] [MA1]USD 6,108 = **PKR 1.69M** [MOU2]Made the change	PKR 125/kg, PKR 630,000/acre	Provides income opportunities and supports a more sustainable waste disposal system by promoting organic waste management.

Table 27. Socio-economic benefits of Vermicomposting in Pakistan

iii. Inclusive Development and Climate Impacts

Vermicomposting presents opportunities for inclusive development and climate mitigation in Pakistan. Vermicomposting **reduces dependence on chemical fertilizers** and can **remove NOx emissions by up to 40% from the BAU scenario**. Pakistan's hot and dry climate in some regions can be **challenging to maintain** optimal temperature and moisture conditions for vermicomposting. Vermicomposting is a source of income generation for individuals and communities, **particularly women**, who can manage small-scale vermicomposting units[360], and contributes to a more sustainable waste disposal system by promoting organic waste management. Collaboration with microfinance institutions, NGOs, and research institutions can facilitate the establishment of small-scale vermicomposting businesses and lead to the development of low-cost and efficient vermicomposting systems. However, challenges such as market price fluctuations, limited organic waste supply, and climatic factors must be addressed to ensure the widespread adoption and success of vermicomposting initiatives.

SWOT Analysis (Summary)

Vermicomposting is valuable for converting organic waste into nutrient-rich compost, improving soil fertility, and reducing reliance on chemical fertilizers. It's well-suited for small-scale operations, creating income opportunities, particularly for women, and fostering sustainable waste management. Despite challenges like high costs, lack of awareness, and limited infrastructure, vermicomposting offers significant environmental and economic benefits (Table 28). With enhanced public awareness and financial support, it can play a crucial role in sustainable agriculture and waste management in Pakistan.

Strengths	Weaknesses
S1. Earthworms efficiently convert organic waste into nutrient-rich vermicompost, a valuable soil amendment that **improves soil fertility and water retention**.[361] **S2**. Vermicomposting **requires minimal space and infrastructure**, making it suitable for **small-scale** implementation in homes and farms.[362] **S3**. Vermicomposting **reduces dependence on chemical fertilizers** and can **remove NOx emissions by up to 40% from the BAU scenario**.	**W1**. There is a **lack of awareness** and recognition of vermicomposting as a viable waste management technique in Pakistan. **W2**. **Limited access to financing and credit facilities** hinders the establishment of larger-scale vermicomposting operations. **W3**. Vermicomposting has a **slower processing** time compared to some industrial composting methods, limiting large-scale organic waste treatment capacity.

[360] https://www.researchgate.net/publication/372717192_VERMICOMPOSTING_A_BOON_OF_INCOME_GENERATION_FORHILLY_REGION

[361] https://www.researchgate.net/publication/26513646_Vermicomposting_recycling_wastes_into_valuable_organic_fertilizer#:~:text=Vermicomposting%20is%20a%20process%20of,a%20natural%20fertilizer%20for%20plants.

[362] https://www.sciencedirect.com/science/article/pii/S0956053X15000926

Strengths	Weaknesses
S4. Vermicomposting is a source of income generation for individuals and communities, **particularly women**, who can manage small-scale vermicomposting units.[363] **S5**. By **promoting organic waste management** and reducing reliance on landfills, vermicomposting contributes to a more sustainable and environmentally friendly waste disposal system.	**W4**. **Maintaining optimal temperature** and moisture conditions within the vermicomposting bin requires some **knowledge** and **management skills**, which are **lacking in Pakistan**. **W5**. Vermicompost is very costly and usually costs around **PKR. 125/kg and is calculated to be PKR. 630,000/acre in Pakistan (Planta Store)**. **W6**. There is **no nationwide policy/guideline/ regulation** for vermicompost. **W7**. The capital cost is USD 6,108[364] (~ **PKR 1.69M**) with a Production capacity of 6000m³/15 days, which makes it a bit costly.

Opportunities	Threats
O1. Microfinance institutions and NGOs can develop **targeted loan schemes** and training programs to facilitate the establishment of small-scale vermicomposting businesses. **O2**. Collaboration with research institutions and vermicomposting experts can lead to the **development of low-cost** and efficient vermicomposting systems. **O3**. Integrating vermicomposting with existing waste management systems can **optimize organic waste processing and resource recovery**. **O4**. Educational programs and extension services can **provide training on proper vermicomposting techniques** and management practices. **O5**. Public awareness campaigns and community workshops can **promote the benefits of vermicomposting** and encourage wider adoption. **O6**. Establishing **market linkages between vermicompost producers and potential buyers**, like organic farmers and urban gardeners, can enhance economic benefits for local communities.	**T1**. Fluctuations in market prices of conventional fertilizers could **affect the economic competitiveness** of vermicompost. **T2**. The availability of a consistent supply of organic waste materials is crucial for vermicomposting operations, and **competition from alternative waste disposal methods limits access**. **T3**. Pakistan's hot and dry climate in some regions can be **challenging to maintain** optimal temperature and moisture conditions for vermicomposting. **T4**. **Limited access to land** or space for setting up vermicomposting units might be a challenge, particularly in urban areas. **T5**. The **market for vermicompost** as a soil amendment in Pakistan is limited, especially because awareness of its benefits among farmers is low.

Table 28: SWOT Analysis of Vermicomposting in Pakistan

[363] https://www.researchgate.net/publication/372717192_VERMICOMPOSTING_A_BOON_OF_INCOME_GENERATION_FORHILLY_REGION
[363] Factory Price Automatic Vermicompost Composting Machine - Buy Humic Acid Organic Fertilizer Compost Double Screws Turning Machine,Industrial Poultry Organic Fertilizer Compost Product Turning Making Machine Waste Price,Cow Manure Compost Turner Machine For Bio Organic Fertilizer Turning Mixing Organic Compost Product on Alibaba.com

5.5.3 Integrated Biomass Gasification (IBG) / pyrolysis for syngas and biochar (Emerging)

Integrated Biomass Gasification / pyrolysis is a complex thermochemical process that converts biomass into syngas (combustible gas) and biochar through gasification. The syngas is then used in a fuel cell to generate electricity. Biochar is used to improve soil health and in agriculture and as an industrial fuel.

Figure 14. Schematic representation of the biomass pyrolysis process

i. Legal, Regulatory, and Economic Landscape

Integrated Biomass Gasification (IBG) technology faces challenges in Pakistan **due to the lack of clear regulations and standards governing its implementation and the use of syngas**. However, there exists a proposed **policy on biomass energy technology submitted to UNIDO**, which requires advisory services from UNIDO on making the policy for biomass energy. Limited access to financing, especially for smaller projects, further impedes the establishment of IBG plants. Additionally, the absence of a robust monitoring and evaluation (M&E) framework hinders project development and improvement. Moreover, **Access to financing** for establishing IBG plants, especially for smaller projects **is limited** in Pakistan, which is a barrier to private sector investment for this technology.

ii. Socio-Economic Feasibility

IBG technology offers economic and technical feasibility by converting various types of biomass waste into usable syngas, a clean-burning fuel source. The **technical expertise required** for operating and maintaining IBG plants is limited in Pakistan, which poses challenges to its widespread adoption. **Skills development programs** can address the need for trained personnel to operate IBG plants.

To delve into the economic viability of this technology two recent studies provide insights into the economic feasibility of biomass gasification in Pakistan. The first study, titled "**Techno-Economic Modeling of Biomass Gasification Plants for Small Industries in Pakistan**[365]" examines the feasibility of biomass gasification for small and medium enterprises (SMEs).

[465] Techno-Economic modeling of biomass gasification plants for small industries in Pakistan

The study assesses technical viability, performs an economic analysis to determine cost-effectiveness, and addresses the country's energy crisis by proposing sustainable solutions for SMEs. It includes analysis of technical aspects, detailed economic studies, and case studies from selected SMEs, using simulation tools to model the gasification process.

For a 100-kW[366] plant using corn stover with a 20 km sourcing radius, **35%[378]** plant efficiency, and 66%[378] capacity utilization, the total investment is estimated at USD 56,882[378], yielding an Internal Rate of Return (IRR) of **35.2%**[378]. Sensitivity analysis shows the system remains viable with a sourcing radius of up to **27 km**, plant efficiency of **27.5%**[378], and capacity utilization of **55.6%**[378]. Corn stover provides the highest savings per kWh, whereas wheat straw offers the lowest savings. The average cost of electricity production for biomass gasification is **USD 0.12**/kWh[378] with fuel sourced within a 20 km radius, dropping to **USD 0.07**/kWh[378] when sourced on-site. Biomass gasification proves more cost-effective than biogas, solar-diesel hybrids, and solar-biomass hybrids, though it is slightly more expensive than solar photovoltaics when using external biomass. The technology demonstrates advantages in both capital and operational expenditures, suggesting its viability for small industries with local biomass resources.

The second study, "**Thermo-Economic Analysis of Integrated Gasification Combined Cycle Co-Generation System with Carbon Capture and Integrated with Absorption Refrigeration System**[367]" evaluates an advanced Integrated Gasification Combined Cycle (IGCC) system. The IGCC system, which co-fires various coal qualities with biomass and integrates carbon capture, aims to address greenhouse gas emissions from coal-based power in Pakistan. The study simulates different IGCC configurations, including designs for 100%[378] power generation with and without carbon capture, and co-generation systems producing electricity, methane, and ammonia, along with integration of an Absorption Refrigeration System (ARS) to reduce CO_2 emissions.

The study finds that using low-quality coal in an IGCC system achieves **32.33%**[378] electricity generation efficiency while capturing 92%[378] of carbon emissions. An IGCC plant producing electricity, methane, and ammonia reduces CO_2 emissions by about **25%**[378] compared to an electricity-only plant while maintaining similar profitability. Incorporating an ARS slightly improves efficiency to **32.61%**[378] and reduces CO_2 emissions by approximately **13,000** tons[378] annually. Despite these advancements, the high electricity cost of **USD 155.9**/MWh underscores the need for further economic optimization. The study concludes that producing multiple products from low-quality coal can enhance emission reductions while remaining economically viable, though further research is required to refine these findings.

Overall Integrated Biomass Gasification Fuel Cell technology provides a moderate reduction in carbon emissions and efficiently converts biomass into electricity through gasification and fuel cells. The byproduct of this process – which is biochar, also has promising applications and value. It has a relatively low production cost for electricity compared to diesel, with a substantial initial capital investment and a notable monthly operational cost (Table 29). This technology offers a cost-effective and environmentally friendly energy solution.

[366] Ibid.

[367] Thermo-economic analysis of integrated gasification combined cycle co-generation system with carbon capture and integrated with absorption refrigeration system

In addition to gasification, pyrolysis systems have also been employed in Pakistan on a pilot scale. These small-scale initiatives have been employed with a primary focus of producing biochar for use in agriculture and as fuel. However, large scale pyrolysis applications have not yet been implemented in Pakistan and they have similar benefits to the gasification systems discussed above.

Emissions Reduction/ Resource Conservation	Other Benefits/ Cost Savings	Capital Cost/ Total Investment	Operational cost	Social Benefits
14.7% reduction in carbon emissions	The production cost of electricity through gasification is 0.09-0.16 USD/ kWh, which is lower than that of diesel-fueled engine	Based on the study: Techno-Economic Modeling of Biomass Gasification Plants for Small Industries in Pakistan For 100 kW plant using corner stove with 20 km sourcing radius Cost: USD 56,882 Viable upto 27 km IRR: 35.2%	USD 8580 for 60 kW power generation (PKR 2.3M/month)	Reduces GHG emissions, enhances waste management and sustainability, improves air quality by lowering SOx and NOx pollutants, and decreases exposure to emissions from waste disposal

Table 29: Socio-economic benefits of Integrated Biomass Gasification Fuel Cell technology in Pakistan

iii. Inclusive Development and Climate Impacts

IBG technology presents opportunities for inclusive development and climate mitigation in Pakistan. By utilizing waste materials, Integrated Biomass gasification power generation technology has a **14.7% reduction in whole-life carbon emissions** compared to **coal power generation technology**. The **transportation of biomass feedstock** can have environmental implications if not managed properly. IBG plants in rural areas **create local jobs and economic opportunities**, including for women, and **improve living standards and access to electricity in remote areas**.[368] Collaboration with international companies and research institutions can promote technology transfer and cost reduction, while sustainable biomass sourcing practices can minimize the environmental impacts associated with feedstock transportation. However, threats such as unstable economic conditions, fluctuations in fuel prices, and competition from alternative renewable energy technologies must be addressed to ensure the successful implementation of IBG projects.

[368] www.researchgate.net/publication/222680825_Identifying_a_role_for_biomass_gasification_in_rural_electrification_in_developing_countries_The_economic_perspective

SWOT Analysis (Summary)

IBG technology converts biomass waste into syngas and biochar, offering a cleaner alternative to fossil fuels and contributing to a circular economy. It can reduce carbon emissions, enhance energy security, and create local jobs, particularly in rural areas. Despite challenges such as high initial costs and limited technical expertise, IBG can improve energy access and environmental sustainability (Table 30). With supportive policies and financing, it has the potential to make a significant impact on waste management and energy production in Pakistan.

Strengths	Weaknesses
S1. Integrated Biomass Gasification (IBG) can convert various types of biomass waste into usable syngas, a **clean-burning fuel source**. **S2**. This technology has the potential to **reduce reliance on fossil fuels and enhance energy security**. **S3**. Integrated Biomass gasification power generation technology has a **14.7% reduction in whole-life carbon emissions** compared to **coal power generation technology**. **S3**. By utilizing waste materials, IBG can contribute to a **more circular economy** and waste management. **S4**. Integrated Biomass Gasification (IBG) plants can be established in rural areas, creating **local jobs and economic opportunities** for local communities, including **women**. **S5**. By providing a clean and reliable energy source, Integrated Biomass Gasification (IBG) can **improve living standards** and **access to electricity in remote areas**. **S6**. There exists a proposed **policy on biomass energy technology submitted to UNIDO**, which requires advisory services from UNIDO on making the policy for biomass energy.	**W1**. Clear regulations and standards for IBG technology and syngas use are lacking in Pakistan. **W2**. **Access to financing** for establishing IBG plants, especially for smaller projects is limited in Pakistan. **W3**. The **absence of a robust M&E framework** hinders project development and improvement. **W4**. The **initial set-up cost** of IBG plants is very high, **requiring significant investment**. **W5**. The **technical expertise required** for operating and maintaining IBG plants **is limited in Pakistan**. **W6**. The **transportation of biomass feedstock** can have **environmental implications** if not managed properly. **W7**. Biomass gasifiers cost around **PKR 5M** (~INR 1.5M) with a **capacity of 7.5 TPD**, making it very costly.

Opportunities	Threats
O1. **Public-private partnerships** and innovative financing models can facilitate investment in IBG projects.	**T1**. **Unstable economic conditions** or lack of government support can hinder investment in IBG technology.
O2. Establishing **M&E frameworks** can attract further investment by demonstrating the technology's effectiveness.	**T2**. **Fluctuations in the price of conventional fuels** might impact the economic viability of IBG-generated syngas.
O3. **Collaboration with international companies** and research institutions can promote technology transfer and cost reduction.	**T3**. The **availability and affordability of biomass** feedstock can significantly impact the operational costs of IBG plants.
O4. **Skills development programs** can address the need for trained personnel to operate IBG plants.	**T4**. **Rapid advancements in alternative renewable energy** technologies could pose future competition.
O5. By prioritizing community engagement and local participation, IBG projects can ensure **social benefits and minimize conflicts**.	**T5**. A **lack of awareness** about the benefits of IBG technology hinders its adoption by communities.
O6. **Sustainable biomass sourcing** practices can minimize environmental impacts associated with feedstock transportation.	**T6**. **Improper management** of IBG plant emissions could have negative environmental consequences.

Table 30: SWOT Analysis of Integrated Biomass Gasification in Pakistan

6. Conclusion

The stakeholder feedback on the scoring criteria for prioritizing waste management technologies is presented in Table 31,32,33 and 34. Stakeholders highlighted the importance of addressing regulatory and financial challenges, particularly in Balochistan and Gilgit-Baltistan. While there was broad approval of the criteria, concerns were raised about inconsistent regulatory frameworks and insufficient financial resources. Technologies like Livestock Feeding and Integrated Biomass Gasification were identified as more feasible due to better alignment with legal and economic conditions, while others, such as Downcycling and Waste Valorization, face significant challenges. The evaluation also underscored the importance of inclusive development and social impacts, with Composting and Non-Biodegradable Plastic Pyrolysis emerging as promising technologies for sustainability and climate action.

Based on the criteria and stakeholder feedback, the prioritized waste management technologies in Pakistan include both existing and emerging solutions. Based on the total scores from all three criteria's **Composting** ranks first, followed by **Waste Segregation**, RDF, and **Engineered Landfill Technology** among existing technologies. For emerging technologies, **Integrated Biomass Gasification** is prioritized as a leading option as shown in table 34. These selections reflect a balance between legal feasibility, economic viability, and potential for inclusive development, offering a strategic pathway for sustainable waste management in Pakistan.

Major Group	**Legal, Regulatory, and Financial Landscape**					
Group Score	**15**					
Criteria	Are there any clear guidelines or regulations for this technology?		Do existing financial structures exist to invest in this technology in Pakistan? (i.e. Existing bankable projects? PPP? Targeted financing facilities?)		Is there an opportunity for private sector investment in this technology?	
Scoring for each criterion	Individual score (scale of 1-5)		Individual score (scale of 1-5)		Individual score (scale of 1-5)	
Criteria Weightage	5%		5%		5%	
Technologies	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score
Municipal Solid Waste						
Composting	**4**		**4**		**4**	
Remarks	Existing guidelines in the Draft Solid Waste Management Guidelines 2005 and potential for private sector investment					
Engineered Landfill Technology	**5**		**4**		**4**	
Remarks	Guidelines exist in the National Hazardous Waste Policy and ADB reform roadmap for Pakistan, and potential for private sector investment as seen from the Lakhodair Facility					
Waste Segregation	**5**		**2**		**2**	
Remarks	Guidelines exist in the Draft SWM guidelines 2005, but low potential for private investment					
Waste Valorization (e)	**1**		**3**		**3**	
Remarks	No guidelines or regulation and moderate potential for private sector investment					
Plastic Waste						
Refuse Derived Fuel	**3**		**4**		**4**	

Remarks	Clear guidelines exist for the production and use of RDF by MSW in the cement sector but no focus of Plastic feed only, being implemented by private sector already in various cities of Pakistan but with MSW plant					
Downcycling	**1**		**3**		**4**	
Remarks	No guidelines or regulations but good potential for private sector investment as seen from the previous initiatives (Levi's)					
Non-biodegradable Plastic Pyrolysis (e)	**2**		**1**		**3**	
Remarks	Regulations have been implemented in Pakistan but on tyre pyrolysis plants, and moderate potential for private investment					
Agriculture Waste						
Livestock Feeding	**1**		**2**		**1**	
Remarks	No existing guidelines or regulations, lack of bankable projects, and low potential for private investment					
Vermicomposting	**1**		**2**		**3**	
Remarks	No existing guidelines, and low projects exist, moderate potential for private investment					
Integrated Biomass Gasification	**3**		**1**		**4**	
Remarks	Proposal for Biomass Gasification policy has been submitted to UNIDO, no bankable projects, but good potential for private investment					

Table 31: Evaluation of scoring criteria based on legal, regulatory and financial landscape of Pakistan

Major Group	Economic and Technical Feasibility											
Group Score	30											
Criteria	Does this technology efficiently minimize the use of energy and other resources?		Does this technology promote efficiency in the management and delivery of the waste sector?		Is this technology affordable?		Is this technology successfully in use in Pakistan? or there is a potential for a pilot?		Do the skills to implement and operate this technology exist in Pakistan?		Does Pakistan have the capacity to inculcate skills training for this technology through its research and technology institutions?	
Scoring for each criterion	Individual score (scale of 1-5)		Individual score (scale of 1-5)		Individual score (scale of 1-5)		Individual score (scale of 1-5)		Individual score (scale of 1-5)		Individual score (scale of 1-5)	
Criteria Weightage	5%		5%		5%		5%		5%		5%	
Technologies	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score
Municipal Solid Waste												
Composting	4		3		4		4		4		5	
Remarks	Existing projects, training programs, and initiatives prove the technical feasibility and ability to scale up, and the low capital cost also shows its economic feasibility											
Engineered Landfill Technology	4		3		3		2		3		3	
Remarks	Not successfully used in Pakistan, only one site (incomplete), low-skill availability											
Waste Segregation	5		4		3		2		3		4	
Remarks	Efficiently minimizes use of other resources, segregation is being done but not with conveyor belts, the skills are present, and training can be done for advanced segregation methods											

Waste Valorization (e)	**3**		**3**		**2**		**4**		**1**		**4**	
Remarks	Minimizes the use of other resources, research suggest it cuts-down the waste management cost, and there is potential for a pilot as the food waste in Pakistan is a lot, the skills are not available but can be made available through training and awareness											
Plastic waste												
Refuse Derived Fuel	**4**		**3**		**3**		**3**		**4**		**4**	
Remarks	Efficiently minimizes the use of other fuel sources in the cement sector, it is being done for MSW but not for Plastic Waste, and the Skills are available											
Downcycling	**2**		**4**		**4**		**3**		**4**		**4**	
Remarks	Minimizes other resource use, promotes efficiency, and is currently being done by the informal sector which makes the skills available											
Non-biodegradable Plastic Pyrolysis (e)	**4**		**3**		**3**		**3**		**2**		**4**	
Remarks	Minimizes other resource use, lack of skills, but potential for training as tyre pyrolysis is common practice											
Agriculture waste												
Livestock Feeding	**4**		**3**		**3**		**5**		**5**		**4**	
Remarks	Minimizes use of external feed or nutrients for livestock, Skills available											
Vermicomposting	**4**		**3**		**3**		**5**		**4**		**4**	
Remarks	Minimizes use of external fertilizers, implemented in Pakistan, and skills are available											
Integrated Biomass Gasification	**4**		**3**		**3**		**4**		**2**		**3**	
Remarks	Minimizes use of other resources for energy generation, promotes efficiency in the management of biomass waste, skills are not present but can be attained through training											

Table 32: Evaluation of scoring criteria based on Economic and Technical Feasibility of Pakistan

Major Group	Inclusive Development and Climate Impacts											
Group Score	30											
Criteria	Does this technology possess emission reduction potential?		Does this technology contribute to building resilience and adaptive capacity in Pakistan?		Does this technology enhance the quality of life in target communities?		Does this technology contribute to inclusive development and just transition?		Does this technology have any negative/positive impacts on women and/or minorities or youth and children?		Does this technology address gender specific needs and promote social equality?	
Scoring for each criterion	Individual score (scale of 1-5)		Individual score (scale of 1-5)		Individual score (scale of 1-5)		Individual score (scale of 1-5)		Individual score (scale of 1-5)		Individual score (scale of 1-5)	
Criteria Weightage	5%		5%		5%		5%		5%		5%	
Technologies	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score
Municipal Solid Waste												
Composting	**4**		**3**		**2**		**3**		**3**		**3**	
Remarks	Good emissions reduction potential but bad public perception due to bad odor, and does not address gender-specific needs											

Engineered Landfill Technology	**4**		**3**		**2**		**3**		**1**		**2**	
Remarks	Good emissions reduction potential but badly impacts the surrounding communities devaluing the property nearby and producing a bad odor. Does contribute to Just transition but not significantly											
Waste Segregation	**5**		**4**		**4**		**3**		**3**		**3**	
Remarks	Good reduction potential and leads to building adaptive capacity, while also enhancing the lives of the community. Informal sector involves a lot of women and progress leads to more employment for women.											
Waste Valorization (e)	**3**		**3**		**4**		**5**		**4**		**4**	
Remarks	Moderate emissions reduction and water conservation potential, contributes to Just transition, and creates more job opportunities											
Plastic Waste												
Refuse Derived Fuel	**4**		**3**		**2**		**3**		**3**		**2**	
Remarks	Good emissions reduction potential, high energy recovery efficiency leading to just transition, does not address gender-specific needs											
Downcycling	**3**		**2**		**2**		**2**		**4**		**3**	
Remarks	NOx reductions only, does not cause much impact on targeted communities, creates job opportunities for women											
Non-biodegradabl e Plastic Pyrolysis (e)	**3**		**2**		**2**		**2**		**3**		**2**	
Remarks	Moderate emissions reduction, leads to just transition due to fuel production, impacts on gender not available											
Agriculture waste												
Livestock Feeding	**5**		**3**		**3**		**2**		**2**		**1**	
Remarks	Excellent emissions reduction, improves livelihoods due to livestock productivity, does not impact gender											
Vermicompo sting	**3**		**3**		**3**		**2**		**4**		**3**	
Remarks	Good emissions reduction potential, moderately builds adaptive capacity and moderately impacts gender sensitivity by providing business opportunity for women											

Table 32: Evaluation of scoring criteria based on Economic and Technical Feasibility of Pakistan

Waste Sub-Sector	Shortlisted Technology	Rank
Municipal Solid Waste	Composting (Existing)	1st
	Waste Segregation (Existing)	2nd
	Engineered Landfill Technology (Existing) with LFG capture	3rd
Agricultural Waste	Integrated Biomass Gasification including Biochar (Emerging)	1st
Plastic Waste	Refuse-derived Fuel (Existing)	1st

Table 34: Technology prioritization based on total score

7. WAY FORWARD

The technology prioritization we have created for Pakistan's waste management sector is a critical next step in addressing the growing waste crisis and its associated environmental and health challenges. Despite various policies and efforts at provincial and national levels, waste management remains fragmented, with informal systems and unsustainable practices dominating. This roadmap offers a structured pathway to overcome these challenges by prioritizing scalable, sustainable technologies like waste-to-energy, composting, and formalized recycling systems that can significantly improve efficiency and resource recovery.

Following this phase, a more detailed roadmap will be developed, focusing on the deployment and scaling of the prioritized technologies. This will be a concise version of the comprehensive document, tailored for stakeholders such as the Global Green Growth Institute (GGGI) to pitch these solutions to potential investors. The roadmap will include clear actions, define stakeholder roles—ranging from government agencies to local communities—and emphasize capacity building to ensure that local actors are well-equipped to adopt these technologies. Policy recommendations will also be provided to create an enabling environment that fosters technology transfer and innovation in both the water and waste sectors.

Sustainability and inclusivity are at the core of this roadmap, ensuring that technological advancements benefit all communities, especially vulnerable populations. The strategic guidance provided through this document will support the GGGI in securing investments and driving sustainable development, thereby contributing to Pakistan's climate resilience and environmental goals.

ANNEX-I – Committee Composition

Waste Technical Committee Composition

Institution	Designation	Gender
Ministry of Food Security	Director CEWRI Ministry of National Food Security and Research	M
Pakistan Bureau of Statistics	Deputy Director General (Agriculture)	M
Department of Agriculture in provinces	Directorate General of Agri Punjab Agriculture Department	M
	Deputy Director Technical-IV Sindh Agriculture Department, GoS.	M
	Additional Secretary KP Agriculture and livestock Department	M
	Director General Balochistan Agriculture Department	M
	Director GB Agriculture, Livestock and Fisheries Department	M
	Planning officer Agri Department of Agriculture, Govt. of AJ&K	M
Ministries Responsible for Waste Management	Section Officer (SO) Companies LGRD Complex, Punjab	M
	Deputy Director LGRD Complex, Sindh	M
	General Manager PMER LGRD Complex, KPK	M
	Superintendent Engr LGRD Complex, Balochistan	M
	Deputy Director (Waste) LGRD Complex, AJK	M
	Deputy Director LGRD Complex, GB	M
Punjab	Assistant Chief (Env. & CC)/P&D Board ,NDC Focal Punjab	M
Sindh	Secretary ECC&CD, NDC Focal	M

KPK	Director, EPA KPK , NDC Focal	M
Balochistan	DD EPA , NDC Focal	M
GB	Scientific Officer, EPA , NDC Focal	F
AJK	DD, Environmental Protection Agency , NDC Focal	M

Technology Roadmap Committee Composition

Focal Persons/Designation	Institution	Gender
Mr. Hidayatullah Joint Secretary	Ministry of Science and Technology, Islamabad	M
Mr. Sohail Akhter SO IF-2	Ministry of Industries & Production, Islamabad	M
Mr. Asfand Yar Khan Director General	Ministry of Information Technology and Telecommunication	M
Dr. Imran Ali Shah	Ministry of Poverty Alleviation and Social Safety	M
Mr. Syed Hussain Abidi, Director General (PCRET)	Pakistan Council of Renewable Energy Technologies (PCRET)	M
Dr. Syed Hussain Abidi, Chairman	Pakistan Council of Scientific & Industrial Research (PCSIR)	M
Fazal Hingoro Section Officer (Commerce)	Industries and Commerce Department, Sindh	M

DoCC	Climate Change & Coastal Development, Directorate of Climate Change (DoCC), Govt. of Sindh	
Mr. Mudassar Zeb Khan Manager Planning	Industries, Commerce and Technical Education Department, KP	M
Mumtaz Ali Deputy Director, EPA	Environment Protection Agency, KP	M
Mr. Amir Habib Assistant Director	Science & Technology and Information Technology Department, KPK	M
Rizwan Ali Assistant Chief, P&D Board Punjab	Planning and Development, (P&D) Punjab	M
Mr. Asim Javaid Hashmi (PAS) & Managing Director	Industries, Commerce, Investment and Skill Development Department, Punjab	M
Mr. Iqbal Sarpara Director	Industries and Commerce Department	M
Mr. Ibrahim Baloch Director General	Science and Information Technology Department, Balochistan	M
Wali Muhammad Khilji, Deputy Director (Climate Change)	Environment Protection Agency, Balochistan	M
Mr. Waqar ul Hasaan Deputy Director (IT)	Information Technology Department GB	M

Mr. Siraj ud Din Assistant Director Labour	Industries and Commerce Department GB	M
Mehtab Munir Butt, Deputy Director	Department of Industries, Commerce and Labor, AJK	M
Sardar Muhammad Rafiq Khan Deputy Director, Climate Change	Environment Protection Agency, AJK	M
Mr. Waqar Abdullah Planning Officer	Planning and Development, (P&D) AJK	M
Niaz Ullah Khan CEO, AWF Mr. Kamran Naeem WASH Specialist	Experts	M
Designation	**Institution**	**Gender**
Joint Secretary	Ministry of Science and Technology, Islamabad	M
SO IF-2	Ministry of Industries & Production, Islamabad	M
Director General	Ministry of Information Technology and Telecommunication	M
	Ministry of Poverty Alleviation and Social Safety	M
Director General (PCRET)	Pakistan Council of Renewable Energy Technologies (PCRET)	M
Chairman	Pakistan Council of Scientific & Industrial Research (PCSIR)	M
Section Officer (Commerce)	Industries and Commerce Department, Sindh	M
DoCC	Climate Change & Coastal Development, Directorate of Climate Change (DoCC), Govt. of Sindh	
Manager Planning	Industries, Commerce and Technical Education Department, KP	M
Deputy Director, EPA	Environment Protection Agency, KP	M
Assistant Director	Science & Technology and Information Technology Department, KPK	M

Assistant Chief	Planning and Development, (P&D) Punjab	M
Managing Director	Industries, Commerce, Investment and Skill Development Department, Punjab	M
Director	Industries and Commerce Department	M
Director General	Science and Information Technology Department, Balochistan	M
Deputy Director (Climate Change)	Environment Protection Agency, Balochistan	M
Deputy Director (IT)	Information Technology Department GB	M
Assistant Director Labour	Industries and Commerce Department GB	M
Deputy Director	Department of Industries, Commerce and Labor, AJK	M
Deputy Director, Climate Change	Environment Protection Agency, AJK	M
Planning Officer	Planning and Development, (P&D) AJK	M
CEO, AWF Mr. Kamran Naeem WASH Specialist	Experts	M

ANNEX-II – Long List of Technologies

Sector	Existing technologies	Emerging technologies
Municipal Solid Waste	• Waste Segregation • Incineration • Composting • Pyrolysis • Engineered landfills • Manual Drain Cleaning and Sludge Suction Machines • Anaerobic digestion • Landfill gas recovery technology • Organic Municipal Waste • Smart Waste Bins	• Waste Valorization • Automated Vacuum Collection System
Plastic Waste	• Downcycling • Refused Derived Fuel (RDF)	• Non-biodegradable plastic Pyrolysis • Polyethylene terephthalate (PET) Backfilling
Agriculture Waste	• Soil Mulching • Livestock Feeding • Remote Sensing tech for mapping hotspots • Rice Straw Shredders • Happy Seeders • Vermi Compost Technology • Stoker/FBC Steam-Electric Combustion • Bio-methanation • Bio-Hydrogen	• Integrated Biomass Gasification Fuel Cell

ANNEX-III – Waste Technical Committee for Technology Prioritization

Name	Gender	Department	Province
1. Sanullah Solangi	Male	Agriculture	Sindh
2. Dr. Muhammad Junaid	Male	Project Coordinator, Ten Billion Tree Tsunami	KPK
3. Dr. Arif Shah Kakar	Male	Agriculture	Balochistan
4. Adil Hussain	Male		
5. Babar H Minhas	Male	LGRDD	AJK
6. Javed Akhtar	Male	Agriculture	GB
7. Dr Sardar Muhammad Rafique	Male	EPA	AJK
8. Mishal Zahra	Female	EPA	GB
9. Saeed Khan	Male	WSSP	KPK
10. Syed Asif Ali Shah	Male	EPA	KPK
11. Farhana Jameel	Female	DGA, OWFM	Punjab
12. Sohaib Zaheer	Male	P&D	Punjab
13. Zamir Hassan	Male	General Manager WASA	KPK
14. Waqas Abdullah	Male	Agriculture Department	AJK
15. Dr Arshad	Male	NARC	Federal
16. Mirza Karim	Male	Local Government	GB
17. Abdul Wali	Male	EPA	Balochistan
18. Zunaira Gill	Female	Agriculture	Punjab
19. Afsar Khan	Female	EPA	KPK
20. Muhammad Aslam Nadeem	Male	LGCD	Punjab

Annex IV - Waste Technical Committee List

Name	Department	Province	Google Forms Response Status
1. Dr. Sardar Rafique	EPA	AJK	Yes
2. Raja Mirza Kareem	DD LG& RD	Gilgit	Yes
3. Dr. Habib Jan	Dy Director EPA	KPK	Yes
4. Sanaullah Solangi	DD, Agricultural Research	Sindh	Yes
5. Malik Muhammad Akram	DGA (OFWM)	Punjab	Yes
6. Zamir Hassan	General Manager Planning WASA	KPK	Yes
7. Saira Saeed	Planning and Development Board	Punjab	Yes
8. Muhammad Tahir	Additional Secretary Agriculture	KPK	Yes
9. Waqas Abdullah	Agriculture	AJK	Yes
10. Ghulam Mustafa	Director Agriculture	Gilgit	Yes
11. Arshad Ashraf	National Food Security and Research Islamabad	Federal	Yes
12. Mishal Zahra	Assistant director-EPA	Gilgit	Yes
13. Rizwan Ali	P&D Board	Punjab	Yes
14. Dr. Saima Shafique	MoCC	Federal	-
15. Mumtaz Ali	Deputy Director Legal, EPA	KPK	Yes
16. Dr. Faisal Raheem	SEED Certification Officer	AJK	Yes