ENERGY AND CLIMATE
PANORAMA

WASTE MANAGEMENT

IN METROPOLITAN CITIES OF PAKISTAN

Challenges and Oppurtunities

ABOUT US

Who we are

We are a dedicated team of researchers and experts who recognize the urgent need for action in addressing climate resilience and energy transition in Pakistan. Our mission is to develop and implement effective policies for cleaner, renewable energy sources like solar and wind, aligning with Pakistan's 2030 goal of 30% renewable energy in its electricity mix. As a multidisciplinary team, we leverage expertise in three key disciplines of study—Energy Systems Engineering, Thermal Energy Engineering, and Electrical Power Engineering—to drive our mission forward. We are united by a shared vision of creating a sustainable and resilient future for Pakistan, where cleaner energy sources play a pivotal role in reducing the nation's vulnerability to climate-related challenges.

What we do

We conduct in-depth, evidence-based research to analyze and improve energy policies in Pakistan. Our focus is on advancing renewable energy solutions and engaging stakeholders to ensure effective policy implementation. Our methodology involves a critical examination of current energy policies to pinpoint areas of improvement and formulate strategies for the widespread adoption of renewable energy sources across various levels.

In line with our commitment to fostering sustainable practices, we have established a fellowship program as part of our broader initiatives that aims to facilitate evidence-based research for promoting energy transition in Pakistan. Through research studies, surveys, and forecasting, we plan to assess various aspects of energy transition, including the adoption of renewable energy technologies and their impact on climate change. Our approach involves active engagement with stakeholders to address their concerns and facilitate the effective implementation of policies, fostering the growth of renewable energy manufacturing and marketing facilities.

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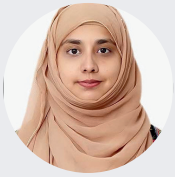

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Executive Summary

This study explores the waste management practices in urban areas of Pakistan, with focus on sustainable waste management and disposal strategies, especially Waste-to-Energy (WtE) facilities as a transformative solution. The study discusses WtE facilities such as incineration to convert municipal solid waste into energy resources. It also highlights the global issue of plastic waste and the importance of gasification, pyrolysis, recycling, and reuse methods to minimize its environmental impact. The study also examines the anaerobic digestion pathway to convert organic waste, sewage, and agricultural residues into methane and carbon dioxide, thereby creating an economical energy resource for rural communities. The study also investigates how urban communities in Pakistan view and manage municipal solid waste. The exploration starts by looking at city cleanliness, waste collection frequency, waste handling improvements, and the health impacts of inadequate waste management. This examination explores the connection between public expectations and urban sanitation, highlighting the negative impact of poor waste management on public health. Public awareness of waste management is investigated, including child labor, community involvement, and knowledge of new technologies. The challenges and recommendations or policymakers to enhance municipal solid waste management are explored in this study. Our findings indicate that the public consider investing in advanced waste-to-energy technologies to be crucial. They also emphasize the need for collaboration between the government and private sector, along with incentives for research in this area. The Surveys also reflect the need for a robust, standardized regulatory framework for successful operation of WtE projects in Pakistan. The study concludes that current waste management system requires improved waste segregation, collection, and processing as well as enhanced Public-Private Partnerships (PPPs) to accelerate WtE projects through collaboration and shared resources. Moreover, incorporation of WtE facilities into urban planning is needed along with integration with city energy grids to alleviate energy crisis. Promotion of public awareness campaigns, waste recycling programs, composting initiatives, and WtE projects are expected to reduce landfill reliance and conserve valuable materials. Similarly, continuous monitoring and evaluation, driven by data insights, will drive the management system towards sustainability. Finally, the study calls for action to stop child labor in waste handling and emphasizes the importance of climate-resilient waste management strategies to address climate change issues.

1. Introduction

TMunicipal solid waste (MSW), commonly known as trash, encompasses a broad range of ordinary items including but not limited to product packaging, yard trimmings, furniture, clothing, bottles and cans, food, newspapers, appliances, electronics, and batteries. The origins of Municipal Solid Waste (MSW) can be traced to various sources, including but not limited to, household waste, commercial waste, and institutional waste. The latter includes waste generated by establishments such as restaurants, grocery stores, schools, hospitals, and industrial facilities. The category of industrial waste encompasses waste generated from non-process sources such as offices, cafeterias, and packaging, while excluding process waste. The EPA's delineation of Municipal Solid Waste (MSW) is exclusive of hazardous waste, industrial process waste, and construction and demolition (C&D) waste. Upon its generation, Municipal Solid Waste (MSW) necessitates collection and proper management. Frequently employed techniques in the field of management encompass recycling, composting, combustion with energy recovery, and landfilling. A significant proportion of waste materials that are deposited in landfills are potentially reusable, recyclable, or convertible to energy, thereby reducing the need for virgin materials [1].

The rapid progression of human society towards contemporary urban living has resulted in the substantial accumulation of municipal solid waste. This surge in waste generation is occurring at a faster pace than the rate of urbanization globally, with developing nations experiencing particularly pronounced effects. The global production of solid waste is experiencing a steady rise due to factors such as population expansion, continuous economic development, urbanization, and industrial progress. The global municipal solid waste (MSW) generation witnessed a substantial increase over a span of ten years, with the amount doubling from 0.68 billion tones in 2000 to 1.3 billion tones in 2010. Moreover, it is projected that the annual quantity will escalate to 2.2 billion tones by the year 2025, and subsequently, to 4.2 billion tones by the year 2050 [2]–[4]. The acceleration of consumption rates in developing countries can be attributed to several factors, including the rapid expansion of population, urbanization, and economic growth. The projected municipal solid waste (MSW) production in Asia is expected to reach a daily output of 1.8 million tons by the year 2025. The potential inability to effectively manage the substantial waste burden of urbanized regions may exert a significant impact on the viability of sustainable lifestyles, the surrounding ecosystem, and the well-being of individuals [5], [6]. The municipalities, entrusted with the responsibility of overseeing waste management in urban areas, encounter a formidable challenge in devising a system that is concurrently efficacious and streamlined to cater to the needs of the inhabitants [7]. The management of municipal solid waste (MSW) is influenced by various factors, including socio-economic, cultural, institutional, physical, and

environmental aspects. These factors pose challenges to effectively handle the substantial volume of waste. The generation of sustainable waste (SW) is subject to significant variations influenced by socio-economic characteristics, including age, income, and education level [8]. Population size and density in a region directly affect waste production. Waste generation is linked to higher population and densely populated urban areas due to increased consumption, production, and human activities. Waste generation is influenced by economic development and affluence. As societies become more prosperous, consumption patterns increase, leading to more packaging waste, disposable products, and overall waste generation. Urbanization and lifestyle changes significantly contribute to waste generation. Rural areas becoming urban often leads to a shift from traditional practises to consumer-driven lifestyles. The shift in consumption patterns and adoption of convenience products may lead to more waste. Industrial and commercial activities can greatly affect waste generation rates. Industrial activities, including manufacturing, construction, and commercial operations, commonly generate waste. These activities generate large amounts of waste, including packaging materials, industrial byproducts, and construction debris. Waste generation fluctuates due to seasonal variations and tourism. During peak tourist seasons, areas with popular attractions see an increase in waste due to higher consumption, hospitality services, and recreational activities. Waste generation patterns are influenced by culture and social practises. Diverse cultural practises, traditions, and religious events can Tcreate unique waste streams, like food waste during festivals or ceremonies. Consider the impact of social norms, awareness, and attitudes on waste management, especially recycling rates, and waste reduction efforts.

Similar to other developing nations, Pakistan faces significant environmental challenges due to the absence of adequate waste management infrastructure. The majority of municipal waste is disposed of through incineration, landfilling, or illegal dumping on unoccupied land, posing a significant risk to the well-being and safety of the public. According to the estimation of the Government of Pakistan (GOP), a total of 87,000 tons of solid waste is produced on a weekly basis, predominantly originating from the primary urban centers. The metropolis of Karachi, which holds the distinction of being the largest city in Pakistan, produces a daily quantity of municipal waste that exceeds 16,500 tons. Metropolitan areas encounter significant obstacles in regard to the effective management of urban waste. The issue at hand is attributed to a variety of factors, including but not limited to bureaucratic obstacles, insufficient urban planning, subpar waste management infrastructure, limited public knowledge and understanding, absence of dependable data, incapacity to formulate novel initiatives within the field, and failure to guide the industry towards the implementation of sector-specific policies [9], [10]. Pakistan's limited municipal institutional capacity has resulted in inadequate waste management, leading to the disposal of untreated solid and sewage waste on land and in water bodies. This may potentially

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result in the emission of greenhouse gases into the atmosphere and the spread of airborne pollutants through dust. Annually, more than 5 million fatalities are attributed to illnesses associated with sewage and solid waste [11]. The implementation of efficient waste-minimization tactics in Pakistan has been inconsistent at best. The private firms and manufacturing sector have emerged as key players in driving this movement. However, it is important to note that their efforts have primarily been focused within the boundaries of their respective organizations.

The issue of plastic pollution is widespread, leading to numerous private initiatives that primarily aim to address the problem of plastic waste. In 2019, Unilever made a commitment to reduce the utilization of virgin plastic in their packaging by 50% by the year 2025. This commitment extended to their operations in Pakistan. The corporation has made a commitment to increase their plastic collection and processing efforts to exceed the amount of plastic they sell. The achievement of these targets will primarily involve a transition from single-use packaging to multi-use packs, which include reusable and refillable formats. Additionally, alternative packaging solutions, such as 'naked' products, will be explored. Unilever, in its commitment to reducing plastic waste, actively invests in and collaborates with various countries to enhance waste-management infrastructure. Additionally, the company demonstrates its dedication by procuring and utilizing recycled plastics in its packaging materials. Furthermore, Unilever ctively engages in Extended Producer Responsibility schemes, assuming responsibility for the collection of its packaging and covering associated costs [12]. The partnership between WWF andactively engages in Extended Producer Responsibility schemes, assuming responsibility for the collection of its packaging and covering associated costs [12]. The partnership between WWF and Coca Cola Corporation serves as a notable example of a collaboration between a prominent corporate entity and an environmental organization with a shared objective of plastic recovery. The program, which was initiated in 2019, focused on collecting PET bottles from three shopping malls located in Lahore. These collected bottles were then sent to a recycling facility that the organization had partnered with. The initiative included the implementation of general public-awareness campaigns in malls, which were further supported by monetary incentives and other incentives [13], [14]. Procter and Gamble, Pakistan, a prominent corporate entity, has made waste reduction a key focus of its sustainability agenda. By the year 2018, Procter and Gamble Pakistan managed to produce packaging that was recyclable to the extent of 86%. It is noteworthy that the corporation has set a target to further enhance this percentage to 90% by the year 2030 [15]. Other than that, the Ministry of Climate Change in Pakistan has implemented various measures to address the issue of plastic waste. One notable action taken by the government was the imposition of a comprehensive ban on the use of polyethylene bags in Islamabad in 2019. This initiative was aimed at curbing the negative environmental impact caused by the excessive use and improper disposal of

plastic bags. Over time, the government has enlisted the services of various external consultants, with the assistance of multilateral development organizations, to establish guidelines for managing solid waste, as well as to produce initial literature on the topics of "waste to energy" and composting. The Lahore Waste Management Company established a formal waste management system, making Lahore the inaugural city in Pakistan to implement such a system in the province of Punjab. Despite the implementation of comparable measures in other provinces, such as the Sindh Cities Improvement Investment Program (SCIP) and the development of a landfill site in Peshawar, the effectiveness of these interventions has been restricted [16].

The current governmental initiatives and actions in Pakistan regarding Municipal Solid Waste (MSW) management have revealed a significant research gap in this area. The existing body of research has provided valuable insights into different facets of municipal solid waste (MSW) generation and management. However, there remains a notable lack of comprehensive studies that thoroughly explore the viewpoints and opinions of stakeholders regarding waste management practices. The comprehension of stakeholder perception is of utmost importance, as it has the potential to greatly influence the effectiveness of waste management endeavors. In addition, it is necessary to conduct a thorough investigation into the specific challenges and opportunities associated with the transition to sustainable waste management practices, including Waste to Energy (WtE) itechnologies and recycling. The objective of this study is to address the existing research gaps by presenting significant findings on stakeholder perceptions. It aims to identify areas that require interventions and provide recommendations for sustainable management of municipal solid waste (MSW) in metropolitan cities of Pakistan.

In order to maintain a comprehensive approach, it is important to acknowledge the limitations and boundaries of this study. The study primarily focuses on metropolitan cities within Pakistan. The findings of this study, while valuable in understanding the challenges and opportunities in MSW management, may not be directly transferable to rural areas or smaller towns due to their distinct waste generation patterns. In addition, it is important to note that the study's findings are based on survey responses and existing literature. It is worth considering that these sources may contain inherent biases or limitations that could affect the accuracy of the data. The study's time frame is limited by the availability of resources and the predetermined research schedule. The study's objective is to offer valuable insights on MSW management. However, it is important to note that the study may not encompass all nuances or aspects of this topic.

The significance of this study in the context of MSW management in Pakistan is substantial. The comprehensive understanding of public perceptions and the analysis of existing literature contribute significantly to the development of well-informed policies and initiatives. The formal pathway for sustainable

waste handling and management is in accordance with international best practices, which has the potential to establish a model for waste management strategies that are both more efficient and environmentally friendly. The assessment of technical, economic, and socio-economic factors, guided by public perception and existing literature, aids in the identification of areas that require enhancement and resource optimization. The aim of this study is to support the shift towards sustainable and efficient management of municipal solid waste (MSW). By doing so, it aims to enhance urban environments, promote public health, and contribute to a more environmentally conscious and sustainable future for metropolitan areas in Pakistan.

The study focuses on three primary objectives

1. Assessing the extent of MSW generation and its management challenges in metropolitan cities of Pakistan using available literature
2. Developing a formal pathway for sustainable waste handling and management aligned with international best practices.
3. Evaluating the technical, economic, and socio-economic aspects of the existing waste handling methods.

2. APPROACH & METHODOLOGY

The following chapter provides an overview of the research methodology utilized to obtain a comprehensive understanding of municipal solid waste (MSW) management in Pakistan. The report discusses a methodology that adopts a multi-faceted approach to gain a comprehensive understanding of waste characterization, emerging trends, challenges, and public perceptions related to municipal solid waste (MSW) management.

2.1. Data Collection

In order to ensure a comprehensive approach in addressing the study objectives, data was collected from a wide range of diverse sources.

- **Scholarly Sources**

The study was grounded in a comprehensive analysis of scholarly sources, which encompassed peer-reviewed literature and publications. This approach was crucial for situating the research within the broader global and regional discussions surrounding waste management.

- **Governmental Reports**

In order to obtain information regarding waste characterization, government policies, initiatives, and regulations concerning municipal solid waste (MSW) management, a thorough examination was conducted on

official reports and documents issued by pertinent government entities.

- **Local Waste Management Authorities**

The engagement with local waste management authorities played a vital role in the data collection process. Qualitative insights into regional practices, challenges, and ongoing initiatives were obtained through discussions with these authorities.

- **Public Surveys**

A comprehensive study was undertaken to gather data from residents residing in specific urban regions of Pakistan. The study involved a series of well-organized surveys. The surveys conducted in this study comprised a set of questions that were carefully crafted to gather information about the perceptions and attitudes of the general public regarding the management of municipal solid waste (MSW).

2.2. Data Analysis

The data analysis for this study was conducted using a multifaceted approach, which involved a combination of thematic and statistical methods. The qualitative data was subjected to thematic analysis in order to identify recurring themes and patterns. The qualitative approach utilized in this study aimed to gain insights into the public perceptions and regional practices concerning municipal solid waste management. In addition, an analysis was conducted on the quantitative data obtained from structured survey questions.

This analysis involved applying statistical methods to identify significant relationships, trends, and draw meaningful inferences. The utilization of a comprehensive data analysis approach in this study has facilitated a thorough examination of waste characterization, emerging trends, challenges, and public perceptions. This approach has been instrumental in achieving the overarching objectives of the study on municipal solid waste (MSW) management in Pakistan.

2.3. Recommendations Based on Data Analysis

The study concludes with a set of recommendations based on a thorough analysis of data. This analysis covered various aspects such as waste characterization, emerging trends, challenges, and public perceptions regarding municipal solid waste management in Pakistan. The following report presents a set of recommendations that provide practical strategies and initiatives. These recommendations are based on a comprehensive analysis of various data sources, including scholarly literature, government reports, input from local authorities, and public surveys. The report offers a comprehensive and well-informed plan for policymakers and stakeholders to improve the efficiency and long-term viability of municipal solid waste (MSW) management strategies in major cities of Pakistan.

2.4. Summary

The present study aims to address the existing research gaps in the management of Municipal Solid Waste (MSW) in Pakistan. The report delves into the examination of public perceptions, challenges, and opportunities pertaining to sustainable waste management. The analysis primarily concentrates on metropolitan areas and draws information from various sources, including surveys, literature, and government reports. The significance of the matter lies in the implementation of informed policies that are in line with international best practices, with the aim of improving various aspects including technical, economic, and socio-economic factors. The focus of this research is to promote sustainable management of municipal solid waste (MSW) in Pakistan, with the aim of benefiting urban areas and improving public health.

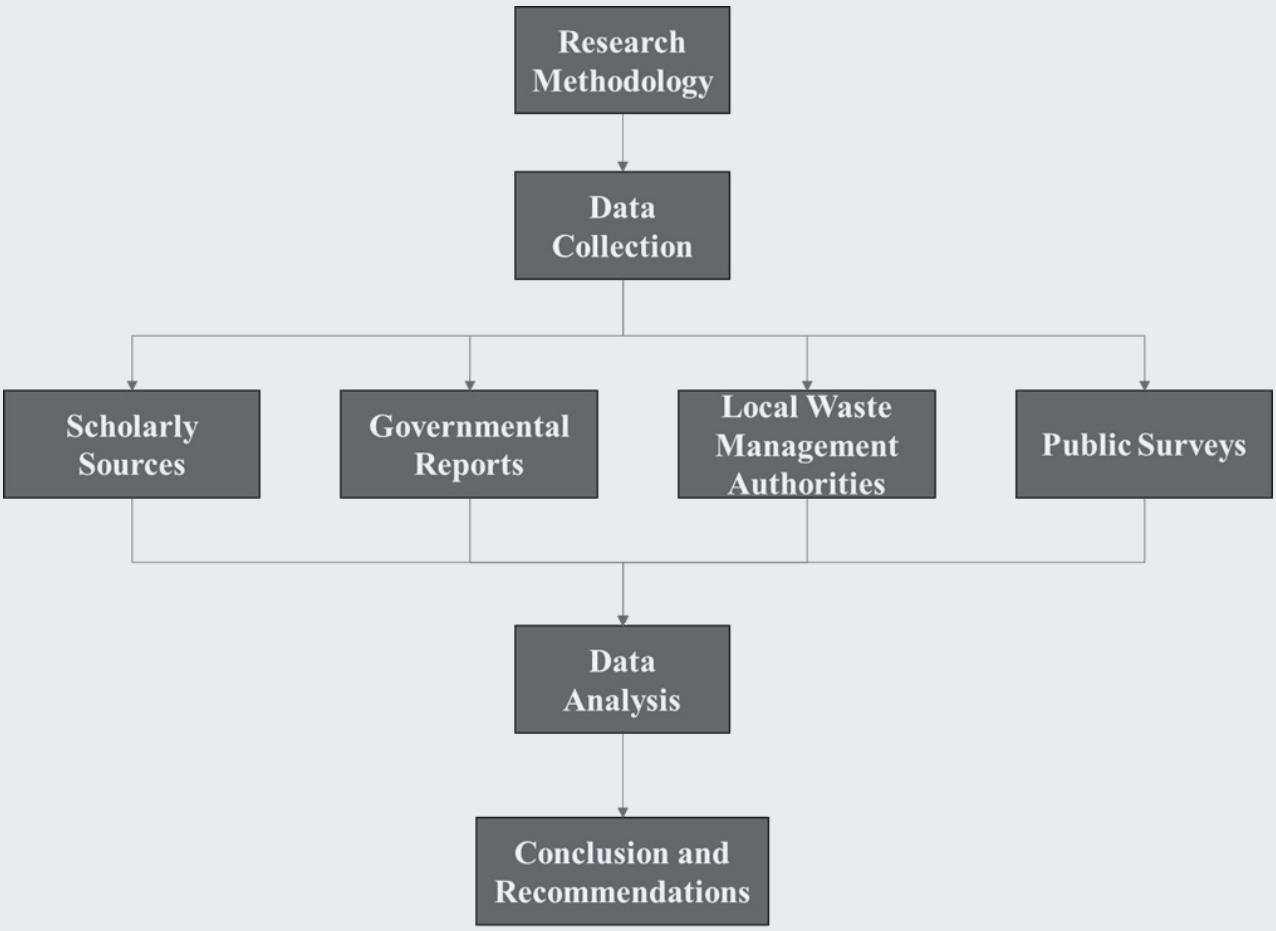

Figure 1. *Research Methodology Flow Diagram*

3. Major Findings

3.1. MSW Characterization in Different Metropolitan Cities of Pakistan

The management of Municipal Solid Waste (MSW) poses a significant environmental challenge, particularly in urban areas of developing nations like Pakistan. The escalation of solid waste production in major Pakistani cities such as Karachi, Lahore, Faisalabad, and Islamabad can be attributed to urbanization, population expansion, and evolving lifestyles.

- **Karachi**

Pakistan's largest metropolis, Karachi, borders the Arabian Sea. Karachi's diversified population exhibits economic and cultural strength. Due to its coastal location, features mild winters, hot summers, and monsoons. The city's geography creates busy neighborhoods. Karachi generates 0.449 kg of solid waste per person. Karachi has two SSWMB districts: Malir, South, East and West, and Central and Korangi [17], [18]. Karachi is divided into districts and their waste characterization is as follows

- **District Malir, South, East and West**

Organic waste dominated MSW. Organic waste is largely kitchen and food waste, especially fermenting fruits. Styrofoam, bags, and packing wrappers are also ubiquitous. Municipal Solid Waste Characterization of District Malir, South, East and West District is as follows [18].

Figure 2. *MSW at different sites in Karachi (Self-taken)*

Sr No.	Item	District Malir	District East	District South	District West	Average
1	Kitchen Waste	38.23	48.09	52.74	49.48	47.135
2	Paper	0.75	3.71	1.81	1.83	2.025
3	Textile	10.35	8.29	8.12	6.51	8.3175
4	Grass and Wood	2.78	3.48	1.57	1.52	2.3375
5	Plastic	16.26	18.97	19.54	20.34	18.7775
6	Leather and Rubber	1.36	0.61	0.97	0.98	0.98
7	Metal	0.04	0.04	0.1	0.15	0.0825
8	Bottle and Glass	0.13	0.34	0.61	0.48	0.39
9	Ceramic, stone	0.61	0.23	1.17	3.27	1.32
10	Domestic Hazardous Material	0.13	0.21	0.15	0.35	0.21
11	Residue Remaining (remaining material sheet)	5.21	2.89	2.84	4.61	3.8875
13	Tetra pack	0.69	0.49	0.43	0.38	0.4975
14	Hairs	0.09	0.01	0	0.01	0.0275
15	Pampers	7.2	9.14	6.08	5.65	7.0175
16	Bones	0.46	0.09	0.11	0.24	0.225
17	Dust / Silt	15.59	3.4	3.73	4.16	6.72
18	E-Waste	0.11	0	0.02	0.05	0.045
	Total	100	100	100	100	100

Table 1. *Municipal Solid Waste Characterization of District Malir, South, East and West District [18]*

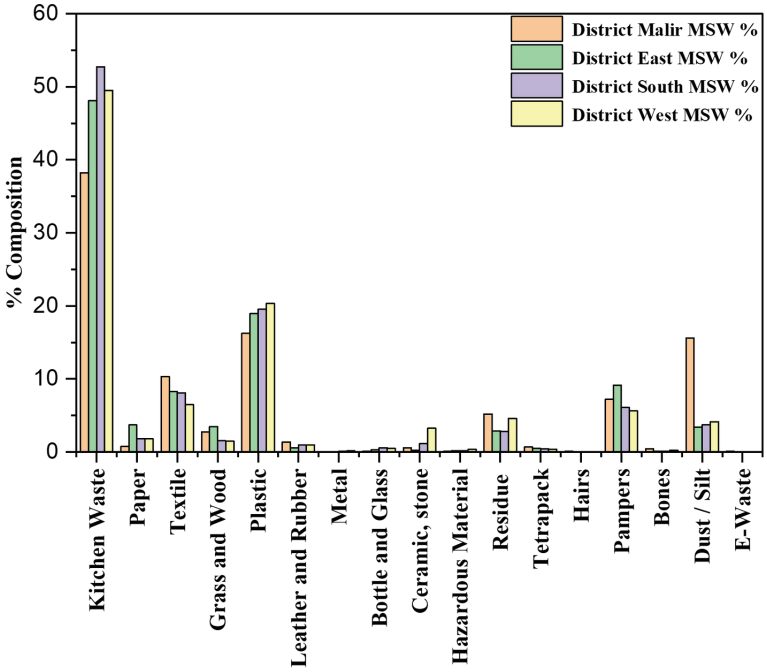

Figure 3. *Municipal Solid Waste Characterization of District Malir, South, East and West District [18]*

- **District Central and District Korangi, Division Karachi**

The findings of the study indicate that the primary waste category observed in residential areas was kitchen or food waste. Municipal Solid Waste Characterization District Central and District Korangi, Division Karachi is as follows

Sr No.	Items	District Central %	District Korangi %	Average %
1	Kitchen Waste	44.85	46.515	45.6825
2	Paper	8.3	7.445	7.8725
3	Textile	7.365	4.715	6.04
4	Grass and Wood	0.385	1.855	1.12
5	Plastic	17.885	13.505	15.695
6	Leather and Rubber	0.77	0.685	0.7275
7	Metals	0.34	0.195	0.2675
8	Bottle and Glass	0.51	0.47	0.49
9	Ceramic, stone	0.87	0.475	0.6725
10	Domestic Hazardous Material	0.72	2.31	1.515
11	Residual Material	2.15	3.35	2.75
12	Tetra pack	0.48	0.34	0.41
13	Hairs	0.02	0	0.01
14	Pampers	10.53	8.855	9.6925
15	Bones	0.435	0.085	0.26
16	Dust	3.64	7.75	5.695
17	E-Waste	0.075	0.325	0.2
	Total	100	100	100

Table 2. *Municipal Solid Waste Characterization District Central and District Korangi, Division Karachi [17]*

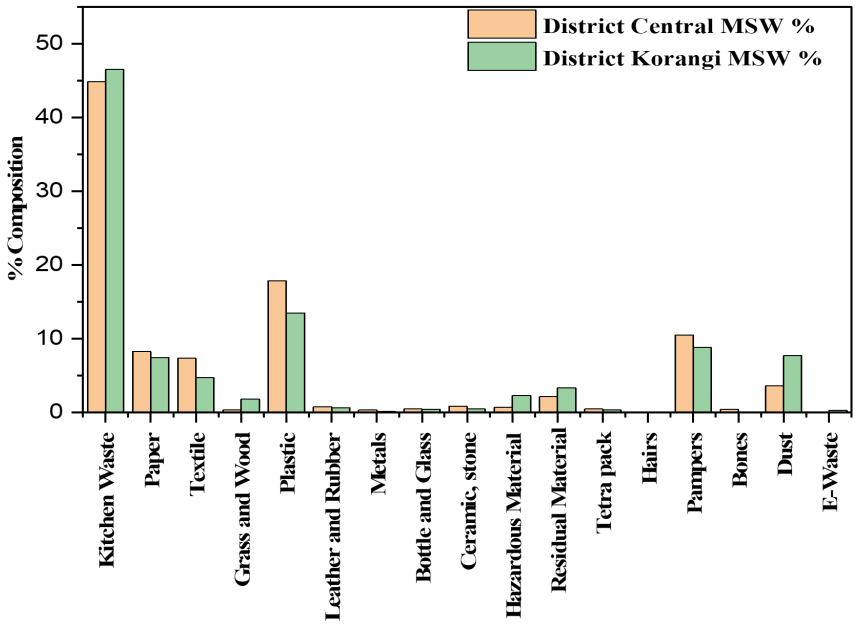

Figure 4. *Municipal Solid Waste Characterization District Central and District Korangi, Division Karachi [17])*

- **Lahore**

Lahore, a major cultural and historical center in Pakistan, blends old and new. The area's streets reflect its various population's traditions, languages, and lifestyles. Lahore, on the Ravi River, has mild winters, hot summers, and a monsoon season. Its districts' charm gives Lahore its dynamic individuality. The urban trash generation rate is 0.54 kg per inhabitant per day, according to Lahore trash Management Company (LWMC) data from 2011 to 2022 [19].

Sr. No.	Items	Lahore MSW %
1	Combustibles	5.93
2	Diaper	5.06
3	Electric/Electronic	0.08
4	Glass	0.78
5	Hazardous Waste	0.89
6	Biodegradable	56.53
7	Metals	0.09
8	Non-Combustibles	6.4
9	Paper-cardboard	2.18
10	PET	0.23
11	Nylon	10.92
12	Plastics	0.74
13	Tetrapak	0.96
14	Textile	9.21
	Total	100

Table 3. *Municipal Solid Waste Characterization of Lahore[20]–[22]*

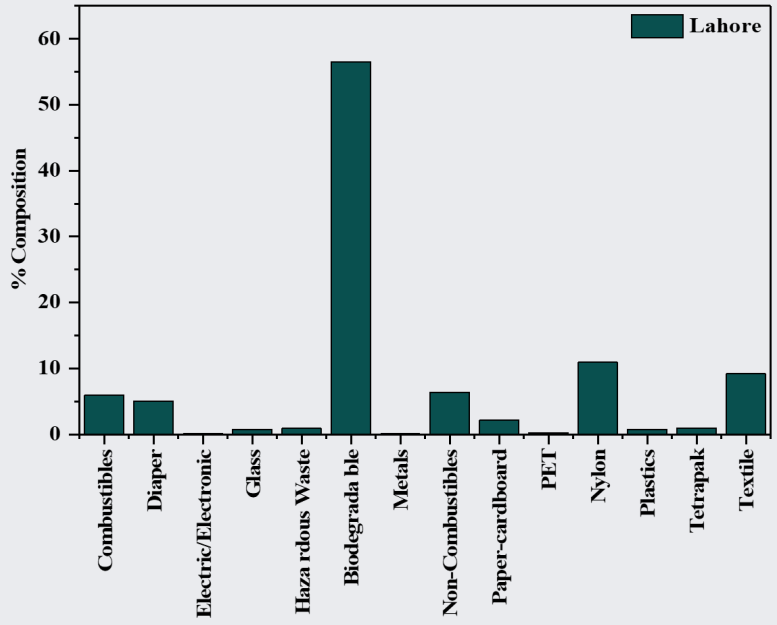

Figure 5. *Municipal Solid Waste Characterization of Lahore [20]–[22]*

- **Faisalabad**

Faisalabad, nicknamed as the "Manchester of Pakistan" for its textile industry, is a major industrial and economic center. The area's diversified population creates a vibrant and ever-changing urban scene. Faisalabad has a semi-arid climate with hot summers and mild winters. The city's administrative divisions shape its identity. As per Faisalabad Waste Management Company[23] the city generates 1600 tons of MSW every day. FWMC collects 1300 tons, while city residents dispose of the rest. Due to a lack of waste treatment infrastructure, Faisalabad dumps rubbish in an open landfil at Muhammad Wala on Jaranwala road. This landfill is nearing depletion. PC-2 has been submitted to the Punjab Government to create a sanitary landfill site in Muhammad Wala Chak 211. The waste composition analysis of Faisalabad city reveals that a substantial portion of the waste, approximately 60%, is constituted of organic materials such as wood (1.07%), paper and cardboard (7.6%), textile (6.53%), animal waste (2.34%), bones (2.4%), and food waste (33.81%). The residual waste is predominantly comprised of Plastic at 6.6%, Rubber at 3.3%, Glass at 2.34%, Metals at 1%, and miscellaneous debris such as dust, ashes, and bricks accounting for 28% [24].

Sr. No.	Components of Waste	Faisalabad MSW %
1	Food Waste	33.8
2	Paper and Cardboard	7.6
3	Plastic	6.6
4	Textile	6.53
5	Rubber	3.3
6	Garden Trimmings	7.36
7	Animal Waste	2.34
8	Wood	1.07
9	Glass	2.4
10	Metals	1
11	Dust, ashes, bricks	28
	Sum	100

Table 4. *Municipal Solid Waste Characterization of Faisalabad [25], [26]*

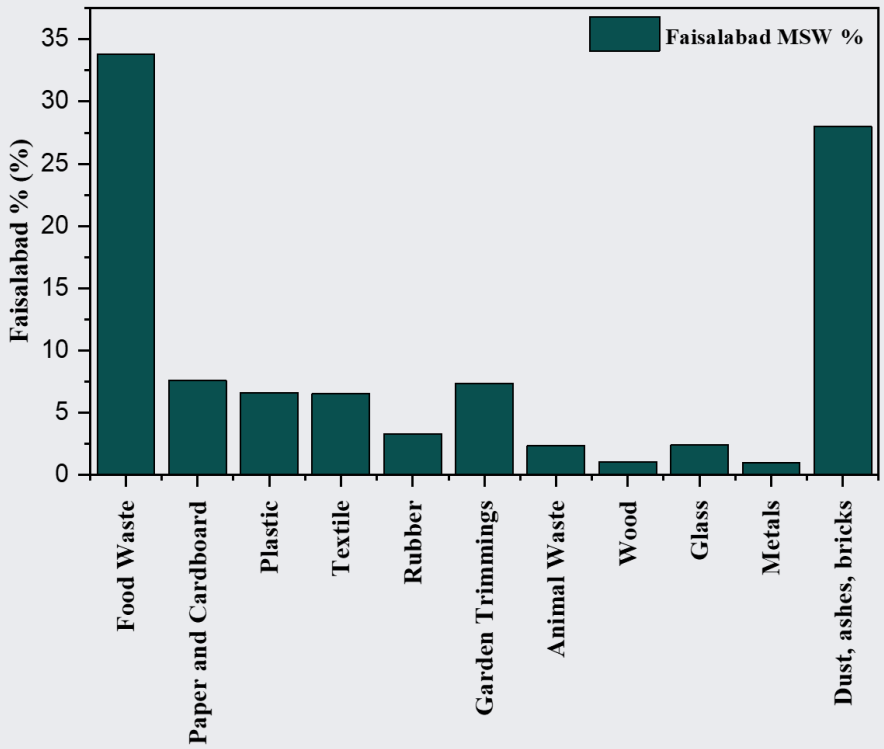

***Figure 6**. Municipal Solid Waste Characterization of Faisalabad [25], [26]*

- **Islamabad**

Islamabad, Pakistan's capital, blends calm and modernity among the Margalla Hills. The carefully planned green spaces nearby provide a peaceful break from metropolitan life. Islamabad, with its diversified population, emphasizes its political and administrative significance. The city has a temperate climate with distinct seasons. The city of Islamabad has many areas, each with its own charm. Islamabad garbage is 55.08% biodegradable [27].

***Figure 7**. Islamabad's landfill site sector I-12 (self-taken)*

Sr No.	Waste components	Islamabad MSW %
1	Combustibles	4.48
2	Diaper	13.03
3	Electric/Electronic	0.06
4	Glass	1.66
5	Hazardous Waste	0.77
6	Biodegradable	55.08
7	Metals	0.22
8	Non-Combustibles	1.42
9	Paper-cardboard	3.45
10	PET	0.28
11	Nylon	12.26
12	Plastics	0.99
13	Tetrapak	1.43
14	Textile	4.87
	Total	100

Table 5. *Islamabad Municipal Solid Waste Characterization [28]*

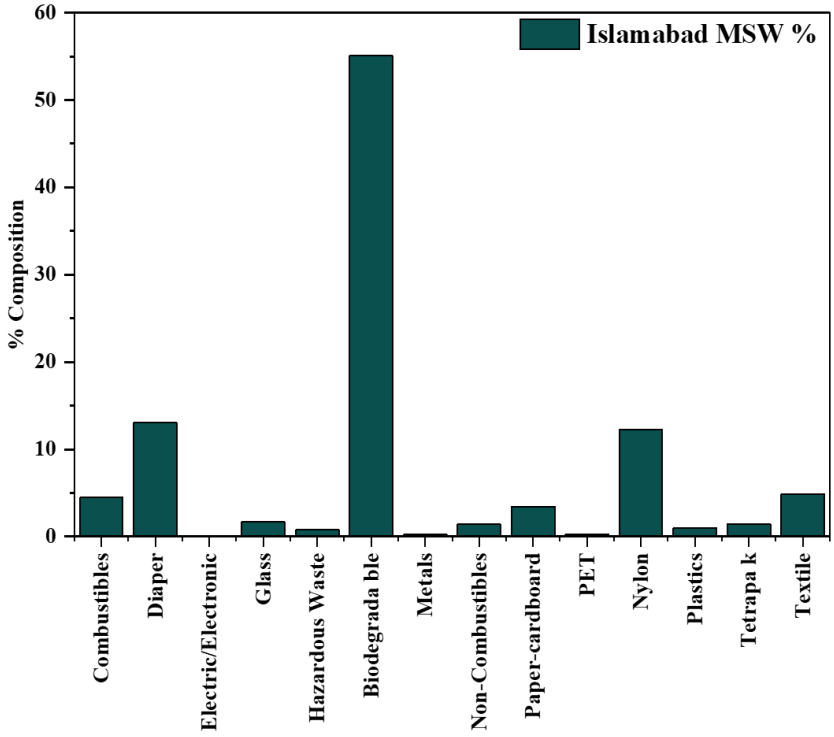

Figure 8. *Islamabad Municipal Solid Waste Characterization [28]*

3.2. Solid Waste Management Challenges in Pakistan

Climate change, extreme weather events, insufficient funding for waste management, uncontrolled urban expansion, lack of waste collection and transportation vehicles, and lack of public awareness contribute to poor solid waste management in Pakistan.

Municipal solid waste mismanagement harms the environment and society. Water contamination, impaired water reserves, atmospheric pollution, soil pollution, epidemic outbreaks, and other repercussions are notable. Surface and underground groundwater are contaminated by solid waste leachate. Incineration or open dumping of solid waste releases smoke and greenhouse gases, polluting the air. In places with trash buildup, vector-borne illnesses are common [29].

As the sixth most populous nation, consumerism leads to significant waste generation. Like other emerging nations, Pakistan's waste management industry faces social, cultural, legislative, and economic challenges. Rural areas have waste quantity exceeding limited waste management capacity. Several issues exist:

- The absence of an adequate waste management system is evident.
- The deposit of waste occurs on the streets.
- The segregation of various waste types is not implemented during the collection process.
- Currently, there is a lack of regulated sanitary landfill facilities. The practice of open burning is frequently observed.
- The public is unaware of the link between improper waste disposal and its harmful effects on the environment and public health.

These issues caused waste buildup in public areas like roadsides and canals. Burning trash is common and harmful to humans and the environment due to toxic emissions. Limited landfill sites exist, with a reduced subset currently operational. Road waste attracts flies, harming humans and other organisms. In Pakistan, poor waste management causes health issues and environmental problems. [30].

- **Dangers to Health**

- The subsequent text enumerates prevalent health risks associated with solid waste.
- Frequent occurrences of infections affecting the skin and eyes have been observed.
- The presence of airborne particulate matter at landfill sites has been linked to respiratory issues in both pediatric and adult populations.
- The breeding of flies is commonly observed on exposed heaps of decomposing waste, which can lead to the transmission of various diseases such as diarrhea, dysentery, typhoid, hepatitis, and cholera.
- Mosquitoes are known to transmit various diseases, such as malaria and yellow fever.
- Canines, felines, and rodents coexisting in proximity harbor a diverse range of

- illnesses, such as the bubonic plague and typhus fever transmitted by fleas.
- Workers involved in the collection of refuse are susceptible to contracting intestinal, parasitic, and skin diseases.

- **Contamination of Groundwater**

Groundwater contamination is a major issue. Water percolation can dissolve chemicals in a substance, known as leaching. The mixture is called leachate. Water percolating through Municipal Solid Waste produces leachate containing decomposing organic matter and metals like iron, mercury, lead, zinc, from discarded appliances, batteries, and rusting cans. The substance can include pigments, insecticides, solvents, printing ink, and other chemical agents. Impurities in water impact ecosystems and humans.

- **The Problem of Air Pollution**

Incinerating waste spreads lead, noxious gases, and smoke in residential areas. Besides its main functions, wind carries waste, dust, and decomposed gases. Sunlight exposure causes waste to putrefy, emitting odor and reducing visibility [31].

3.3. Municipal Solid Waste through Public Eyes: Perception and Management

- **City Cleanliness and Waste Management**

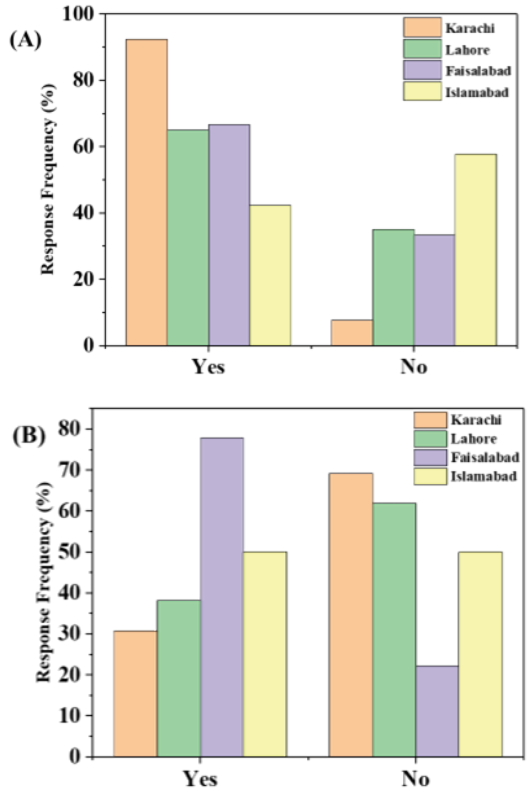

Figure 9. *Public response on solid waste management with respect to (A) health issues experience related to waste handling (B) improvement in waste handling.*

The subject of investigation pertains to the maintenance of urban hygiene and the handling of waste in Pakistan, which strongly correlates with various Sustainable Development Goals (SDGs) within the nation. Its contribution to the realization of SDG 11 (Sustainable Cities and Communities) is significant as it assesses the effectiveness of waste management systems in urban egions. Furthermore, it plays a role in achieving SDG 3 (Promote Healthy Lives and Well-being) through its efforts to tackle the health consequences of insufficient waste disposal. It also contributes to SDG 6 (Ensure Access to Clean Water and Sanitation) by guaranteeing the cleanliness of water sources. Additionally, it supports SDG 12 (Foster Responsible Consumption and Production) by advocating for responsible management of waste materials.

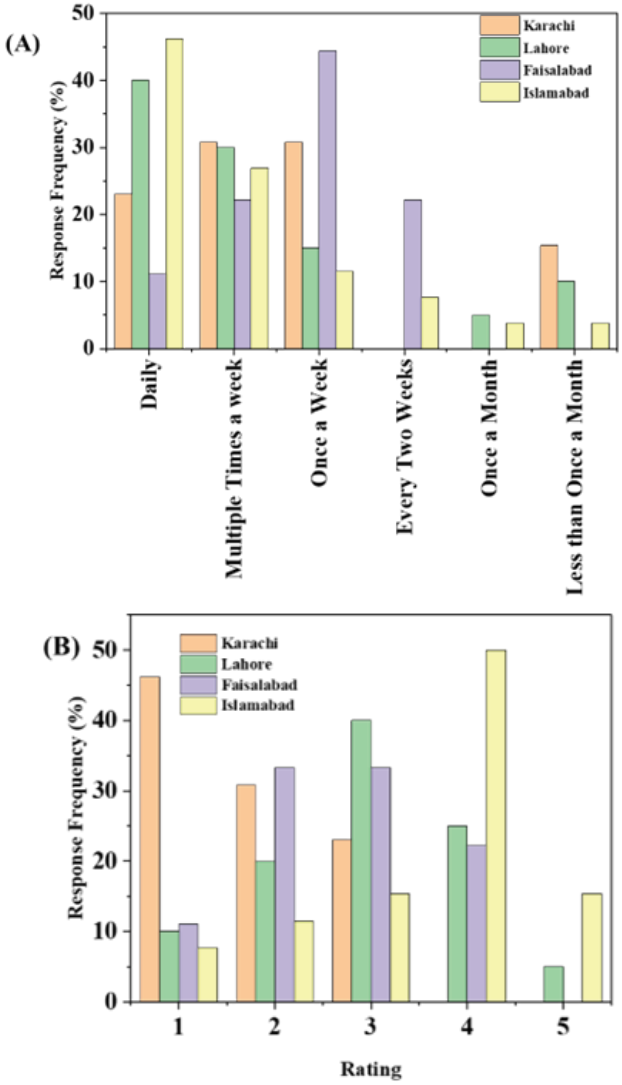

Figure 10. *Public response on solid waste management with respect to (A) waste collection frequency, and (B) city cleanliness rating.*

- **Education, Awareness, and Community Involvement in Waste Management**

The set of questions presented here closely corresponds to the main objectives of Sustainable Development Goals (SDGs) in Pakistan. Their efforts align with SDG 4 (Quality Education) as they evaluate understanding of waste management, align with SDG 8 (Decent Work and Economic Growth) by tackling the problem of child labor, and align with SDG 11 (sustainable cities and communities) is significant as it assesses the effectiveness of waste management systems in urban regions. Furthermore, it plays a role in achieving SDG 3 (Promote Healthy Lives and Well-being) through its efforts to tackle the health consequences of insufficient waste disposal. It also contributes to SDG 6 (Ensure Access to Clean Water and Sanitation) by guaranteeing the cleanliness of water sources. Additionally, it supports SDG 12 (Foster Responsible Consumption and Production) by advocating for responsible management of waste materials.

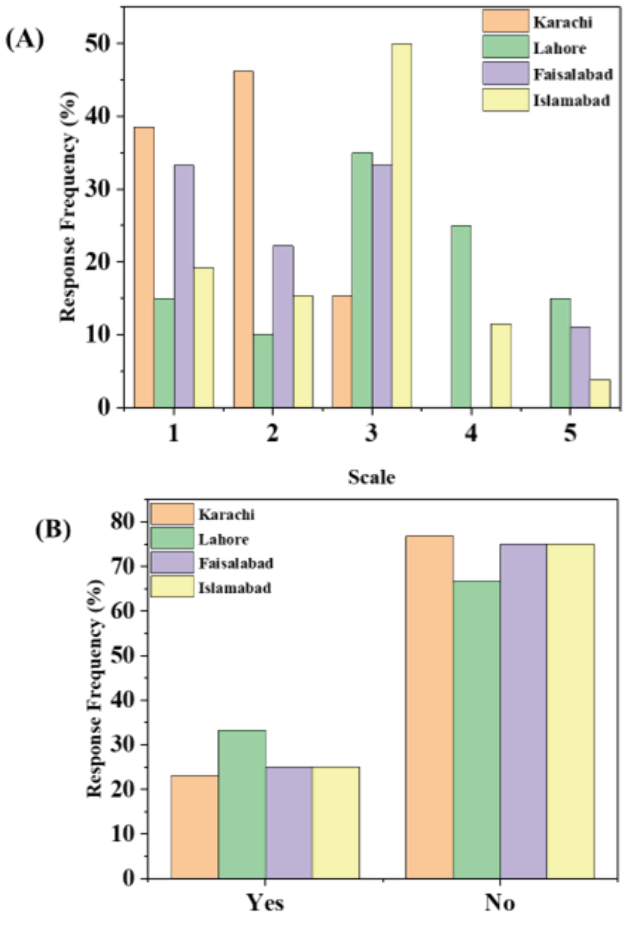

Figure 11. *Public response on solid waste management with respect to (A) awareness and education level, (B) involvement of child labor*

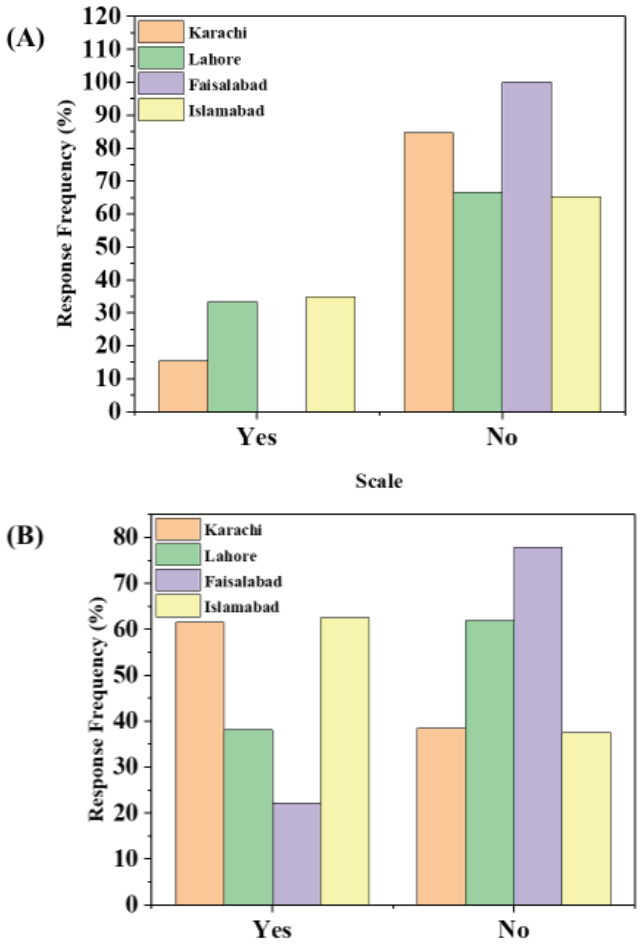

Figure 12. *Public response on solid waste management with respect to (A) involvement of local community in decision-making about waste management, and (B) awareness regarding new technologies or methods in waste management*

- **Challenges in Waste Management**

These series of questions provide a thorough structure for examining the difficulties present in waste management systems, which are in line with various Sustainable Development Goals (SDGs).

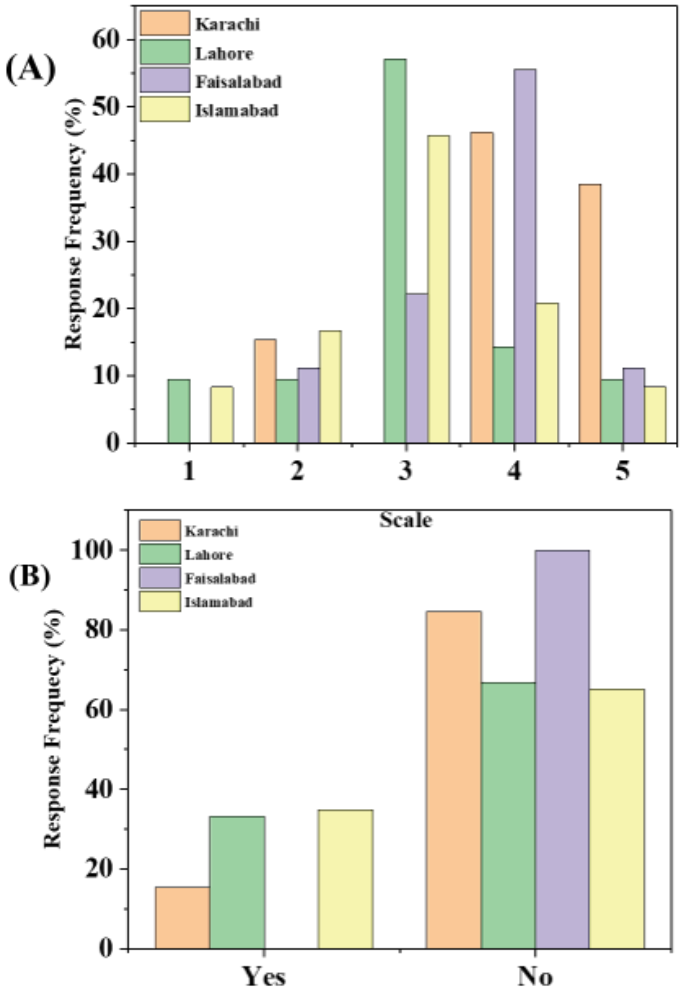

Figure 13. *Public response on current waste management system with respect to (A) observed technical failures, and (B) durability to withstand climate change.*

Through the examination of malfunctions in waste management procedures, valuable observations can be made regarding the susceptibilities encountered in urban areas, thereby making a significant contribution to the achievement of Sustainable Development Goal 11, which focuses on creating sustainable cities and communities. At the same time, the inquiry into a municipality's ability to tackle waste management challenges in the face of climate change highlights the intersection of current logistical hurdles and larger ecological considerations, in line with Sustainable Development Goal 13 (Climate Action).

- **Financial Aspects and Perception of Investment in Waste Management**

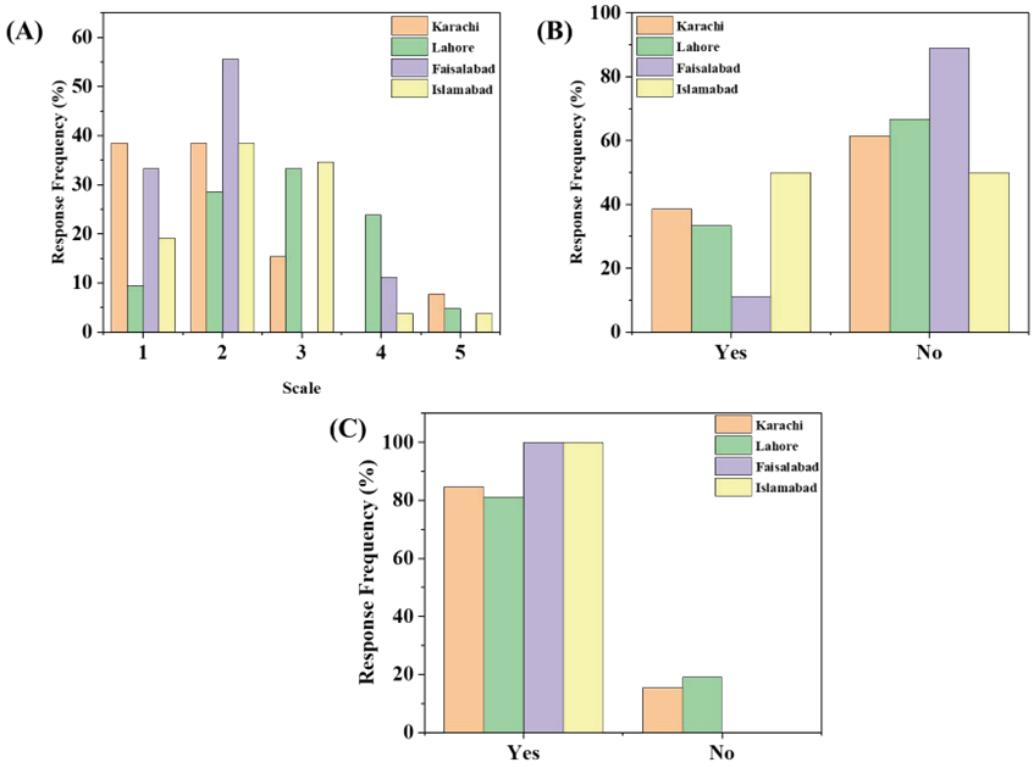

Figure 14. *Public perception regarding waste management sector in Pakistan in terms of (A) Salary Fairness, (B) Transparency in Financial Assessment, (C) Budget Allocation*

- **Financial Aspects and Perception of Investment in Waste Management**

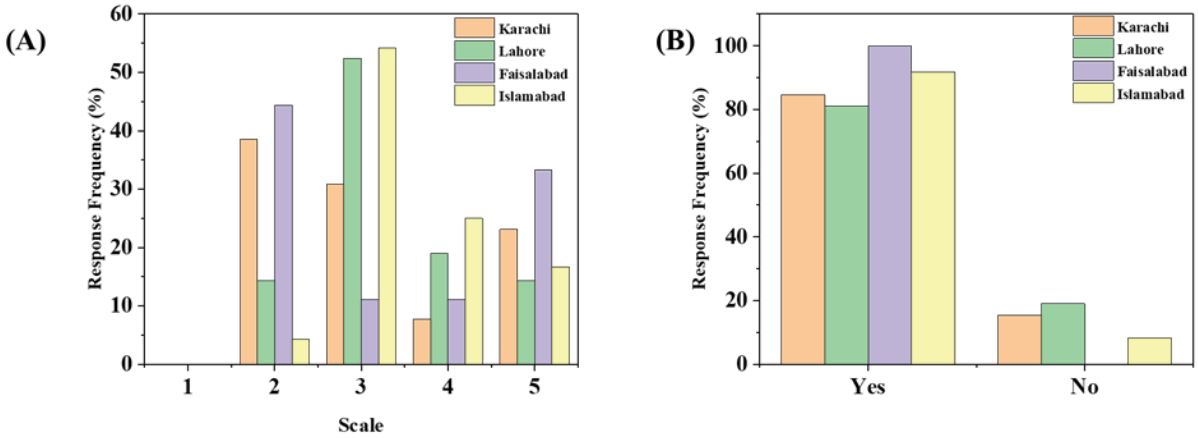

Figure 15. *Public perception regarding waste management sector in Pakistan in terms of (A) Cost-Benefit Evaluation of Waste Management, and (B) Worthiness of Investment.*

The investigations uncover complex links between the way people respond and the financial aspects related to waste management, in line with various Sustainable Development Goals (SDGs). The topic of fair wages (SDG 8: Decent Work and Economic Growth), financial transparency (SDG 16: Peace, Justice, and Strong Institutions), and resource distribution (SDG 17: Partnerships for the Goals) are all discussed. Responsible consumption and production (SDG 12) are enhanced by the assessment of advantages and disadvantages, whereas the examination of fresh technological investments showcases ingenuity and eco-friendly approaches.

- **Energizing Sustainability: Waste to Energy and Shaping Urban Futures**

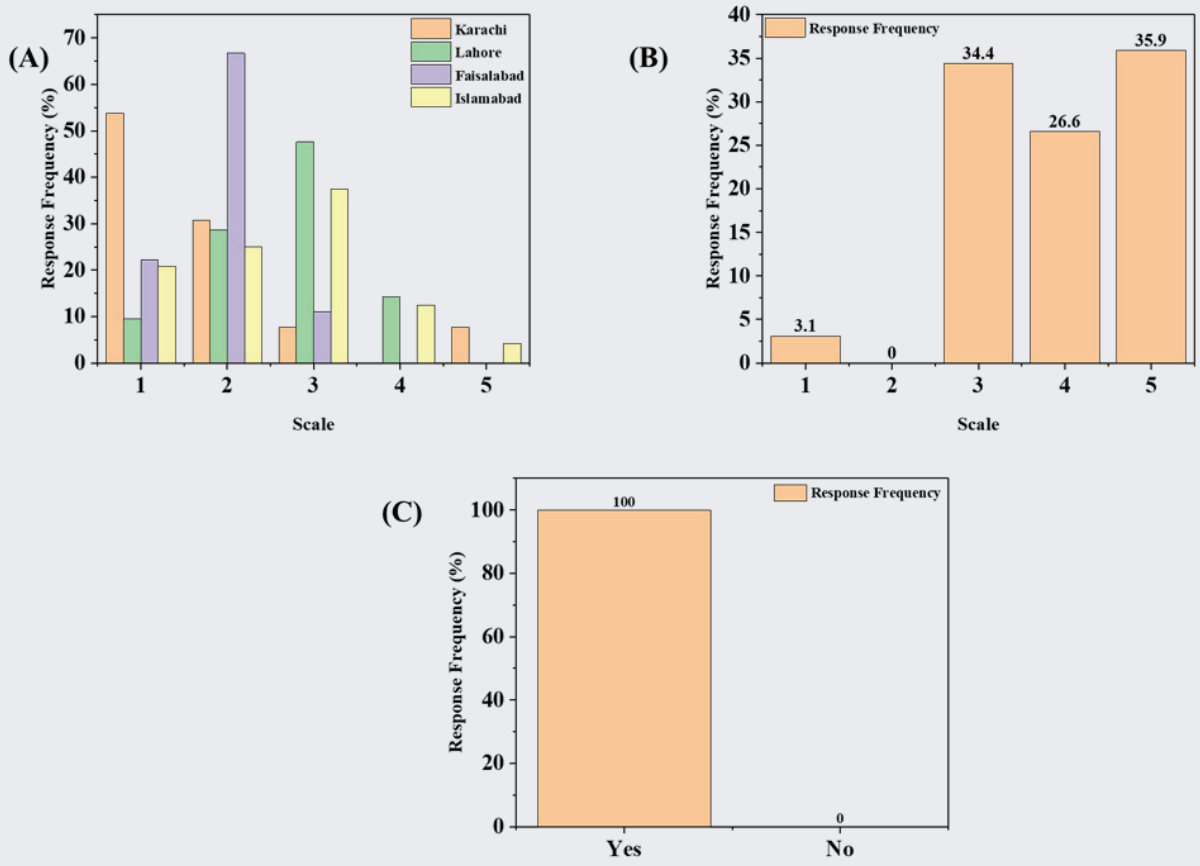

Figure 16. *Public awareness and opinion on (A) city's profitable waste utilization, (B) familiarity with Waste to Energy (WtE) technology, (C) WtE's role in addressing challenges.*

The investigations uncover complex links between the way people respond and the financial aspects related to waste management, in line with various Sustainable Development Goals (SDGs). The topic of fair wages (SDG 8: Decent Work and Economic Growth), financial transparency (SDG 16: Peace, Justice, and Strong Institutions), and resource distribution (SDG 17: Partnerships for the Goals) are all discussed. Responsible consumption and production

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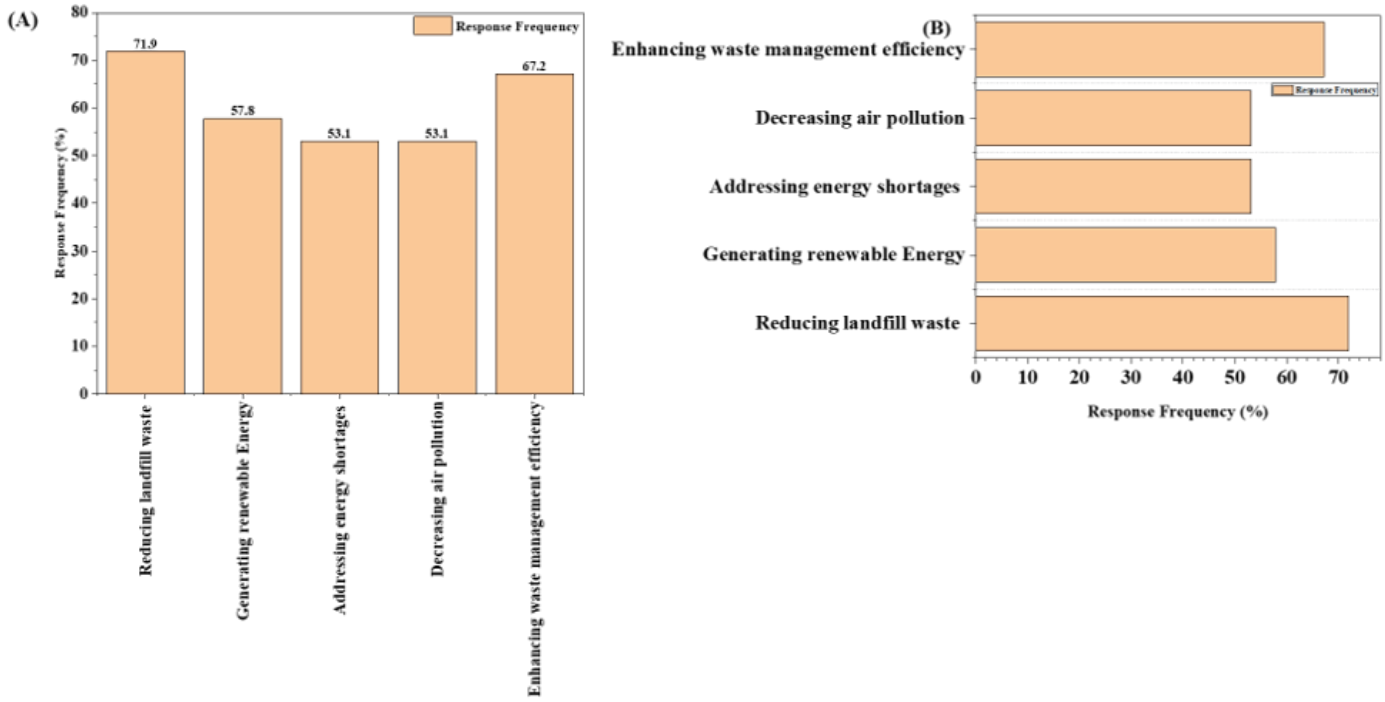

Figure 17. *Public awareness and opinion on (A) benefits of WtE technology, and (B) support towards environmentally compliant WtE project.*

- **Incentives and Public Participation**

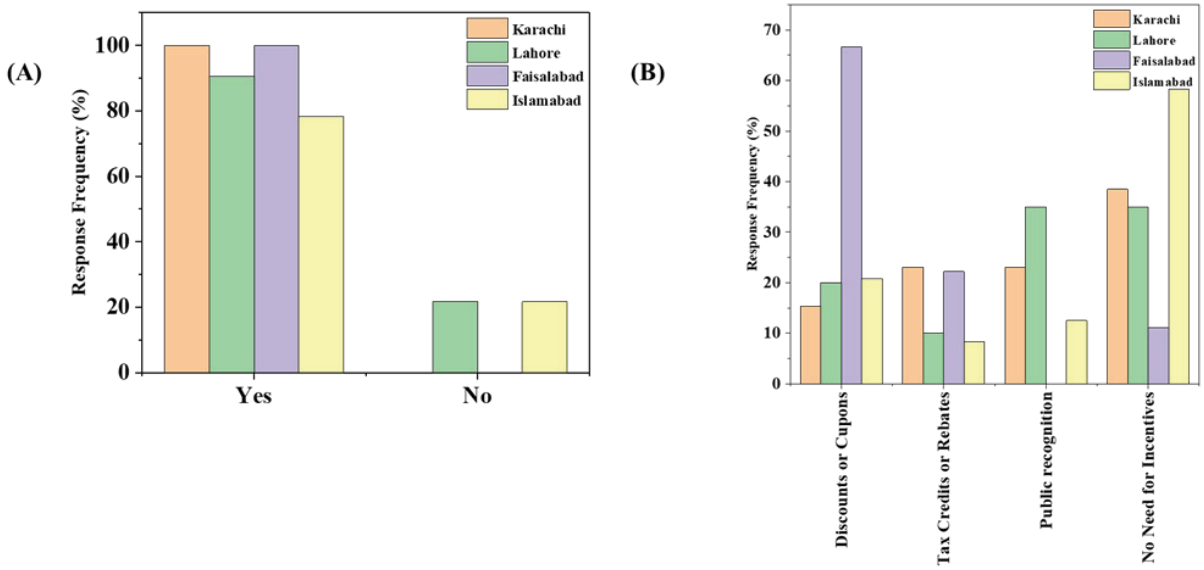

Figure 18. *Public preference to encourage waste collection and management through (A) Incentive-Driven Waste Bin Usage, and (B) Motivating Incentives for Regular Public Waste Bin Usage*

These series of questions showcase the intricate dynamics between public responses, highlighting the symbiotic relationship between incentives and community engagement in waste disposal. The questionnaire commences by assessing the potential impact of incentive schemes on waste management practices, a subject that is further investigated in subsequent questions. The questionnaire offers valuable information on the different kinds of rewards that people prefer, giving us a better grasp of the wide array of factors that can impact responsible waste management actions. The previously mentioned replies can be combined to create a coherent story, where motivations play a vital part in linking personal behaviors to their overall impact on the environment. Based on the data collected, it appears that there is a situation where the synchronization of personal aspirations with group goals leads to various outcomes, shaping an improved waste disposal system through responsible participation and shared benefits.

4. Socio-Economic Significance of the Study

Examining the composition of Municipal Solid Waste (MSW) in various metropolitan cities of Pakistan has considerable socio-economic significance across multiple dimensions

4.1. Environmental Impact Mitigation

It is crucial to develop efficient waste management strategies by gaining a comprehensive understanding of the composition and qualities of municipal solid waste (MSW) in major cities of Pakistan. Authorities can effectively implement recycling and disposal methods by accurately identifying the various types and quantities of waste that are being generated. As a result, it minimizes the impact on the environment, prevents the pollution of soil and water, and decreases the release of harmful emissions like greenhouse gases.

4.2. Resource Optimization

Analyzing waste composition offers valuable knowledge about the possible hidden assets within municipal solid waste. By implementing effective systems for categorization and reprocessing, it is possible to reclaim and repurpose various materials such as plastics, paper, and metals. This practice not only alleviates the burden on our planet's finite resources but also promotes the adoption of

sustainable consumption habits. Pakistan's commitment to achieving Sustainable Development Goal 12 (Responsible Consumption and Production) is exemplified by its dedication to resource optimization.

4.3. Waste to Energy Opportunities

The research results are essential in determining the viability of waste to energy (WtE) initiatives. As urban centers experience a surge in energy requirements, the implementation of Waste-to-Energy (WtE) solutions can play a crucial role in transforming organic waste into usable forms of power, such as electricity or heat. Not only does this tackle the issue of energy shortages, but it also lessens the environmental impact of waste disposal sites. Implementing effective Waste-to-Energy (WtE) projects in Pakistan has the potential to enhance the country's energy security while also contributing to the achievement of Sustainable Development Goal 7, which focuses on ensuring access to affordable and clean energy.

4.4. Economic Growth and Job Creation

Efficient waste disposal systems generate economic prospects and employment opportunities in metropolitan regions. Local communities can benefit from the creation of jobs through the process of collecting, organizing, and reusing waste materials. Moreover, the development of waste management systems, including advanced waste treatment facilities and efficient recycling methods, plays a crucial role in fostering economic prosperity within these areas. The progress in socio-economic advancement is in accordance with Sustainable Development Goal 8, which focuses on promoting decent work opportunities and fostering economic growth.

4.5. Public Health Improvement

Effective waste disposal systems have a direct correlation with the well-being of the general population. Promoting the elimination of open dumping and implementing measures to combat waste-related illnesses, such as those caused by insects and polluted water, play a significant role in fostering healthier societies. Enhancing the well-being and productivity of individuals contributes to the advancement of socio-economic development and the achievement of healthcare objectives as stated in Sustainable Development Goal 3 (Good Health and Well-being).

4.6. Tourism and Aesthetic Value

Cities that are tidy and efficiently maintained have a greater appeal to both tourists and investors. The economy of Pakistan greatly benefits from tourism, as it plays a crucial role in boosting the country's financial status. Moreover, a more pristine urban setting not only improves Pakistan's reputation but also stimulates investments in the tourism sector. This enhances the growth of nearby economies and contributes to the achievement of Sustainable Development Goal 11 (Sustainable Cities and Communities).

4.7. Climate Change Mitigation

Implementing efficient waste disposal methods, such as Waste-to-Energy (WtE), has the potential to greatly diminish the release of harmful greenhouse gases into the atmosphere. Pakistan has the potential to make a significant impact on global climate change mitigation (Sustainable Development Goal 13) and improve energy security by redirecting organic waste away from landfills and using it for energy generation.

4.8. Public Awareness and Education

The research results have the potential to establish a solid basis for public awareness initiatives and educational initiatives. Through comprehending the composition of waste and its consequential effects, individuals can actively participate in the conscientious management of waste and the promotion of recycling methods. This will cultivate a societal ethos centered around environmental guardianship, ultimately aiding in the advancement of Sustainable Development Goal 4, which focuses on ensuring quality education for all.

4.9. Policy Development and Investment

The study's data can provide valuable insights for policymakers to develop waste management policies and strategies that are grounded in evidence. The potential to draw in funding from governmental entities, private industries, and global institutions can result in the advancement and enhancement of waste management infrastructure.. To put it briefly, the extensive and diverse socio-economic importance of researching the composition of municipal solid waste (MSW) in major cities of Pakistan cannot be overstated. It involves the protection of the environment, the optimization of resources, the generation of employment opportunities, the enhancement of public health, and the support for global sustainability objectives. Furthermore, it highlights the capacity of waste-to-energy projects to meet energy demands while mitigating ecological consequences. The findings of this study provide a solid basis for making informed decisions and implementing revolutionary modifications in the field of urban waste management. These changes will have a positive impact on society and the economy as a whole.

5. Conclusions

To summarize, the extensive examination of the composition of municipal solid waste (MSW) in prominent cities of Pakistan offers significant observations and meaningful results. The findings of this study provide valuable insights into effective approaches for managing waste in a sustainable manner. These approaches aim to safeguard the environment, maximize resource utilization, foster economic development, and enhance public health. Additionally, it underscores the capacity of waste-to-power alternatives in addressing energy needs and alleviating the impacts of climate change. The results of our research provide a solid basis for making well-informed policies, promoting public awareness, and allocating resources towards the development of waste management systems. These efforts will ultimately lead to a cleaner and more sustainable urban environment in Pakistan.

5.1. Value Addition/ Impactful Outcomes

- Promoting sustainable waste disposal practices to mitigate environmental damage caused by soil and water contamination and detrimental emissions.
- Recognizing the worth of materials encourages sustainable consumption and the preservation of resources.
- Creating effective waste management systems not only stimulates job growth but also contributes to the overall economic well-being.
- Proper management of waste contributes to the overall improvement of community welfare and efficiency.
- Energy-from-waste solutions help mitigate the release of greenhouse gases and tackle the issue of climate change.
- Urban areas entice capital and bolster the field of tourism.
- Gaining knowledge leads to a greater sense of responsibility for the environment and encourages the pursuit of education.
- The utilization of research data plays a crucial role in shaping policy decisions and fostering investments in the field of waste management.

5.2. Recommendations for Policy Makers for Effective Municipal Solid Waste Management

Municipal Solid Waste (MSW) management in Pakistan's growing cities is difficult. Population expansion and rapid urban development have put strain on waste management infrastructures. The Waste-to-Energy (WtE) conversion process is a notable solution among the emerging options for waste management. This method not only provides a sustainable approach to handling waste but also presents an opportunity for the generation of renewable energy. Pakistan must use a multifaceted waste management strategy in addition to Waste-to-Energy. This approach makes WtE the key component while supporting other feasible waste management strategies. The following guidelines explain the multi-dimensional approach and recommend integrating multiple methods to solve urban waste management problems.

- **Invest in WtE Technologies**

Innovative solutions are needed to address the growing urban garbage problem. Investing in cutting-edge Waste-to-Energy (WtE) technologies is crucial. The government and commercial sector should work together to improve research and development and attract international expertise. Businesses researching novel and efficient waste-to-energy conversion processes should be incentivized. The proposed solution reduces waste and uses renewable energy.

- **Strengthen Regulatory Framework for WtE**

A strong regulatory framework is needed to promote Waste-to-Energy (WtE) activities. Effective governance requires transparency, promotion, and standardization of legislation throughout metropolitan regions. Waste-to-Energy (WtE) operations must have clear environmental criteria to be clean and sustainable. In addition, the implementation of a streamlined process for the acquisition of permits and approvals has the potential to significantly accelerate the development of Waste-to-Energy (WtE) projects.

- **Enhance Waste Segregation and Collection for WtE**

Waste-to-Energy (WtE) systems depend on waste quality. Metropolitan authorities should establish sources-based trash segregation systems. Citizens should be taught how to sort recyclables, organic garbage, and non-recyclables. Improved collection systems help deliver waste to Waste-to-Energy (WtE) plants quickly and efficiently, reducing contamination and maximizing energy conversion efficiency.

- **Promote Public-Private Partnerships in WtE**

Waste-to-energy (WtE) projects require significant funding and expertise. Public-Private Partnerships (PPPs) can consolidate resources, distribute risks, and combine specialized knowledge and skills, affecting many sectors. Public-Private Partnerships (PPPs) can accelerate Waste-to-Energy (WtE) technology adoption by combining government regulation with private sector innovation.

- **Integrate WtE into Urban Planning**

Waste-to-Energy (WtE) plants should be strategically integrated into future urban metropolis design. Urban planners must consider garbage generation sources, access, and energy grid integration. Like water treatment and electricity generation plants, waste-to-energy (WtE) facilities should be essential urban infrastructure.

- **Implement Recycling Programs**

Waste-to-Energy (WtE) technologies manage much waste. However, recycling is essential to preserving precious materials. Metropolitan authorities should implement comprehensive recycling programs to utilize glass, plastics, and metals. Recycling reduces natural

resource use and helps Waste-to-Energy (WtE) systems separate non-combustible materials.

- **Promote Composting of Organic Waste**

Organic materials make up much of urban garbage. Waste can be turned into nutrient-rich compost, an alternative to incineration or landfilling. Local governments should promote community composting, household composting, and compost use in parks and gardens.

- **Educate and Raise Awareness about MSW Management**

Any waste management strategy needs public participation to succeed. Regular campaigns, workshops, and school programs should promote waste-to-energy (WtE), recycling, and composting. Informed citizens are more likely to segregate waste, support waste-to-energy (WtE), and promote sustainability.

- **Monitor and Evaluate MSW Management Initiatives**

Continuous assessment underpins improvement. Waste-to-Energy (WtE) and other waste management programs must be reviewed regularly. Performance measures, environmental impact, and public response are monitored and assessed. Data-driven insights can guide policy changes.

- **Child Labor Eradication**

Cities should work with relevant organizations and authorities to establish programs that especially target the elimination of child labor given the prevalence of child labor in garbage processing. These initiatives should put a strong emphasis on giving kids access to education, career development, and other alternatives to break the cycle of waste-related work.

- **Climate-Resilient Waste Management:**

Considering the concerns raised by respondents regarding climate change, it is recommended that cities incorporate climate-resilient strategies into their waste management plans. The scope of this report encompasses disaster preparedness, adaptive infrastructure, and waste reduction initiatives, all of which consider the potential consequences of climate-related events.

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