Feasibility and Experimental Validation and Cost-benefit Analysis of Municipal Solid Waste to Energy

By

Waqas Ahmad

00000206184

Session 2017-19

Supervised by

Dr. Muhammad Hassan

A Thesis Submitted to U.S. – Pak Centers for Advance Studies in Energy in partial fulfillment of the requirements for the degree of

MASTER of SCIENCE in

THERMAL ENERGY ENGINEERING

U.S. – Pak Centers for Advance Studies in Energy (USPCAS-E)

National University of Sciences and Technology (NUST)

H-12, Islamabad 44000, Pakistan

September 2019

Feasibility and Experimental Validation and Cost-benefit Analysis of Municipal Solid Waste to Energy

By

Waqas Ahmad

00000206184

Session 2017-19

Supervised by

Dr. Muhammad Hassan

A Thesis Submitted to U.S. – Pak Centers for Advance Studies in Energy in partial fulfillment of the requirements for the degree of

MASTER of SCIENCE in

THERMAL ENERGY ENGINEERING

U.S. – Pak Centers for Advance Studies in Energy (USPCAS-E)

National University of Sciences and Technology (NUST)

H-12, Islamabad 44000, Pakistan

September 2019

THESIS ACCEPTANCE CERTIFICATE

Certified that final copy of MS/MPhil thesis written by **Mr. Waqas Ahmad**, (**Registration No. 00000206184**), of U.S.-Pak Centers for Advance Studies in Energy has been vetted by undersigned, found complete in all respects as per NUST Statues/Regulations, is within similarities indices limit and accepted as partial fulfillment for award of MS/MPhil degree. It is further certified that necessary amendments as pointed out by GEC members of the scholar have also been incorporated in the said thesis.

Signature: ______________________________

Supervisor Dr. Muhammad Hassan

Date: ______________________________

Signature: ______________________________

HoD-TEE Dr. Adeel Javed

Date: ______________________________

Signature: ______________________________

A/Principal Dr. Adeel Waqas

Date: ______________________________

Certificate

This is to certify that work in this thesis has been carried out by **Mr. Waqas Ahmad** and completed under my supervision in, U.S.-Pak Centers for Advance Studies in Energy, National University of Sciences and Technology, H-12, Islamabad, Pakistan.

Supervisor:

____

Dr. Muhammad Hassan
U.S.-Pak Centers for Advance Studies in Energy
NUST, Islamabad

GEC member 1:

____

Dr. Adeel Waqas
U.S.-Pak Centers for Advance Studies in Energy
NUST, Islamabad

GEC member 2:

____

Dr. Adeel Javed
U.S.-Pak Centers for Advance Studies in Energy
NUST, Islamabad

GEC member 3:

____

Dr. Majid Ali
U.S.-Pak Centers for Advance Studies in Energy
NUST, Islamabad

HoD-TEE:

____

Dr. Adeel Javed
U.S.-Pak Centers for Advance Studies in Energy
NUST, Islamabad

A/Principal:

____

Dr. Adeel Waqas
U.S.-Pak Centers for Advance Studies in Energy
NUST, Islamabad

Dedication

I dedicate this thesis to my parents.

Acknowledgements

I am extremely thankful to Allah Almighty without Whose help I would not have been able to complete this work. All the help and support from my parents and teachers were only because of Allah’s Will.

I am thankful to my supervisor, Dr. Muhammad Hassan, for the tremendous supervision, motivation, and guidance he has conveyed all through my time as his understudy. I have been exceptionally honored to have a supervisor who thought such a great amount about my work, and who responded to my inquiries and questions so immediately.

I am very thankful to the HoD TEE Dr. Adeel Javed, HoD Research Dr. Majid Ali, Principal Dr. Adeel Waqas, WSSP Finance Director and Directorate of Sanitation of MCI for their support. I am very grateful to USAID for providing a scholarship to pursue my Master's studies at USPCASE-NUST. I am thankful to my lab mates, lab engineers, lab technicians, all GEC members, USPCAS-E and USAID for their provision all over the program.

Thank you

Waqas Ahmad

Abstract:

Pakistan is rapidly growing economy of the world with one of the highest urbanizations and average annual growth rate of 2.4 %, therefore municipal solid waste generation is also quite high as (0.4 to 0.7) kg/capita/day. This study represents a gap analysis of MSW management companies, Waste to Energy Potential for the selected cities, proximate and ultimate analysis of MSW fuels, and comparison with other fossils fuels, cost-benefits analysis of solid recovered fuels with local fossil fuel. To achieve these objectives surveys, interviews and ground observation were performed. For the WtE technology adaptation, two scenarios were considered; Mass burn and mass burn without recycling materials for the two cities of Islamabad and Peshawar. In experimentation, model fuel is manufactured and there proximate and ultimate analysis was performed. Cost-benefit analysis of SRF and comparison with fossil fuels was performed. The analysis of the WSSP municipality has the problem of bin locations, vehicle underutilization, inexperienced and uneducated labor. The analysis of the potential of WtE shows that Mass Burn with recycling has the potential of producing 178 MW and 141 MW of electricity for Peshawar and Islamabad respectively. While the second scenario based on Mass Burn without recycling has the potential of 23 MW & 14 MW of electricity generation at Peshawar and Islamabad respectively. The calorific value of SRF is very close to that of wood and coal. The replacement of wood, coal, natural gas, and furnace oil gives savings of up to 41%, 24%, 12%, 2% respectively with MSW SRF fuels.

Contents

List of Tables

List of Figures

Chapter 1

Introduction

1.1 Introduction

The sustainable energy resource is the main fields of socio-economic interest due to the limited supply and resources of fossil fuels worldwide. The limited supply of fossils and arising global warming situations has strongly diverted the researchers in alternative renewable energy resources. The condition becomes very challenging to deal with the rising energy demand in the rural sector of the developing countries. There was a time when the concept of the engine was so over the top nobody thought it would happen and now engines that are developed exceeds the speed of sound and more, but the energy expenditure has grown exponentially as well. Similarly, power plants utilized these days demand high energy which is a strenuous task to cope up with just because the natural resources are limited and at the rate, it is being used it can come to an end any second. Human thinking has evolved so much with time and we as humans want to extend the time span as much as possible and with the concept of Waste to Energy comes into play.

1.2 Municipal Solid Waste (MSW)

Municipal solid waste (MSW), those durable goods, non-durable goods, containers and packaging materials, food wastes and yard trimmings, and miscellaneous organic wastes arising from residential, commercial, institutional, and industrial sources. Other types of waste not typically included in municipal solid waste are industrial waste produced by manufacturing and processing operations, construction and demolition waste, agricultural waste, oil and gas waste, and mining waste resulting from the extracting and processing of minerals [1].

1.3 Background

The world population was 7 billion in 2011 and it is expected to reach 8.1 billion by 2025 [2]. This huge increase of population is in direct linkages with economic development and industrialization [3]. Metrapolation of the world is increasing at a fast rate of 1.5 % as compared to the rest of the population. Current statistic of A. Kumar and S. R. Samadder et al. [4] shows that half of the world population live in cities which ultimately produce MSW. The worldwide generation of MSW is 2 billion tons per year, it will reach to 2.2 billion tons per year in 2025[5], [6]. According to World bank and A. Fazeli et al. [7], [8] the per capita generation rate of MSW is higher in developed countries as compare to developing countries, and the main fact behind that is economic and social prosperity. Developing countries are now developing, as the estimation shows that in the coming 2-3 decades the MSW generation rate in such countries will meet the required rate, and which is alarming. Why is that so because people of such countries are adapting the lifestyle of developed nations all because of globalization. MSW generation is mainly connected with changing food habits, consumption pattern and living standards of urban [9].

Most developing countries highly ignore the overall environmental impact of managing there MSW. Developing countries have acquired a worrying attitude towards the effects that can be caused by improper handling of MSW[10]. Managing the MSW in many poor nations takes a substantial share of the Municipal budget, yet existing practices pose a great danger to the environment and to public health and well-being [11]. Waste management planning is a subset of environment planning through limiting, reusing, recycling and getting rid of resources in a way that minimizes overall biophysical and socioeconomic effects [12].

1.4 Municipal Solid Waste Management

Municipal Solid Waste (MSW) is an unavoidable side-effect of human exercises. MSW generation increases as with the economic prosperity of the nation due to their upgraded lifestyle, for the wellbeing and betterment of the people, the municipal solid waste must be managed and treated properly [13]. In the developing countries, the municipal solid waste generation rate is increasing drastically, like in Pakistan MSW is increasing by 2.4%. On a regular basis bulk amount of waste is being produced, (0.283-0.612) kg/capita/day [14], which is likewise another's a country issue. The generic municipal solid waste collection is being done in the different cities of Pakistan with the main objective of dumping it in the open landfill without considering the recycling process, which is one of the important prerequisites [15]. The recycling framework exists at many places which include the gathering of recyclable materials like metals, cardboards and bones from dump yard and trash compartments [13]. Figure 1(d) shows the scavenger which collects the recyclables, according to them they sell the collected materials to junk shops from there they send them to a company like glass manufacturing, brick kilns, etc. This MSW ought to be considered as a significant hotspot for reused materials and vitality. The above part of the MSW creation rate is the consequence of the absence of network-wide projects to upgrade the ecological mindfulness, and to support decreased MSW generation, and to support recycling. A developing country like Pakistan which needs to fulfill its fundamental needs like power and dispose of waste being produced on regular basis, the waste to energy (WtE) is the best perpetual arrangement which decreases 90 % volume of the waste along with 80 % reduction in its mass. As most of the dump yard was being matured in the country, like Hayatabad in Peshawar and I-12 of Islamabad. It causes various issues like underground water sullying and contamination, methane gas emission, leachate, municipal waste sludge, odor pollution, irresistible ailments like malaria, dengue and so forth thus other.

Figure 1(a) waste collection in Hayatabad using a donkey cart, (b) Dumping process Islamabad, (c) Dumping site I-12 Islamabad, (d) Scavengers sorting and collecting the recyclables, (e) Scavengers collecting glass bottles for recycling, (f) Leather and regzine for burning in a kiln

1.5 Electricity demand

Electricity is a necessary element of any country's growth and prosperity. The total electricity production in Pakistan from both renewable and non-renewable sources is shown in Figure 2. The total electricity demand of Pakistan is 31097 MW and the total generation of electricity is 30034 MW on 30 June 2019 which shows a gap of 1063 MW [16]–[19] . The consequences of this gap country face in the term of severe load shedding both in rural and urban areas. Cities like Peshawar faces around 3.30 hrs.

average daily load shedding and 3.33 hrs at Islamabad city in 2017 [17]–[19]. Government failure of providing electricity to local industries like Marbles factories, chemical industries, ice plants and so many are now shut down. Around 40 percent of factories and industrial units are now been closed and around 7.5 percent of the labor force is out of job only because of this dilemma [17].

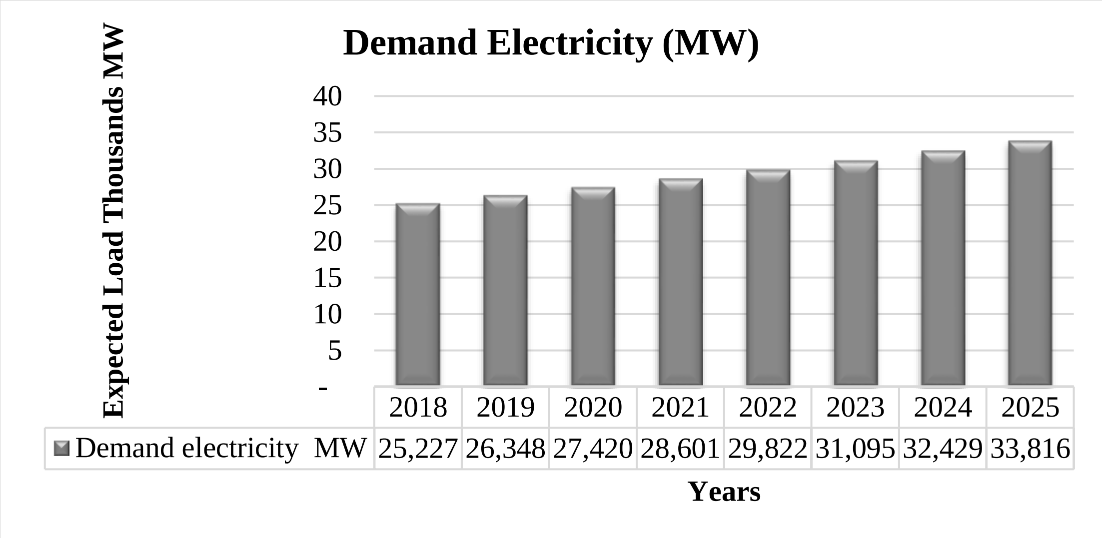


Figure 2 Expected Load Demand [18]

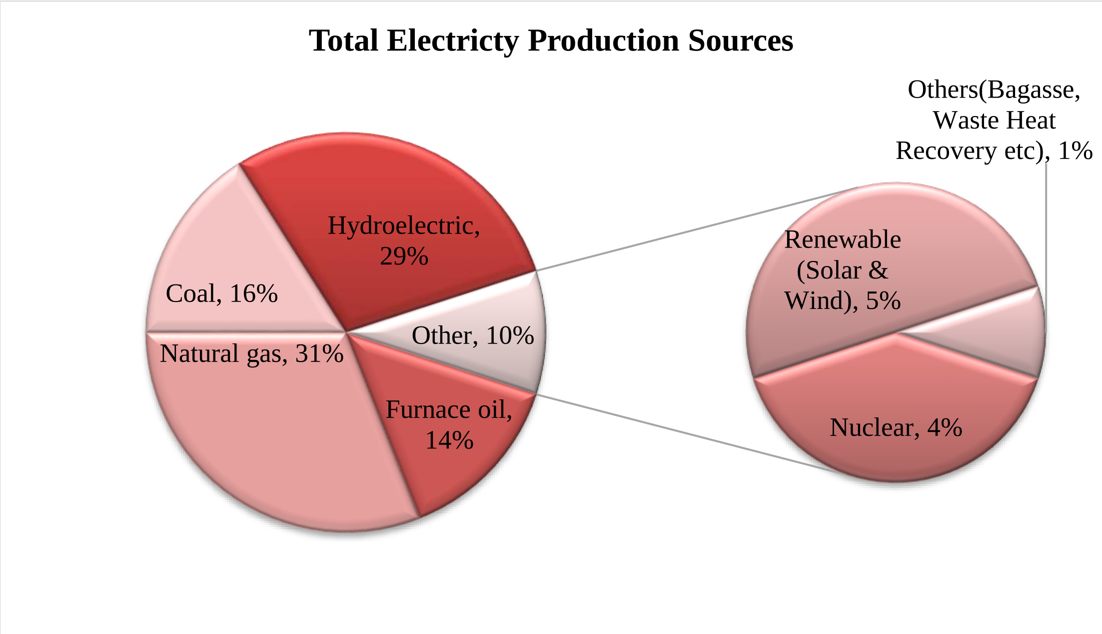


Figure 3 Electricity generation by source[18], [20]

1.6 Pakistan situation

Geographic coordinates of Pakistan are 33 41 N, 73 03E. The territory of Pakistan has 770,875 square kilometers of land [21], [22]. Pakistan is the 36th biggest country on the planet with an absolute area of 796,095 square kilometers [21]. Pakistan is the sixth most crowded nation on the planet with a population of 207,774,520, with an average annual growth rate of 2.4% over a time of 1998-2017 [14], [23]. This circumstance has prompted a fast increase in the country's electricity demand. The municipal solid waste (MSW) generation is also a severe problem of the big cities and the population & MSW have a proportional relationship. The management of MSW in developing countries like Pakistan is very poor and not been taken seriously so far [24]. In Pakistan, the government has established the municipalities for waste management and collection but the MSW is only being landfilled even based on the old techniques. Hence, the landfilling and open waste dumping causes adverse impacts on the environment and health of the public. The big cities of Pakistan are facing communal problems of odor pollution, sight pollution, water contamination, blockage of sewerage system, spread of diseases like malaria, dengue, typhoid and diarrhea [24].

The proposed SRF system should guarantee the minimum environmental contamination during manufacturing processes and, at the end of their working life and guarantee the elimination of waste through the recycling method as shown in figure 4. And not just in the cement industry but various other industries face the same issue and are looking for an alternative source. The industries like brick kilns, tobacco leaf cooking kilns, and so.

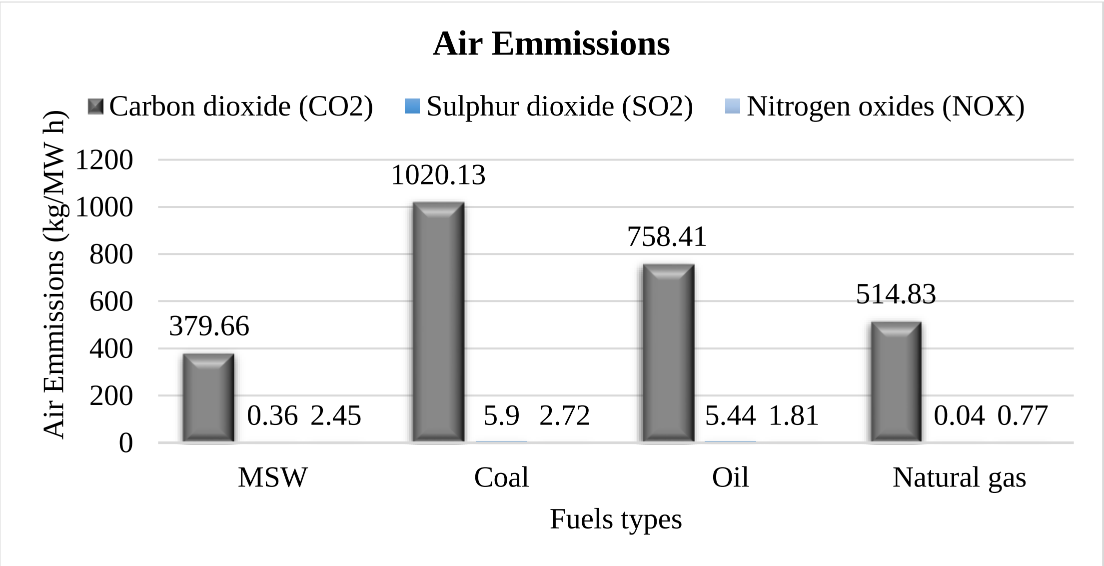


Figure 4 Fuel comparison used in USA power production plants [25]

Figure 5 (a) Waste generation at the site, (b) Waste generation temporary storage, (c) Peshawar dumping site, (d) Islamabad dumping site with scavengers, (e) Process of dumping by pressing, (f) Recyclable material reached junk dealer

1.7 Scope

The area targeted for this study is Peshawar situated in KPK (Khyber Pakhtunkhwa) province with a total population of 4,269,079 [23], [26], [27] and the capital city Islamabad with a total population of 2,006,572 [23], [28], [29]. The capital cost and operating and maintenance costs are not included in cost-benefit analysis.

1.8 Research statement

To examine the current MSW management practices being applied from waste generation to final disposal. Perform gap analysis of both municipalities. Determine waste to energy potential in terms of megawatts to know the feasibility of the project. Solid recovered fuel (SRF) to be made using different equipment and then combustion analysis is to be performed. Comparison of SRF with fossil and then cost-benefit analysis.

1.9 Objective

The main objectives of this research work are;

- To determine the gap in management of MSW in Islamabad and Peshawar and its electricity generation potential.
- To determine the amount of waste generated in the city of Islamabad & Peshawar and its fractional analysis.
- To determine the fuels type used by the local industries of Peshawar.
- Economic analysis i-e cost-benefit analysis of MSW fuel and local fossil fuel.

1.10 Organization of thesis

The study of this thesis is summarized are as follow;

Chapter 2: This chapter includes the literature on what is going on in the world regards MSW management and the conversion of MSW to energy. The trend being followed in Pakistan. This section will help us better understand the problem of the MSW.

Chapter 3: This chapter will be consisting of the complete methodology of work which is to be carried out that is surveys structures, fuel making, combustion tests, cost-benefit analysis techniques.

Chapter 4: This chapter will sum up the results of the Surveys and audits, SRF fuel structures, comparisons with fossil fuels, detailed results of economic analysis of SRF with other fuels.

Chapter 5: This chapter includes the conclusion of research and recommendations.

References

[1] M. G. K. Charles R. Rhyner, Leander J. Schwartz, Robert B. Wenger, *Waste management and resource recovery*, vol. 53, no. 9. 1995 by Taylor & Francis Group, LLC CRC Press is an imprint of Taylor & Francis Group No, 1995.

[2] FAO(Food and Agriculture Organization of the United Nations), *The state of the world's forests 2018 - Forest pathways to sustainable development*. Rome: THE STATE OF THE WORLD, 2018.

[3] O. K. M. Ouda, S. A. Raza, A. S. Nizami, M. Rehan, R. Al-Waked, and N. E. Korres, "Waste to energy potential: A case study of Saudi Arabia," *Renew. Sustain. Energy Rev.*, vol. 61, pp. 328–340, 2016.

[4] A. Kumar and S. R. Samadder, "An empirical model for prediction of household solid waste generation rate – A case study of Dhanbad, India," *Waste Manag.*, vol. 68, pp. 3–15, 2017.

[5] Urban Development & Local Government Unit World Bank, "What a waste a global review of Solid Waste Management," 2012.

[6] A. Khalid, M. Arshad, M. Anjum, T. Mahmood, and L. Dawson, "The anaerobic digestion of solid organic waste," *Waste Manag.*, vol. 31, no. 8, pp. 1737–1744, 2011.

[7] U. D. S. Wolrd Bank, *What a Waste 2.0: Global snapshot of Solid Waste Management to 2050*. 2018.

[8] A. Fazeli, F. Bakhtvar, L. Jahanshaloo, N. A. Che Sidik, and A. E. Bayat, "Malaysia's stand on municipal solid waste conversion to energy: A review," *Renew. Sustain. Energy Rev.*, vol. 58, pp. 1007–1016, 2016.

[9] D. Khan, A. Kumar, and S. R. Samadder, "Impact of socioeconomic status on municipal solid waste generation rate," *Waste Manag.*, vol. 49, pp. 15–25, 2016.

[10] S. A. Batool and M. N. Chuadhry, "The impact of municipal solid waste treatment methods on greenhouse gas emissions in Lahore, Pakistan," *Waste Manag.*, vol. 29, no. 1, pp. 63–69, 2009.

[11] R. Joshi and S. Ahmed, "Status and challenges of municipal solid waste management in India: A review," *Cogent Environ. Sci.*, vol. 2, no. 1, pp. 1–18,

2016.

[12] S. Oduro-Appiah, K., Aidoo, D.O. and Graham, "Fee-based solid waste collection in economically developing countries: The case of Accra metropolis," *Int. J. Dev. Sustain.*, vol. 2, no. 2, pp. 629–639, 2013.

[13] A. M. Troschinetz and J. R. Mihelcic, "Sustainable recycling of municipal solid waste in developing countries," *Waste Manag.*, vol. 29, no. 2, pp. 915–923, 2009.

[14] M. S. Korai, R. B. Mahar, and M. A. Uqaili, "The feasibility of municipal solid waste for energy generation and its existing management practices in Pakistan," *Renew. Sustain. Energy Rev.*, vol. 72, no. January 2016, pp. 338–353, 2017.

[15] J. Aleluia and P. Ferrão, "Assessing the costs of municipal solid waste treatment technologies in developing Asian countries," *Waste Manag.*, vol. 69, pp. 592–608, 2017.

[16] NEPRA(National Electric power Regulatory Authority), "State of Industry Report 2018," Islamabad, 2018.

[17] N. Iqbal, S. Nawaz, and S. Anwar, "Electricity demand in Pakistan : A nonlinear estimation," *Pak. Dev. Rev.*, vol. 52, no. 4, pp. 479–494, 2013.

[18] NEPRA (National Electric power Regulatory Authority), "State of industry report 2014," 2017.

[19] H. S. Awan, G. Samad, and N. Faraz, "No . 03 : 2019 PIDE research brief : Electricity subsidies and welfare analysis in Pakistan," no. 03, pp. 1–3, 2019.

[20] NEPRA(National Electric power Regulatory Authority), "State of industry 2017," 2017.

[21] Finance Division Govement of Pakistan, "Pakistan economic survey," 2019.

[22] Finance Division Govement of Pakistan, "Pakistan Economic Survey," 2018.

[23] G. of P. M. of Statistics, "Population Census 2017," 2017.

[24] G. Murtaza and A. Rahman, "Solid waste management in Khulana City and a case study of a CBO: Amader Paribartan," *Maqsood Sinha, AH Md., Enayetullah, I.(Eds.), Community Based Solid Waste Manag. Asian Exp. Waste Concern, Dhaka, Bangladesh*, 2000.

[25] C. S. Psomopoulos, A. Bourka, and N. J. Themelis, “Waste-to-energy: A review of the status and benefits in USA,” *Waste Manag.*, vol. 29, no. 5, pp. 1718–1724, 2009.

[26] Pakistan Bureau of Statistics, “District and Tehsil Level Population Summary With Region Breakup Population of Peshawar KPK,” 2017.

[27] Pakistan Bureau of Statistics, “Population and household detail from block to district Level-Peshawar KPK,” 2017.

[28] Pakistan Bureau of Statistics, “District and tehsil level Population summary with region breakup of Islamabad,” 2017.

[29] Pakistan Bureau of Statistics, “Population and household Census from block to district level of Islamabad,” 2017.

Chapter 2

Literature Review

2.1 Status of MSW in developed countries

Around the globe, whether it is a developed or developing country the main headache of them is MSW. According to Johan Karlsson et al. [1], in the European Union (EU) 28 countries generated around 2.5 billion tons of MSW in 2012. In 2014 a report published [2], Sweden had a huge contribution in the management of MSW, that the country had 33 operational power plants of waste to energy and utilized around 7.5 Mt of MSW [22-23]. Sweden the leader in the waste management system, the country made huge improvements as in 1975 only 62 % of total waste to landfills, during 4 decades of works on management MSW in 2016 data it shows that less than 1 percent is now being landfill. The interesting fact about Sweden, as its waste generation in the country, has increased so as to the energy recovery potential in WtE CHP plants. The country like Sweden importing a huge amount of waste from Europe to run their WtE CHP plants, the waste which is being imported from countries include Norway, and the UK [5]. It utilizes all of their waste [6]. The comparison is shown in Figure 6.

Another example of a developed country is Germany has also improved the MSWM system having zero tons of landfills in the past half decades [7]. According to [8] around 47 million tons of MSW generated in Germany in 2010. Due to the advancement in the management system and different strategies applied Germany used 0 % of MSW to landfills. It utilizes all its waste as 19 % recycled as organic waste, 45 % material recycling which contains metals and glass, 36 % incinerated.

In Italy, around 1.3 kg of waste per capita per day produce, which leads to 30 million tons of MSW per year of the whole country. The major portion of MSW that is 30 % ends in landfills, 16 % incineration and a major of 34 % recycled, and only 9 % is composted [9]. Landfills mean depositing waste into or onto land, but it is a temporary solution. Incineration thermal conversion of MSW to energy which is a permanent solution for that same as recycling [10].

A developed nations like the USA a huge portion of solid waste that is 64 % is used as landfill material, 28.5 % solid waste being recycled, while 7.4 % of waste converted into energy that is waste to energy [11]. In that 7.4 % waste, that is 26.3 million tons of waste, converted to energy means produce 2700 MW of electricity which is 0.3 % of total US generation [12]. The MSW waste to energy renewable energy source is far better as compared to other renewable energy sources like wind, geothermal, solar [13].

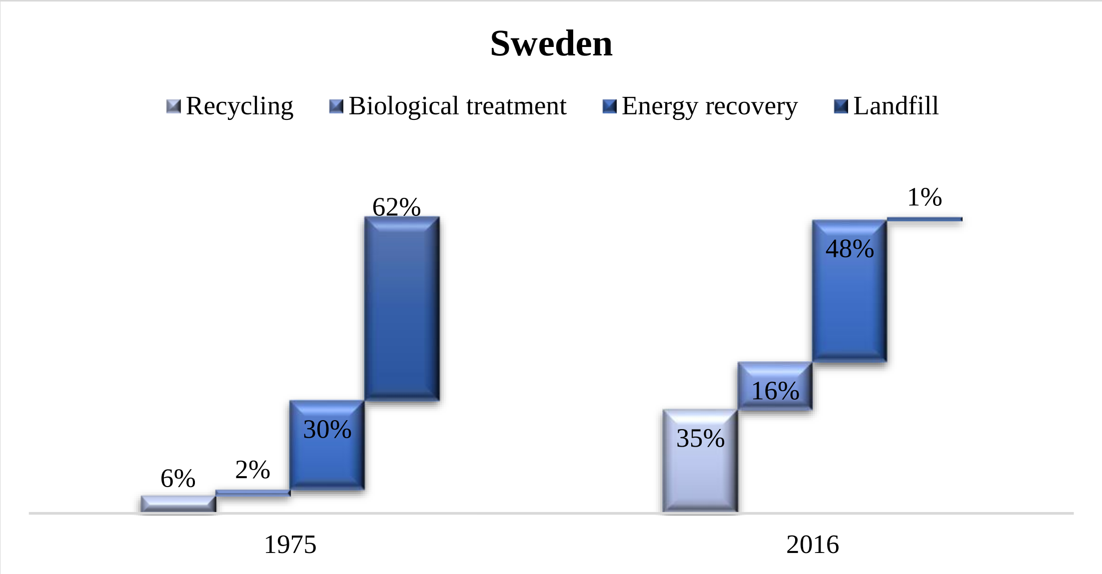


Figure 6 MSW management comparison

2.2 Status of MSW in developing countries

Over the last four decades the middle eastern country, the Kingdom of Saudi Arabia generated huge revenue from crude oil production through export and achieve significant development both socially and economically [14]. The total population according to census 2010 was 27 million [15] with the MSW production rate of 1.4 kg/capita/day [16],[17]. By keeping that figure in mind as average, the total MSW generation in-country is 15.3million tons. The generated amount is disposed to landfills, only 10-15% paper and cardboard are recycled. During the months of Ramadan and Hajj millions of Muslims come to the holy cities of KSA that is Makkah and Medina to perform religious rituals. Most of the food and drinks are served in disposable plastics [18]. For this huge amount of waste to dump it require landfills area of 2.8 million m2/year [19]. The most alarming situation in the country is that in the whole country, not even a single WtE plant exists, nor even the potential study of MSW being performed till 2015 [19]. The government of KSA is now in search of a sustainable solution for solid waste management and research work is started to treat the MSW.

The United Arab Emirates (UAE) an oil and gas-rich country. According to energy consumption, UAE is the 18th largest consumer [20] of energy and their annual average energy consumption is 11263 kWh per capita. Around 98.5 % of electricity production comes from fossil fuel-generated plants. The growth rate of the UAE population and MSW which is 1.25 % and 1.55 kg/capita/day respectively. The total annual waste generation is 5.7 million tons in 2018 [20]. The government now stepped up to shift its energy focus towards renewables' [21] but still not even install a single WtE facility.

After Saudi Arabia's second-largest economy of the Middle East is Iran with an estimated Gross Domestic Product GDP in 2016 of USD 412.2 billion [22]. Developing country [23], has a population of 81 million according to 2017 data. Out of which 74.6% live in urban areas[23], [24]. The total MSW generation only 71.2% of waste is collected from the capital city, Tehran [23]. It is estimated that 20 million tons of MSW produced every year [25]. In that amount, only 20% is recycled that is 3200 tons while the rest is consumed by landfills that are illegal dumping. Only one WtE plant is in operation in the whole country [26].

In neighbor Iran, a developing country [23], has a population of 81 million according to 2017 data [23], [24]. The total MSW generation only 71.2 % of waste is collected from the capital city, Tehran. According to M. R. Alavi Moghadam et al. [27] 83.6 % of Tehran waste ends up in landfills, while 10.5% in composting and only about 5.9 % is recycled. P. F. Rupani et al. [23] conclude that currently no proper management.

Fast developing countries like China, the world's second-largest energy consumer and largest oil importer country [28]. The total population of China is 1.421 billion according to 2017 [29]. According to the China Statistical Yearbook, 2018 says that at the end of 2017 the total urban population will be 58.52% [30], [31].In china cities per capita generation of MSW is 1.12 kg which is very high [32]. According to Dorn et al. [33] around 400 cities have no suitable places for landfills and they face the problem of waste siege. As population growth in cities increases the sacristy of land for living decreases. Dongliang Zhang et al. [28] says in 2013 china had the largest waste output in the world, producing seven billion tons of untreated waste, which occupied over three billion square meters of land, and many cities were struggling with a garbage disposal problem. Most cities shifting their management of waste to WtE plants because it requires less land and reduces the volume of waste up to 90% and the mass of waste to

80% [34]. So far china installed 166 plants with a capacity of MSW utilization is 46.3 million tons a year [28]. According to M. M. Mian et al. [35] the total MSW 60.16% ends up in landfills, while 29.84% in incineration and 8.21% untreated discharge and 1.79% in other treatments.

In developing countries, like India [37] with a population of 1.36 billion. According to [38], [39] the total waste generation of the Indian cities in 2009 was 90 million tons and it is expected to increase up to 735 million tons in 2051. The main reason for this intense population is the migration of people from rural areas in search of employment and education [40]. And due to the high occupancy rate, its production of MSW is also high [41]. The situation gets worse as only 30% of MSW converted into compost and recycling plants while the rest of MSW i-e 85-90 % is disposed of through landfilling [38], [42]. In this 30 % MSW, around 10 % are treated through 36 RDF plants that are operational in different cities. The government of India made a policy for industries to utilize at 5 %-15 % of RDF instead of fossil fuels [38]. However, the government also made an investment in incineration projects at Delhi and Timarpur, but the investment is wasted because of high moisture and low calorific value of fuel.

2.3 Pakistan and MSW

Pakistan, a developing nation [43], having a population of 207 million according to 2017 [44]. Out of which 36.38% are urban population [44]. An estimation of around 25.420 million tons of MSW except perilous wastes is produced per annum [45]. The collection of waste from generation site is only 60% in most of the cities while the rest lies in topographic depressions, vacant plots, along streets, roads, railway lines, drains, storm drains, and open sewers within overall urban areas [46], [47]. Pakistan has 29 cement plants with a total installed capacity of 44 million tons. The shortage of natural gas and the increasing cost of oil and coal have adversely affected cement production in the country. The cement entrepreneurs are exploring different avenues to supplement their fuel requirement and bringing down their cost of production. One of the options for them is to use a certain percentage of refuse as fuel, as being practiced in other countries like Turkey the SRF up to 20% co combust with natural gas won’t affect cement property[48]. Several cement units have approached federal and provincial Environmental Protection Agencies for issuance of consent under the environmental laws for processing and use of Solid Recovered Fuel (SRF).

The area targeted for this study is Peshawar situated in KPK (Khyber Pakhtwoon Khuwa) province with a total population of 4,269,079 [44], [49], [50] and the capital city Islamabad with a total population of 2,006,572 [44], [51], [52]. The detail feasibility report would be easy to build as both locations are easy to approach in terms of surveys and both are now evolving and facing the problem of landfills as the allotted areas are filling at high rates and are expected that in mid-2020 it will be mature because the municipalities are started planning for finding and clearing the next location for landfills.

Summary

The extensive literature review is given in this chapter on what is MSW. How developed and developing countries are trying to manage them. A brief overview of MSW generation and management in Pakistan is also presented.

References

[1] J. Karlsson, L. Brunzell, and G. Venkatesh, "Material-flow analysis, energy analysis, and partial environmental-LCA of a district-heating combined heat and power plant in Sweden," *Energy*, vol. 144, pp. 31–40, 2018.

[2] Scottish Environment Protection Agency (SEPA), "Avfall i Sverige 2016. Raport 6839. Naturvårdsverket," 2018.

[3] F. Cucchiella, I. D'Adamo, and M. Gastaldi, "Sustainable waste management: Waste to energy plant as an alternative to landfill," *Energy Convers. Manag.*, vol. 131, pp. 18–31, 2017.

[4] O. Eriksson and G. Finnveden, "Energy recovery from waste incineration - The importance of technology data and system boundaries on CO 2 emissions," *Energies*, vol. 10, no. 4, 2017.

[5] H. Brattebø and M. Reenaas, "Comparing CO 2 and NO X emissions from a district heating system with mass-burn waste incineration versus likely alternative solutions - City of Trondheim, 1986-2009," *Resour. Conserv. Recycl.*, vol. 60, no. X, pp. 147–158, 2012.

[6] K. Bolton and K. Rousta, *Solid Waste Management Toward Zero Land fi ll : A Swedish Model*. Elsevier B.V., 2019.

[7] I. Aniekan and O. Ikechukwu, "Review Of Municipal Solid Waste Management technologies and its practices in China and Germany," *Int. J. Technol. Enhanc. Emerg. Eng. Res.*, vol. 4, no. 5, pp. 1–7, 2016.

[8] European Union, "Municipal waste by waste management operations," *European Union*, 2016. [Online]. Available: http://appsso.eurostat.ec.europa.eu/nui/submitViewTableAction.do.

[9] M. Paolo and M. Paola, "RDF: From waste to resource - The Italian case," *Energy Procedia*, vol. 81, pp. 569–584, 2015.

[10] F. Gabrielli, A. Amato, S. Balducci, L. Magi Galluzzi, and F. Beolchini, "Disaster waste management in Italy: Analysis of recent case studies," *Waste Manag.*, vol. 71, pp. 542–555, 2018.

[11] C. S. Psomopoulos, A. Bourka, and N. J. Themelis, “Waste-to-energy: A review of the status and benefits in USA,” *Waste Manag.*, vol. 29, no. 5, pp. 1718–1724, 2009.

[12] N. J. Themelis, “An overview of the global Waste to Energy industry,” *Waste Manag. World*, vol. 3, no. 3, pp. 40–47, 2003.

[13] US EPA - United States Environmental Protection Agency, “Advancing sustainable materials management: 2015 Fact Sheet,” *United States Environ. Prot. Agency, Off. L. Emerg. Manag. Washington, DC 20460*, no. July, p. 22, 2018.

[14] A. S. Nizami *et al.*, “An argument for developing waste-to-energy technologies in Saudi Arabia,” *Chem. Eng. Trans.*, vol. 45, pp. 337–342, 2015.

[15] P. Size *et al.*, “Main features of KSA population according to preliminary results of the population and housing census The preliminary results of the population and housing census of 2010,” 2010.

[16] O. K. M. Ouda, H. M. Cekirge, and S. A. R. Raza, “An assessment of the potential contribution from waste-to-energy facilities to electricity demand in Saudi Arabia,” *Energy Convers. Manag.*, vol. 75, pp. 402–406, 2013.

[17] A. S. Nizami *et al.*, “The potential of Saudi Arabian natural zeolites in energy recovery technologies,” *Energy*, vol. 108, pp. 162–171, 2016.

[18] T. A. A.S Nizami1,*, S Zafar2, M Rehan1, K Shahzad1, R Miandad1, M.B Baig3, “The environmental and economic value of waste recycling in Makkah,” in *16 th Scientific Symposium for Hajj, Umrah & Madinah Visit – Scientific Portal for 1437AH*, 2016, no. May, pp. 18–20.

[19] O. K. M. Ouda, S. A. Raza, A. S. Nizami, M. Rehan, R. Al-Waked, and N. E. Korres, “Waste to energy potential: A case study of Saudi Arabia,” *Renew. Sustain. Energy Rev.*, vol. 61, pp. 328–340, 2016.

[20] M. Abdallah, A. Shanableh, A. Shabib, and M. Adghim, “Financial feasibility of waste to energy strategies in the United Arab Emirates,” *Waste Manag.*, vol. 82, pp. 207–219, 2018.

[21] IRENA(Internatinal Renewable Energy Agency), “Renewable power generation

costs in 2014," 2015.

[22] S. Azami, M. Taheri, O. Pourali, and F. Torabi, "Energy and exergy analyses of a mass-fired boiler for a proposed waste-to-energy power plant in Tehran," *Appl. Therm. Eng.*, vol. 140, no. 7, pp. 520–530, 2018.

[23] P. F. Rupani, R. M. Delarestaghi, and H. Asadi, "Current Scenario of the Tehran Municipal Solid Waste Handling Rules towards Green Technology."

[24] Iran Population, "Iran population," 2019. [Online]. Available: https://www.worldometers.info/world-population/iran-population/.

[25] E. Khayamabshi, "Current Status of Waste Management in Iran and Business Opportunities, Waste Management on Occasion of Smart Engineering Tokyo 2016, United Nations Industrial Development Organization," 2016.

[26] A. Habibollahzade, E. Houshfar, M. Ashjaee, A. Behzadi, E. Gholamian, and H. Mehdizadeh, "Enhanced power generation through integrated renewable energy plants: Solar chimney and waste-to-energy," *Energy Convers. Manag.*, vol. 166, no. February, pp. 48–63, 2018.

[27] M. R. Alavi Moghadam, N. Mokhtarani, and B. Mokhtarani, "Municipal solid waste management in Rasht City, Iran.," *Waste Manag.*, vol. 29, no. 1, pp. 485–489, Jan. 2009.

[28] D. Zhang, G. Huang, Y. Xu, and Q. Gong, "Waste-to-energy in China: Key challenges and opportunities," *Energies*, vol. 8, no. 12, pp. 14182–14196, 2015.

[29] United Nation, "World Population Prospects 2019," 2019.

[30] B. Zhou, C. Sun, and H. Yi, "Solid waste disposal in Chinese cities: An evaluation of local performance," *Sustain.*, vol. 9, no. 12, pp. 1–20, 2017.

[31] China, "China Statistaical Year Book 2018," 2018. [Online]. Available: http://www.stats.gov.cn/tjsj/ndsj/2018/indexeh.htm.

[32] N. Yang, H. Zhang, M. Chen, L. M. Shao, and P. J. He, "Greenhouse gas emissions from MSW incineration in China: Impacts of waste characteristics and energy recovery," *Waste Manag.*, vol. 32, no. 12, pp. 2552–2560, 2012.

[33] T. Dorn, M. Nelles, S. Flamme, and C. Jinming, "Waste disposal technology

transfer matching requirement clusters for waste disposal facilities in China," *Waste Manag.*, vol. 32, no. 11, pp. 2177–2184, 2012.

[34] H. Cheng and Y. Hu, "Municipal solid waste (MSW) as a renewable source of energy: Current and future practices in China," *Bioresour. Technol.*, vol. 101, no. 11, pp. 3816–3824, 2010.

[35] M. M. Mian, X. Zeng, A. A. N. Bin Nasry, and S. M. Z. F. Al-Hamadani, "Municipal solid waste management in China: a comparative analysis," *J. Mater. Cycles Waste Manag.*, vol. 19, 2016.

[36] Y. Geng, Q. Zhu, and M. Haight, "An overview of municipal solid waste management in China.," *Waste Manag.*, vol. 27, no. 1, pp. 716–24, 2007.

[37] S. Oduro-Appiah, K., Aidoo, D.O. and Graham, "Fee-based solid waste collection in economically developing countries: The case of Accra metropolis," *Int. J. Dev. Sustain.*, vol. 2, no. 2, pp. 629–639, 2013.

[38] Y. Pujara, P. Pathak, A. Sharma, and J. Govani, "Review on Indian Municipal Solid Waste Management practices for reduction of environmental impacts to achieve sustainable development goals," *J. Environ. Manage.*, vol. 248, no. April, p. 109238, 2019.

[39] T. TERI, "Energy data directory and yearbook (teddy) 2001–2002," *Tata Energy Res. Institute, New Delhi, India*, 2002.

[40] R. Ghosh and A. Kansal, "Urban Challenges in India and the Mission for a Sustainable Habitat," vol. 2, no. Vesilund 1982, pp. 281–304, 2014.

[41] V. K. Tyagi, L. A. Fdez-Güelfo, Y. Zhou, C. J. Álvarez-Gallego, L. I. R. Garcia, and W. J. Ng, "Anaerobic co-digestion of organic fraction of municipal solid waste (OFMSW): Progress and challenges," *Renew. Sustain. Energy Rev.*, vol. 93, no. May, pp. 380–399, 2018.

[42] R. Reddy, "Secured Landfills for Disposal of Municipal," vol. 1, no. 1, 2013.

[43] Finance Division Govement of Pakistan, "Pakistan economic survey," 2019.

[44] G. of P. M. of Statistics, "Population Census 2017," 2017.

[45] M. S. Korai, R. B. Mahar, M. A. Uqaili, and K. M. Brohi, "Assessment of

Municipal Solid Waste Management Practices and Energy Recovery Potential in Pakistan," *14th Int. Conf. Environ. Sci. Technol.*, no. September, pp. 3–5, 2015.

[46] W. Management and P. Values, "General country profile," 2019. [Online]. Available:http://www.atlas.dwaste.com/index.php?view=country_report&country_id=10.

[47] S. A. Batool and M. N. Chuadhry, "The impact of municipal solid waste treatment methods on greenhouse gas emissions in Lahore, Pakistan," *Waste Manag.*, vol. 29, no. 1, pp. 63–69, 2009.

[48] M. Kara, E. Günay, Y. Tabak, and Ş. Yildiz, "Perspectives for pilot scale study of RDF in Istanbul, Turkey," *Waste Manag.*, vol. 29, no. 12, pp. 2976–2982, 2009.

[49] Pakistan Bureau of Statistics, "District and Tehsil Level Population Summary With Region Breakup Population of Peshawar KPK," 2017.

[50] Pakistan Bureau of Statistics, "Population and household detail from block to district Level-Peshawar KPK," 2017.

[51] Pakistan Bureau of Statistics, "District and tehsil level Population summary with region breakup of Islamabad," 2017.

[52] Pakistan Bureau of Statistics, "Population and household Census from block to district level of Islamabad," 2017.

Chapter 3

Methodology

3.1 Waste survey

The approach which is used in this study are interviews with companies specifically WSSP (Water and Sanitation Services Peshawar), the waste management governing body. Observation of the management system at ground level from waste generation to disposal. In order to identify how much waste is being generated in both cities. Survey is being conducted with both municipalities. In Peshawar, self-survey is conducted because different zones have different living standards, for that Peshawar University and Hayatabad and town survey is to be performed, to get information about an average waste generation. After that whole Peshawar district zones data is to be collected to know how much waste is being generated daily. Reports were collected from, the municipality which is involved in management city MSW is WSSP. Same as the case for Islamabad but in Islamabad survey on a plus point that it has only one dumpsite that is in I-12 but multiple private companies working in collecting waste from different zones and transfer it to the dump yard. The weekly survey is conducted specifically from each zone vehicle as they are dumping their waste at the dump yard. Through interviews with the supervisor at site and interviews with vehicle driver's information is to be collected.

Figure 7 G9 collection method through the cart

3.2 Fractional analysis

MSW generation is heterogeneous nature, it has different fractions. The Table 2 presents the waste which is considered in MSW. To know how much quantities of these fractions are produced in the current cities, Quartering technique was performed. Weighted each vehicle upon reach to dump yard. Waste is collected then upon mixing, a total of 200-300 kg sample divide equally into four-section reject the two, left with two sections, applying this technique of mixing and rejecting until we final lift with 4-5 kg sample. After that the sample is sorted out properly. Then weight each fraction.

Figure 8 Primary station of MSW at Peshawar moor

3.3 WtE conversion potentials

The potential commitment will be surveyed by directing the quantitative analysis of WtE power generation in Pakistan. It comprises of two scenarios for WtE improvement; Mass Burn and Mass Burn without recycling. The Mass Burn situation suggests full use of MSW for WtE creation. Mass Burn without recycling accepts the evacuation of all conceivably recyclable materials from the waste stream and using the remaining MSW for WtE production. The absolute MSW generation & power generation is forecasted up to 2025. The year 1998 was picked as the beginning year for anticipating. Interviews and reports from MSWM and ground observation are made to know how much MSW is generated and the actual amount reached to the dumpsite. For interviews and data collections the concerned department of concern cities municipalities was contacted which is Water Sanitation and Services Peshawar (WSSP) and Metropolitan Corporation Islamabad (MCI) and Capital Development Authority (CDA). For fraction analysis of MSW, quartering techniques were applied. The caloric value or energy content of different substance present in waste are taken from literature and recorded in table 1. These measures were utilized to ascertain the total energy content per kilogram of Pakistan city waste generation. There are numerously developed and emerging technologies through which energy can be extracted from waste. The utmost frequently active and demonstrated WtE technology is the one through which energy can be produced in the form of thermal energy and electricity from the MSW [1]. The literature has documented an overall average thermal efficiency of the WtE plant is 25 % to 30 % only. In the current study, the calculations of the average thermal efficiency were considered as 25 % [2], [3]. To find out the MSW forecasting and net power generation potential (MW) generated from MSW were calculated by using the following equations;

$$Population\ forecast = (Previous\ year\ data * e^{Growth\ rate*1})$$

$$MSW\ Forecast = \left(Per\ capita\ waste\ generation \left(\frac{kg}{capita * day}\right) * (population) * \left(\frac{ton}{1000kg}\right) * \left(\frac{365days}{year}\right)\right)$$

The growth rate for Peshawar city is 2.89 %, while of Islamabad it is 4.91 %[4].

$$Power\ Generation\ Potential\ (MW) = \left(\frac{Dry\ waste \left(\frac{tons}{year} * \frac{1ton}{1000kg} * \frac{year}{365\ days * 24hrs}\right) * \left(HHV\ of\ Waste \left(\frac{kWh}{kg}\right)\right)}{1000}\right)$$

$$Net\ Power\ Generation\ Potential\ (MW) = \eta * Power\ Generation\ Potential\ (MW)$$

Table 1 Energy content of different types of wastes

Type of waste	Energy content (kJ/kg)
Mixed green yard waste	6280.2
Mixed food waste	5582.4
Mixed plastic	106996
Mixed paper	15816.8
Textiles	18840.6
Demolition softwood	16979.8
Rubber	26051.2
Coal	28609.8
Fuel, oil	42565.8
Leather	18608
Waste hardwood	15119
Natural gas	55126.2

3.4 Fuels survey

Fuel is the necessity of every company to get their job done. Different companies using different fuels like furnace oil, gas, coal, etc. Local industries of Peshawar using fossil fuels for their energy production which includes thermal energy, steam energy and electricity. The Questionnaire based survey technique has been performed. Due to security reasons and some privacy the names of companies are not mentioned in this work. With the help of good regulatory authority and extensive collaboration of Khyber Pakhtunkhwa Economic Zones Development and Management Company (KPEZDMC), a fuel survey of 6 local companies of Peshawar was performed. To perform a survey a questionnaire is made and through interviews with companies' personnel the required data was collected.

Table 2 Fraction of MSW

Component	Materials [5][62][7]
Kitchen and Yard Waste	Food waste (e.g., food and vegetable refuse, fruit skins, corncob), yard waste (e.g., leaves, grass, tree trimmings), etc.
Plastic	High-valued plastics [LDPE bottles (shampoo bottles, detergent bottles, etc.), polypropylene bottles (mess tins made from rigid plastics, etc.), PET bottles (beverage bottles, etc.)], Low-valued plastics (Polythene plastic bags, polystyrene plastic packages such as mess tins made from flexible plastics and plastic cup for yogurt, ice-cream, etc.) and others.
Inert	Stones and silt, soil, ash, dust, other inorganic material, etc.
Paper/Cardboard	Paper bags, cardboard, corrugated board, boxboard, newsprint, magazines, tissue, office paper, and mixed paper, etc.
Clothes	Discarded clothes, rags, leather, rubber
Miscellaneous	used batteries, medical waste, nappies/sanitary products, etc.

3.5 Making of SRF fuels

In order to make fuel, some equipment was designed and built like a shredder and pelletizer machine. The sorting of waste is to be made. Each fraction is shredded up to 2 mm diameter. After shredding different binders is to be maked. Then specific fractions of waste and binders are mixed and the sample is to be made according to ASTM E-16 & E829-16 [8] standard. Trails and error method is used in the making of fuel, the different fraction of component is mixed and fuel is made.

3.6 Combustion analysis

3.6.1 Moisture test

According to ASTM E791-08 [9] standard pre-determined moisture test is performed. After that dry oven test according to ASTM [10] standard is performed to eliminate the moisture.

3.6.2 Calorific Value test

According to ASTM E776-16 standard calorific value test is performed using Bomb calorimeter (Parr Bomb calorimeter 6200). It will show the amount of thermal energy it will produce on burning.

Figure 9 Molasses preparation

Table 3 SRF preparation

Component materials	**By percent mass %**			
	SRF 1	SRF 2	SRF 3	SRF 4
Plastic	12	10	10	14
Cardboard	19	22	25	10
Paper	10	20	15	15
Textile	10	8	8	14
Organic Waste (Leaves, Grass, etc.)	28	22	25	23
Moisture	6.7	12	12	<10
Binder Used	Calcium hydroxide	Starch	Molasses	Molasses
Quantity of Binder	14	5	5	8

3.6.3 CHN test

According to ASTM E777-08 [11] standard elemental test is performed using the CHN analyzer (CKIC 5E-CHN 2200). Through this test the main combustible elements are to be find out that is present in SRF.

3.6.4 Sulfur test

Important element sulfur that causes SOx and acids which harmful for environment. It is necessary to find out that how much sulfur the fuel SRF contain. To find out sulfur in each sample the sulfur test analyzer CKIC 5E-IRS 2 is used.

Figure 10 Bomb calorimeter

3.6.5 Fumes test

Fumes test is performed in the local design furnace. the burning of the samples takes place at ambient atmospheric conditions. Due to excess air and an uncontrolled environment, some incomplete combustion takes place. The main aim of this test to check the burning conditions of fuel.

Figure 11 Fumes analyzer

Figure 12 CHN analyzer

3.6.6 Economic analysis

For Cost-benefit analysis, it is mandatory to know that how much cost the municipality bear from picking municipal solid waste from the generation site to that of landfills. The factor that is considered in finding the cost per ton is the maintenance of a vehicle, fuels used by vehicles, salaries of technical staff, salaries of administration staff. The parameter that is exempted from this analysis is the capital cost and operation and maintenance of the SRF plant.

Figure 13 Sulphur analyzer

3.6.7 Decision making

SRF fuel is being compared with that of fossil fuels used in the local market. The comparison is made on the basis of proximate and ultimate analysis. The SRF fuel then compares with local fossil fuel used in industries based on energy, and cost of the billing they incur on a monthly basis.

3.6.8 Flow chart

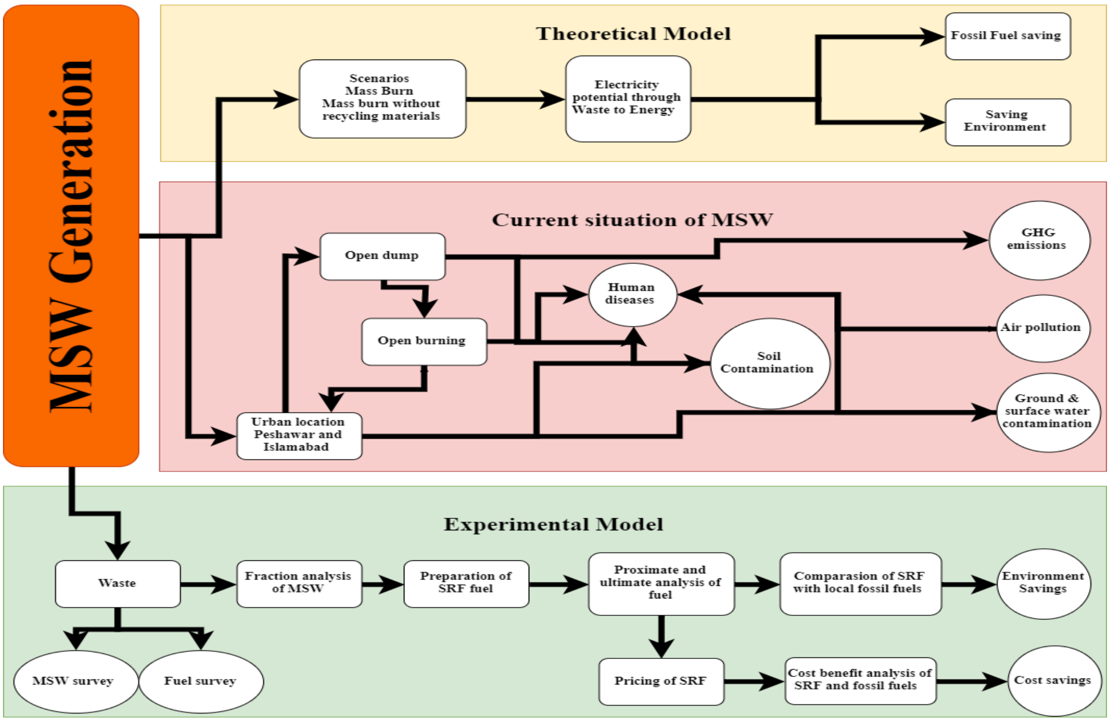


Figure 14 Flow chart of research

Summary

The methods of surveys are explained that are quartering techniques and fossil fuels survey of local industries. Feasibility study scenarios are discussed to know that WtE is possible or not. Fuel making and combustion analysis techniques are discussed along with cost-benefit analysis.

References

[1] M. Elmnifi and M. Amhamed, “Future of Waste to Energy : Case study of Libya,” *Adv. Ind. Eng. Manag. (AIEM),* no. February, pp. 1–4, 2019.

[2] O. K. M. Ouda, S. A. Raza, A. S. Nizami, M. Rehan, R. Al-Waked, and N. E. Korres, “Waste to energy potential: A case study of Saudi Arabia,” *Renew. Sustain. Energy Rev.*, vol. 61, pp. 328–340, 2016.

[3] M. L. N. M. Carneiro and M. S. P. Gomes, “Energy, exergy, environmental and economic analysis of hybrid waste-to-energy plants,” *Energy Convers. Manag.*, vol. 179, no. November 2018, pp. 397–417, 2019.

[4] G. of P. M. of Statistics, “Population Census 2017,” 2017.

[5] B. Z. Bajić, S. N. Dodić, D. G. Vučurović, J. M. Dodić, and J. A. Grahovac, “Waste-to-energy status in Serbia,” *Renew. Sustain. Energy Rev.*, vol. 50, pp. 1437–1444, 2015.

[6] B. T. Eddine and M. M. Salah, “Solid waste as renewable source of energy: Current and future possibility in Algeria,” *Waste Manag. Valorization Altern. Technol.*, pp. 115–141, 2017.

[7] A. Price-Allison *et al.*, “Emissions performance of high moisture wood fuels burned in a residential stove,” *Fuel*, vol. 239, no. August 2018, pp. 1038–1045, 2019.

[8] E. − 16 ASTM, “Standard Practice for Preparing Refuse-Derived Fuel (RDF) Laboratory Samples,” *ASTM Int.*, pp. 1–4, 2016.

[9] A. Drews, “Standard Test Method for,” *Man. Hydrocarb. Anal. 6th Ed.*, vol. i, no. Reapproved 2016, pp. 545-545–3, 2008.

[10] ASTM, “Standard Terminology for Waste and Waste Management,” pp. 1–18, 2012.

[11] ASTM, “ASTM E777-08 Standard Test Method for Carbon and Hydrogen in the Analysis Sample of Refuse-,” *Annu. B. ASTM Stand.*, vol. 08, pp. 1–5, 2011.

Chapter 4

Result and Discussion

4.1 Total waste generation

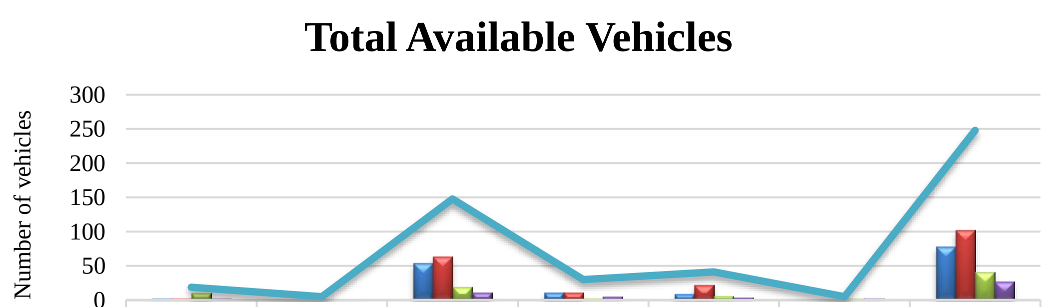
The total population of Peshawar city is 4.3 million. Which on average produces 0.4-0.8 kg/capita/day waste. The average of 0.5 kg/capita/day was took for the analysis, then leads to 2208 tons of waste generated per day. Whereas in an interview with WSSP finance department that a maximum of 1000 tons/day waste is collected. Up to 250 tons/day lifted off by privates companies like Blue Skies and Scavenger and Junk dealers. While the rest lay there, that is 960 tons/day. While in Islamabad around 93% of total waste recived at dumpyard. The MCI out source their collection of MSW in each sector.

4.2 Result of vehicles availability

The total vehicles available with WSSP are presented in Table 4 in detail. It shows that the SUZUKI dumper number is high in each zone, where tucks and 22 cubic meter arm roll are minimal in number.

It is a common observation that each zone not fully utilizing its vehicles. They use limit numbers of vehicles for waste collection while the rest stand there at the garage. Each zone trip detail to dump yard is present in the given Tables 5,6,7 &,8.

Table 4 Summary of available vehicles with WSSP for each Zones (A, B, C, D)



	Arm roll 5m^3 numbers	22m^3 Arm roll numbers	SUZUKI dumper numbers	Tractor trolley numbers	Compactor numbers	Truck numbers	Total
A	3	1	54	11	9	0	78
B	3	2	64	11	22	0	102
C	10	1	19	3	6	2	41
D	3	1	11	5	4	3	27
Total	19	5	148	30	41	5	248

Table 5 Trips details of zone A (WSSP Verified)

Zone A	**Trips/Day 6/6/19**	**Trips/Day 7/6/19**	**Trips/Day 8/6/19**	**Trips/Day 10/6/19**
Arm roll-11($5m^3$)	3	2	2	4
Arm roll-15($5m^3$)	5	1	5	4
Arm roll-8($5m^3$)	0	2	4	5
Trolley 47	2	2	2	4
Arm roll($22m^3$)	4	0	2	4
Comp.-79($7m^3$)	0	0	1	0
Comp.-82($7m^3$)	1	1	1	1
Comp.-85($7m^3$)	1	1	1	2
Comp.-90($7m^3$)	1	2	0	1
Comp.-91($7m^3$)	1	1	1	1
Comp.-92($7m^3$)	0	0	0	0
Comp.-94($7m^3$)	1	1	0	2
Comp.-177($4m^3$)	1	1	2	1
Comp.-180($4m^3$)	1	1	0	1
Comp.-187($4m^3$)	1	1	0	1
Trolley-76	2	1	2	1
Trolley-77	2	2	1	1
Trolley-1 messi	2	0	1	5
Dumper 3	1	2	1	2
Dumper4	2	1	0	2
Total	**31**	**22**	**26**	**42**

Table 6 Trips details of zone B (WSSP Verified)

Zone B	**Trips/Day 6/6/19**	**Trips/Day 7/6/19**	**Trips/Day 8/6/19**	**Trips/Day 10/6/19**
Arm roll-large 1	2	3	4	4
Arm roll-large2	2	3	4	4
Comp.-01($4m^3$)	2	1	2	0
Comp.-64($7m^3$)	1	1	1	1
Comp.-65($7m^3$)	2	1	2	2
Comp.-80($7m^3$)	2	1	1	2
Comp.-84($7m^3$)	2	1	1	1
Comp.-97($7m^3$)	0	0	0	0
Comp.-98($7m^3$)	1	1	1	1
Comp.-99($7m^3$)	1	0	0	0
Comp.-156($7m^3$)	0	0	0	0
Comp.-174($7m^3$)	1	1	1	2
Comp.-175($4m^3$)	2	1	2	2
Comp.-178($4m^3$)	2	1	1	2
Comp.-181($4m^3$)	0	0	0	0
Comp.-182($4m^3$)	2	1	2	2
Comp.-183($4m^3$)	1	1	0	0
Comp.-184($4m^3$)	1	1	1	1
Comp.-185($4m^3$)	2	1	1	2
Comp.-186($4m^3$)	1	1	1	2
Comp.-188($4m^3$)	1	2	0	2
Comp.-189($4m^3$)	2	1	2	2

Comp.-190(4m^3)	2	1	0	0
Comp.-191(4m^3)	1	1	1	2
Comp.-193(4m^3)	2	2	1	2
SUZUKI damper1	4	4	4	4
SUZUKI damper2	4	0	4	0
SUZUKI damper3	5	3	5	4
Trolley Messi4	5	5	5	6
Multi Loader	5	0	0	0
Arm roll large 1	3	0	0	0
Arm roll large 2	2	0	0	0
Arm roll 7	5	3	6	3
Arm roll 8	5	5	5	5
Arm roll 16	4	5	6	6
Trolley 44	0	0	0	0
Trolley 48	3	2	3	3
Trolley 45	0	0	3	0
Trolley 51	2	1	5	1
Trolley 52	3	1	0	3
Trolley 53	4	4	3	4
Trolley 54	0	0	0	2
Trolley 55	5	5	5	5
Trolley 56	0	0	0	0
Trolley 57	6	1	4	0
Truck 29	0	0	0	0
comp.52	1	0	1	1
Total	**66**	**39**	**59**	**47**

There is no precise account of distances that each vehicle traveled because in most machines the speedometers are not working properly. This promotes the dumping of waste at dumpsites located closer to the collection sites other than specified disposal locations. This requires a GPS-based control system to be installed in the vehicles for tracking purposes. It is very uneconomical as wells as inefficient to load and unload the vehicles manually in terms of time and effort. In areas with limited space for storage, it requires the more frequent collection of waste by smaller vehicles due to limited space is an uneconomical practice.

The projected increase in Pakistan's population will be doubled in 2027 based on the current growth rate i.e., 2.4 % per year. This increase in population will increase the generation of municipal solid waste. The overall waste generation of the two cities is shown in Figure 17.

Table 7 Zone C summary details (WSSP verified)

Zone C	Trips/Day 6/6/19	Trips/Day 7/6/19	Trips/Day 8/6/19	Trips/Day 10/6/19
Arm roll-1(5m^3)	6	3	5	5
Arm roll-2(5m^3)	0	0	0	0
Arm roll-6(5m^3)	3	3	5	5
Arm roll-8(5m^3)	5	5	4	6
Arm roll-10(5m^3)	2	1	0	2
Arm roll-12(5m^3)	3	1	1	0
Arm roll-13(5m^3)	6	0	2	0
Arm roll-14(5m^3)	0	0	0	0
Arm roll-17(5m^3)	4	1	3	5
Arm roll-20(5m^3)	1	1	0	0
Arm roll(22m^3)	2	1	2	0
Comp.-96(7m^3)	1	1	1	1
Comp.-86(7m^3)	1	1	1	1
Comp.-179(4m^3)	2	1	1	1
Comp.-03(4m^3)	1	1	0	0
Comp.-165(7m^3)	1	1	1	1
Comp.-93(7m^3)	1	1	0	1
Truck-06	0	0	0	0
Truck-10	2	1	2	2
Trolley-13	0	0	0	0
Trolley-46	0	0	0	0
Trolley-03	0	0	0	0
Multi loader(5m^3)	0	0	0	0
Total	**41**	**23**	**28**	**30**

The estimated amount of MSW of these two cities will be reached 889751.7 and 609865.2 tones/year respectively in 2025. This is quite an alarming situation and the need of the hour is to wisely manage this MSW. Currently, the waste management companies in Pakistan are simply doing the landfilling to dump the waste which has a negative impact on the economy and environment. The government must look for alternative solutions to this problem like WtE and recycling.

Tables 9 & 10 show the theoretical and actual waste generation and the values were found much differed from each other due to the different influencing factors. Around 45 % and 93 % collection of MSW is being detained in Peshawar and Islamabad. In the case of Peshawar, WSSP has two dumpsites and all of the collection was being done through the same department. Because of the suspicious drivers and underutilization of the vehicles the MSW collection is low.

Table 8 Zone D summary details (WSSP verified)

Zone D	Trips/Day 6/6/19	Trips/Day 7/6/19	Trips/Day 8/6/19	Trips/Day 10/6/19
Arm roll-3($5m^3$)	3	3	3	4
Arm roll-4($5m^3$)	3	4	4	3
Arm roll-5($5m^3$)	3	3	3	3
Arm roll2($22m^3$)	2	2	2	2
Comp.-192($7m^3$)	2	1	2	1
Comp.-02($7m^3$)	2	1	2	1
Comp.-176($4m^3$)	1	1	1	1
Comp.-95($4m^3$)	1	1	2	1
Trolley-04	6	4	2	2
Trolley-37	1	2	1	1
Trolley-15	3	1	0	2
Trolley-57	3	2	3	2
Multi loader($5m^3$)	2	0	1	2
Total	**32**	**25**	**26**	**25**

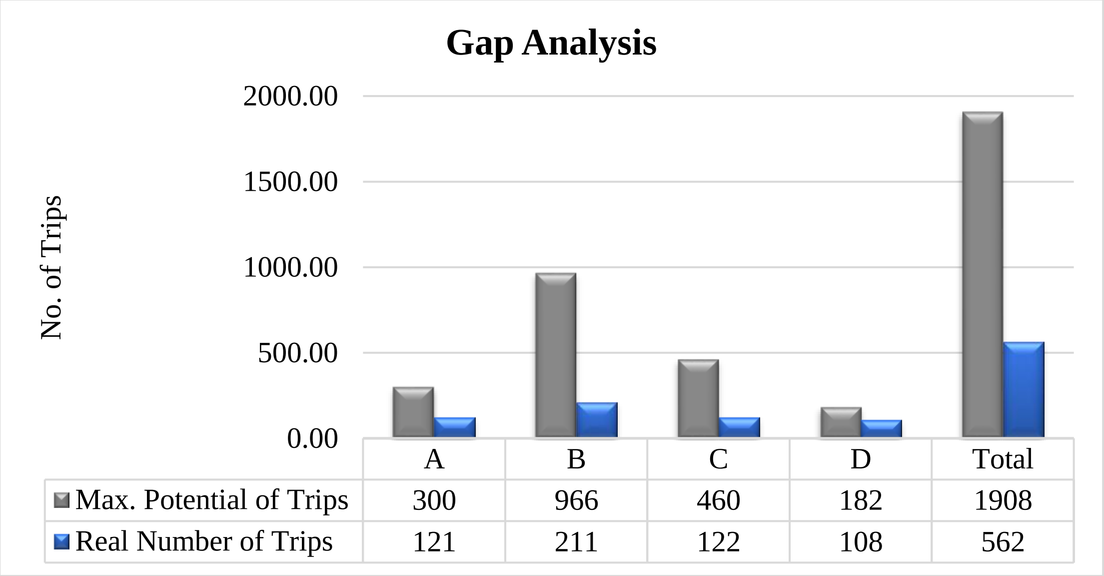


Figure 15 Peshawar Gap summary

Although in Islamabad which is a capital city of Pakistan and most of the area is high income due to which more generation of MSW. MCI took the responsibility of the collection of MSW around the city. Islamabad has one dump yard, but the collection involves private partners which perform the collection of waste from different sectors that is why the collection of waste is maximum.

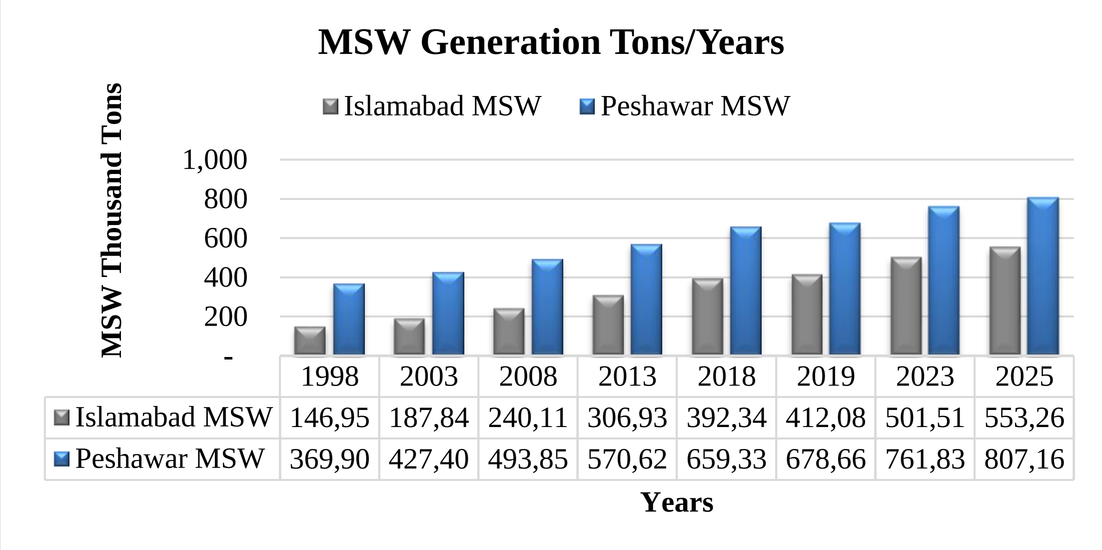


Figure 16 Waste generation forecast

The waste generation is directly related to the increase in population. The waste management companies like WSSP collects nearly (70–80) % of the waste from Peshawar/Islamabad and dumped it into the various dumping sites. The local low-income people collect the recyclable materials (metals, bones, and bottles) from the dumped waste and sell them to the junkshops.

Table 9 Data MSW reach to dumpsite 2019

Cities	Generation per capita kg/c/day	Waste generated tons/day	Waste generated tons/year
Peshawar	0.5	880	321200
Islamabad	0.5	1050	383250

A very few amounts of the recycled material were purchased by the different manufacturing companies; whereas the remaining waste is left around the waste containers along the roadside, bus stands, empty plots, and parking lots. Furthermore, sewerage pipelines are also chocked due to that remaining waste. The difference is shown in Tables 9 and 10.

Table 10 MSW data estimate according to Census 2017 [1]

Cities	Population	Solid waste generation per capita kg/c/day	Waste generation kg/day	Waste generation tons/day	Waste generation tons/year
Peshawar	3509885	0.5	1754942.5	1934.5	706092.5
Islamabad	2046803	0.5	1023401.5	1128.1	411756.5

The waste fraction of both cities was determined using the Quartering technique to analyze both scenarios. The samples were collected from the dump yard on different occasions and after careful sorting, the results are shown in Figures 17 and 18. The fraction of waste in both cities contain 82 % to 96 % of combustible waste. The major component is organic waste i.e., 41 % and 48 % followed by the plastic waste i.e., 23 % and 21 % for Islamabad and Peshawar respectively.

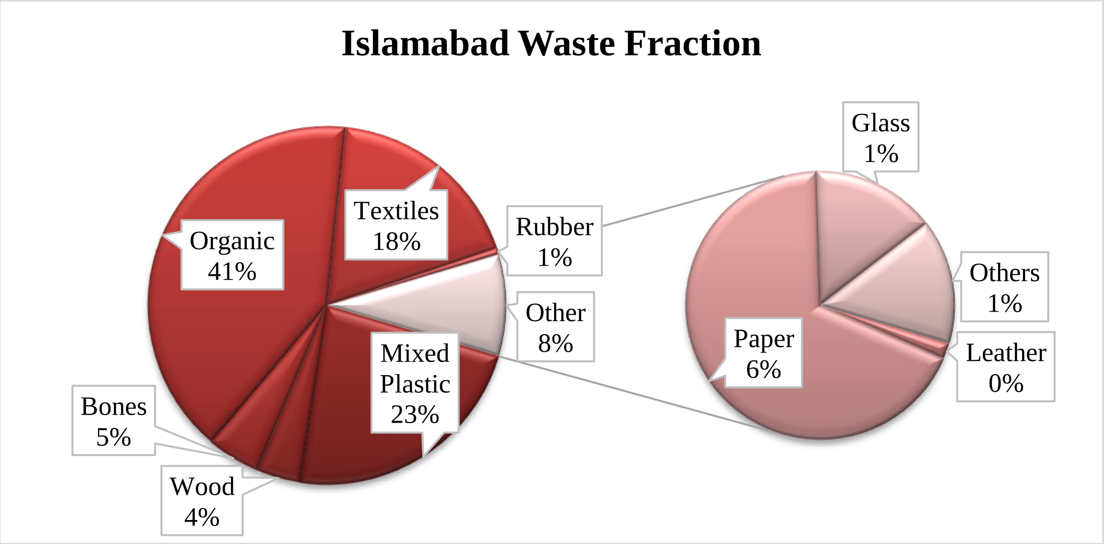


Figure 17 Islamabad waste fraction survey

4.3 MSW Energy Contents

The energy content and MSW composition are shown in Tables 1, 11 and, 12 respectively. Tables 11 and 12 demonstrate the vitality substance in kWh per kg of MSW. On the premise of quantitative analysis, two values are obtained i.e., Mass Burn scenario and Mass Burn without recycling scenario. The Mass Burn scenario shows full use of MSW for WtE generation without recycling the vitality substance is found to be 8.903 kWh/kg for Islamabad and 7.714 kWh/kg for Peshawar. The Mass Burn without recycling scenario assumes evacuation of all conceivably recycled materials from the waste stream and the remaining MSW for WtE generation. The energy content for Mass Burn without recycling materials scenario is estimated to be 0.877 kWh/kg Islamabad and 0.992 kWh/kg Peshawar. The immense contrast in vitality content because of expelling high vitality content materials from the mass-burn scenario and it is considered to be recycled.

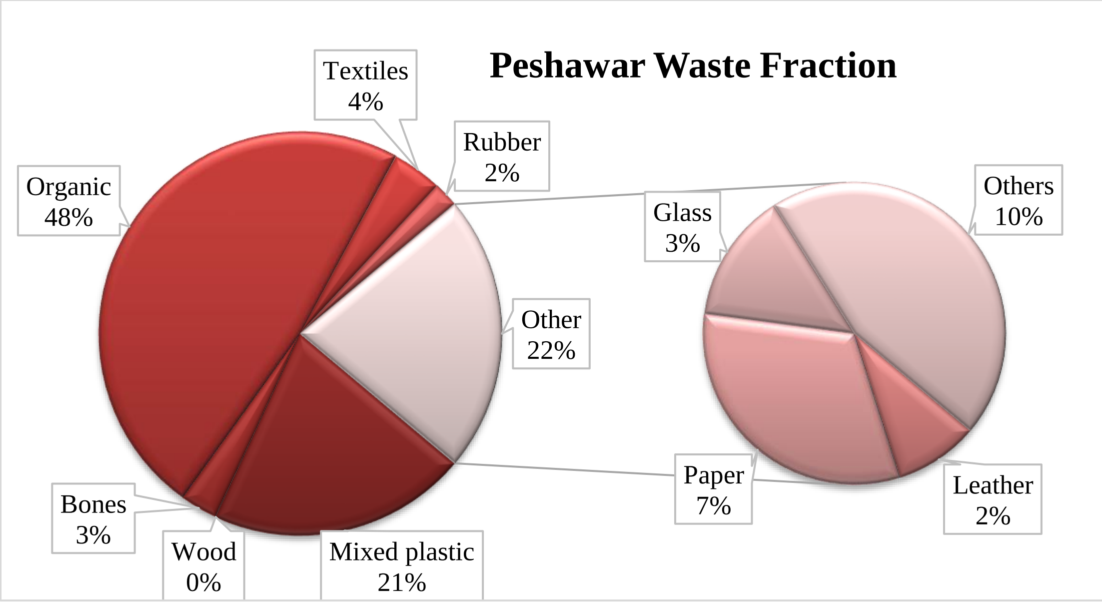


Figure 18 Peshawar waste fraction survey

4.4 Waste to Energy production forecast

The forecasted results of MSW generation as shown in Figure 16. As looking at the trend of growth rate it is estimated that the population will be 3.5 times and 2.2 times that of the base year 1998 of the Islamabad and Peshawar cities respectively so as the MSW generation. Two scenarios were discuses and their net power potential was found as shown in Figures 19 and 20. Considering Mass Burn Scenario, the potential results of electrical energy have 105 MW for Islamabad and 149 MW in Peshawar in 2019 and upon the further forecast, up to 2025, the MSW WtE plant has the potential to produce 141 MW and 178 MW for Islamabad and Peshawar.

The figure shows that it has the potential to generate electricity to meet the country's demand of about 0.96 % in 2025. Where the case of Mass Burn without recycling materials it has the potential to produce 10 MW and 19 MW of electricity respectively in 2019, and the same trend in 2025 will be met 0.11 % of the nation electricity demand.

This forecast results in the two cities on the bases of two scenarios it can be design and built-in respected cities to meet electricity demand. There is also a huge difference in energy in both scenarios. The Mass Burn scenario is 8.8 times more than Mass Burn without recycling materials.

Table 11 Islamabad base energy content

Material	Squander arrangement %	Vitality content kJ/kg	kW h/kg in Waste HHV
Mixed plastic	22.84	106996	6.8
Wood	3.94	16980	0.185
Bones	4.83	0	0
Organic	40.46	5582.4	0.63
Textiles	18.19	18841	0.952
Rubber	0.57	26051.2	0.052
Leather	0.17	18608	0.01
Paper	6.24	15817	0.274
Glass	1.37	0	0
Others (ceramics & stones)	1.38	0	0
Mass Burn without recycling scenario (kW h/kg)			0.877
Mass Burn scenario (kW h/kg)			8.903

Table 12 Peshawar base energy content

Material	Squander arrangement %	Vitality content kJ/kg	kW h/kg in Waste HHV
Mixed plastic	20.8	106996	6.2
Wood	0	16980	0
Bones	3	0	0
Organic	48	5582.4	0.744
Textiles	4	18841	0.21
Rubber	2	26051.2	0.145
Leather	2	18608	0.103
Paper	7.1	15817	0.312
Glass	3.1	0	0
Others (ceramics & stones)	10	0	0
Mass Burn without recycling scenario (kW h/kg)			0.992
Mass Burn scenario (kW h/kg)			7.714

4.5 Economic benefits of the MSW energy recovery

Pakistan's thermal power plants produce 37 % of electricity mainly using diesel and furnace fuel. It is important to import diesel and furnace oil that incur a significant amount of cost. Alternatively, the average generation rate of MSW, based on the population of Peshawar and Islamabad, is estimated simply as shown in Figure 16, no cost on generation only transportation cost from site to the yard. As mentioned earlier, controlled combustion of MSW has numerous benefits, such as mass reduction (~70 %) and volume reduction (~90 %), efficient energy recovery and full cleansing of pathogenic waste. Introducing of WtE plants not just limit reliance on fossil fuels to fulfill electricity demands but can likewise be a great option for MSW management.

MSW's projected capacity for energy recovery as shown in Figures 19 & 20. The potential for energy was calculated based on the annual MSW generation.

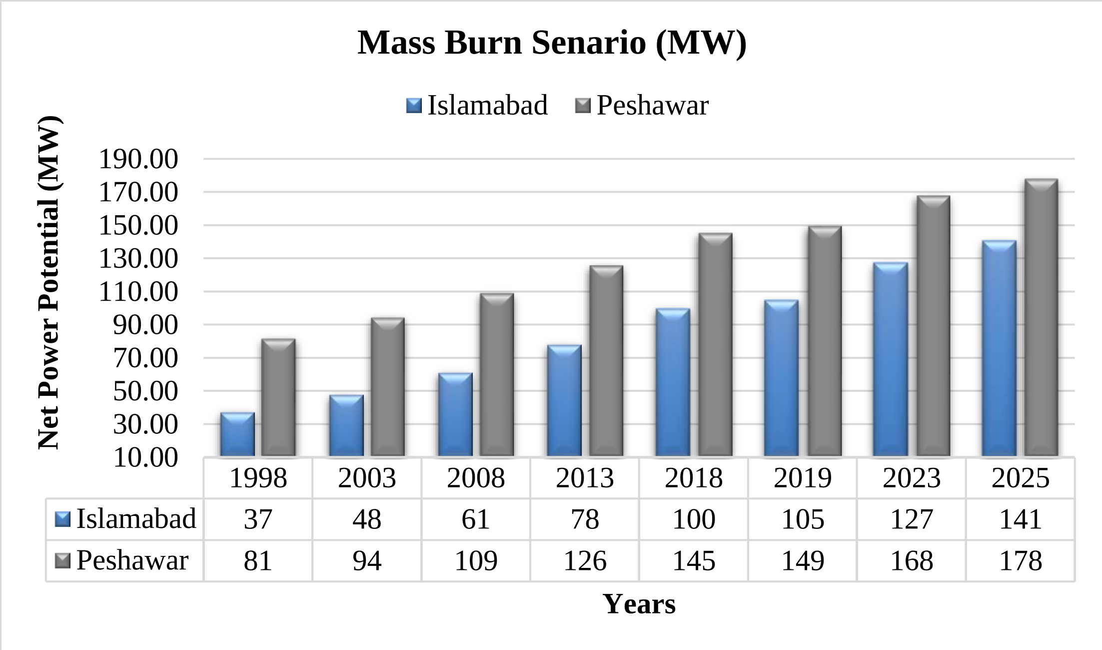


Figure 19 Mass Burn Scenario results

An estimated 14.18 Gg per year of methane emissions from landfills in Pakistan [2]. The induction of methane gas into the atmosphere, which has the ability to traps heat with a greenhouse effect 22 times greater than CO. The implementation of a WtE technology is a decent procedure to discourse the issue of methane gas emissions from landfills is therefore of vital importance. As previously stated, Pakistan's landfills are not planned to capture methane gas for use as fuel. MSW thermal conversion will, therefore, be a good alternative strategy for lowering GHG emissions in contrast to MSW landfilling. This will not only reduce the proportion of greenhouse gas emissions but also reduce fossil fuel utilization in energy production up to a great extent. Therefore, adding thermal conversion technology will be a positive step towards supporting the country's renewable energy sources. As in Europe, in addition to electric power generation, a hefty percentage of the steam produced from MSW's incineration is used for central district heating.

In addition, the steam from these plants will have an economic worth by trade it to various industries in state cities or it can be used for central cooling during the long summer seasons in steam turbine chillers. The use of MSW incineration will result in mitigation of MSW disposal and environmental issues as well as GHG emissions reduction.

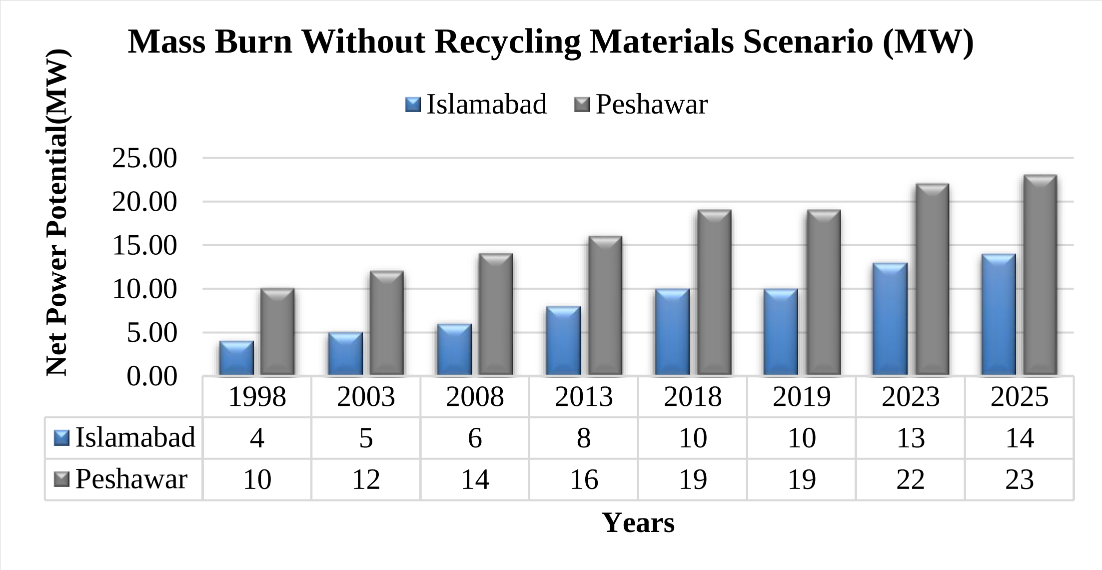


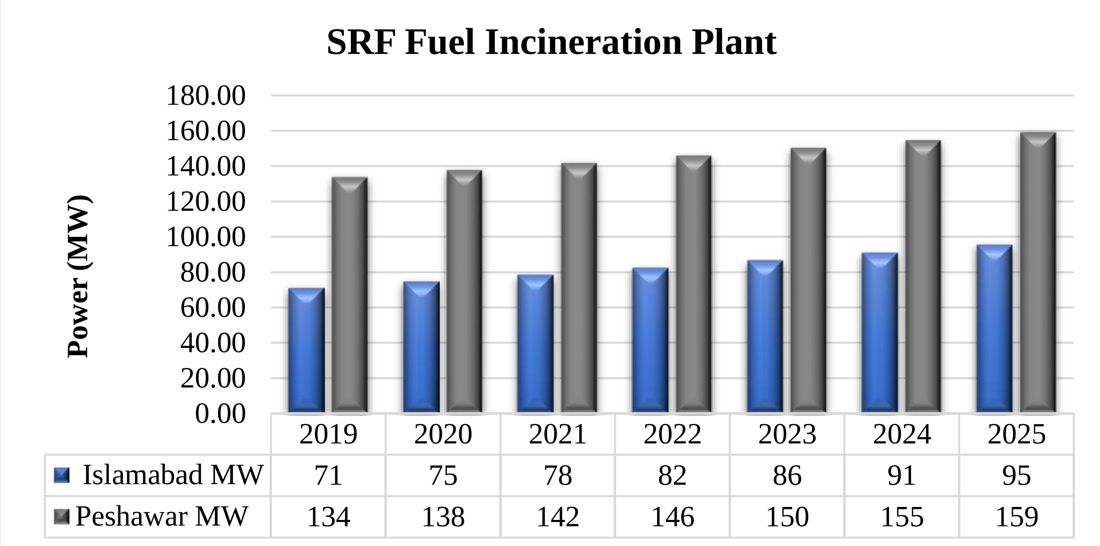
Figure 20 Mass Burn without recycling materials results

4.6 The difference of power in incineration and SRF

Mass burn analysis was performed on the basis of MSW generation and the energy content value were taken from literature. The energy content were then converted to power through use of standard equations. The result of mass burn incineration which includes all element that is combustible. The result on the basis of 2019 data the plant will have the potential to produce 105 MW in Islamabad and 149 MW in Peshawar. For experimental validation when SRF was produce which includes sorting and screening and shredding processes. The SRF sample of Peshawar and Islamabad was tested in lab for their calorific values which is 7069 kJ/kg for Islamabad and 8182 kJ/kg for Peshawar upon converting it into power using the value for SRF based plant in developed countries that is 30% it will produced power of 71 MW for Islamabad and 134 MW for Peshawar based SRF incineration power plant. This result is upon comparison it gave a difference of 32 % in Islamabad and 10% in Peshawar. There are some pros and cons of that values. The value difference as the toxic materials fraction which is of high CV value were removed and were not considered in SRF because of toxicity the materials like hard plastics, tyres, rubber, leather. Second each fraction like organic after removal of Water from SRF its CV value shoot up same in case of incineration in which dry MSW was considered but due fabric nature difference their CV value nature is also differ as the locality is also the issue. For SRF the overall waste is not considered to be used as a composition is made so that limit number of filtration equipment’s to be installed in plant after post combustion process irrespective of direct incineration which is the main cause of capital cost and operation and maintenance cost. Still if we compare this data of SRF to fossil fuel base power plant it will not only compete coal power plant in generation of power but also permanently solve landfills issue and illegal dumps, will save land for other purpose, safe environment. The most important it will save fossil fuel reserve upto great extent.

4.7 Policy and challenges of the WtE adaptation in Pakistan

Pakistan faces a huge energy crisis and the government of Pakistan and the government of China under the umbrella of CPEC installed 5,280 MW of capacity coal power plants and are planning of installing 2,940 MW capacity coal power plants in the country. Most of the power plants will be using imported coal [3], [4]. It will meet the electricity demand but as a developing nation, it will lead to a disastrous situation as Pakistan has faced an economic and energy crisis. It is now the responsibility of the government of Pakistan (GoP) to mainly focus on renewables indigenously available natural resources to meet the energy demand like hydropower, solar, geothermal, MSW, wind. The GoP policy of the renewable energy published by Alternative Energy and Development Board (AEDB) has formulated the renewable energy (RE) policy in 2006, only dealt with mature technologies which are small hydro, solar photovoltaic, wind power. The alternative technologies like landfills methane recovery, biomass gasification, MSW to energy were not considered in that policy [5]. In March 2013; a meeting of the Economic Coordination Committee of the Cabinet (ECC) was held [6], and the GoP has considered the waste to energy, biomass gasification to be included in this policy framework. Recently; during this year a draft of the policy was published by the Ministry of Energy and Power division of GoP which had considered the waste to energy option as pre-requisite on immediate levels. Article 157 of The Constitution of Pakistan allows the Provinces to develop their own power generation projects, lay transmission lines, distribute electricity, and even set their own tariffs if the power generated is for use within the boundary of the relevant Province. Recognizing these constitutional rights, the Provinces are free to institute their own policies for WtE projects where neither the power off-take is by a federal entity nor the interconnection by National Transmission and Dispatch Companies (NTDC) and Distribution Companies (DISCO). In such cases, there shall be no financial or contractual commitment of the Federal Government, or any of its entities, whatsoever [7]. The first WtE plant of 40 MW near Lahore was proposed and executed by the Punjab Government. According to planning, it will start operation in 2021.



	2019	2020	2021	2022	2023	2024	2025
Islamabad MW	71	75	78	82	86	91	95
Peshawar MW	134	138	142	146	150	155	159

Figure 21 Actual value of MW at SRF energy content

4.8 Survey

The fractions of municipal solid waste are mostly produced in household which includes nappies, plastics, organic kitchen waste, food and drinks cans, plastic bottles like cooking oil, shampoo, washing liquid soap, toothbrush, bones, and so. To know on average per capita waste generated in a house. A one-month (December 2018) waste survey was conducted of a house that consist of 4 people. The total weight, fraction of waste, and frequency of fractions were calculated and are summarize in Table 13. The average waste/day of waste is 1.24 kg/day that is 0.4 kg/capita/day waste is being generated in Peshawar.

The survey of MSW generation of two cities were analyzed as total MSW generation of both cities (Peshawar and Islamabad), is 321200 tons/year & 438000 tons/year respectively. The combustible components of MSW is around 84% in Peshawar MSW whereas in Islamabad MSW combustible fractions portion is 90%. The fractions data analyzed, and their summary is shown in Figures 17 & 18. The major components of waste is organic which is 48% and 41% of total waste being generated. Then Plastic second most abundant component which 21% and 23% respectively. Then paper of 7% and 8% and so on for the Peshawar and Islamabad respectively.

Table 13 MSW generation of an individual survey of household

Item (Day)	Total (kg)	Pamper (Nos.)	Veget-ables	Plastic bags	Milk pack	Can metals	Paper	Eggs shell	Plastic bottles
04-12-18	1.670	3	-	8	2	0	-	0	0
05-12-18	1.500	2	-	12	2	2	-	5	2
06-12-18	1.348	2	-	15	3	1	-	3	3
07-12-18	1.236	3	-	16	2	2	-	3	2
08-12-18	1.286	2	-	20	3	3	-	4	0
09-12-18	1.000	2	-	12	5	2	-	4	1
10-12-18	1.450	3	-	15	2	1	-	3	2
11-12-18	1.200	3	-	17	2	0	-	2	0
12-12-18	0.400	0	-	25	0	2	-	4	3
13-12-18	0.500	0	-	24	0	2	-	4	3
14-12-18	1.350	2	-	10	2	2	-	3	0
15-12-18	1.500	2	-	17	2	0	-	3	2
16-12-18	1.400	3	-	16	2	1	-	4	2
17-12-18	1.500	2	-	14	3	1	-	4	2

These fractions are the components which is reached to dump site after sorting of recyclables and metals by scavengers and junkyard collectors. The combustible components fraction is high as organic content is high so as the moisture. Incineration of MSW is then not possible because of high moisture content. The alternate way to get energy from this MSW is to dry it and reduce their size to make it possible.

The fossil fuels used in local industries are natural gas, furnace oil, wood, and coal. these fuels are used in local industries to get their job done. This fossil fuel has a certain price (monthly bill) that must be paid by these industries as Table 14. The main replacement of fossil fuels and easily replaceable are coal and wood, and furnace oil and the owner of such are willing to replace their fuels with SRF.

4.9 Fractional analysis

The factor which is most considered in the fuel is the moisture content as it has direct relation with that of burning and combustion. The MSW fractions generation shows that it has moisture content greater than 50%. The direct incineration is not a vital option because greater the moisture lesser will be the CV and incomplete combustion would take place which will leads to greater production of ash and CO toxic gases. The solution to this problem is the SRF production which main aim to reduce the moisture to minimum levels. The SRF samples which are made from this fraction of waste, will burn only when they have low moisture content. The original moisture content SRF

Table 14 Fossil fuel survey summary

Company Name	Factory A	Factory B	Factory C	Factory D	Factory E	Factory F
Product's	Steel rods	Propylene Woven bags	Paper/Box board	Woven bags	Cooking Tobacco Leaf	Bricks
Type of Fuel's	Furnace oil+ Natural Gas	Natural Gas	Natural Gas	Natural Gas	Wood	Coal
Calorific Value (MMBtu/Scf)	0.017455MMBtu/lb +0.00106	0.00106	0.00106	0.00106	0.008300 MMBtu/lb	0.010103 MMBtu/lb
Supplier's	Attack oil + SNGPL	SNGPL	SNGPL	SNGPL	Local dealer	Amin mines
Price/MMBtu	18000Rs/ton + 600	600	600	600	15000 Rs/ton	10500 Rs/ton
Total Energy Used (MMBtu)	4100 +1666	300	1500	1000	13.28	4041.2
Bill (Rs/Month)	2222500 + 1000000	180000	900000	600000	3 cycles (12000*3=36000)	2100000

contains is 57% in the Peshawar sample while in the Islamabad sample it contains 52% of moisture. The moisture removed in order to get efficient burning. The dry oven test was performed, and results are as shown in Table 15. After removal of moisture the further test are performed on these samples.

Table 15 Moisture test result

Sample	Moisture Removed (%)
Islamabad Yard	64.630
Peshawar	57.285
Islamabad Site Sample	51.600

4.10 Elemental analysis

The core element in SRF which provides thermal energy is carbon and hydrogen. The elemental analysis results as shown in Table 16. The main combustible and energy content values are carbon and hydrogen which is 48% and 7.5% for the Peshawar sample and 41% and 30% of hydrogen for the Islamabad sample. The difference in hydrogen in the sample is because of kitchen waste and plastic. The SOx and NOx are particulate which is harmful to the environment and most of the fossil fuels contain such particulate percentage. The SRF fuel contains almost negligible Sulphur and nitrogen content that is 0.06% and 0.25% Sulphur in Peshawar and Islamabad whereas 0.61% and 0.51% of nitrogen respectively in Peshawar and Islamabad.

Table 16 Fraction analysis summary of SRF

	Peshawar SRF	Islamabad Site	Islamabad Yard
C (%)	48.00	40.67	34.78
H (%)	07.50	31.24	21.97
N (%)	00.61	00.51	00.99
S (%)	00.06	00.25	00.80

4.11 SRF combustion analysis

Different fractions of fuel samples were manufactured based on the Peshawar base fraction. These 4 samples approximate analysis test was performed. their results are shown in Table 17. As upon comparison the sample number 4 is of high calorific value and less moisture content as 18800 kJ/kg and 9% respectively. Then sample 4 is considered standard and on that basis, Islamabad fuel samples were manufactured, and a further test was performed. The difference in calorific value involves different factors; fraction organic nature, plastic quality, and so.

Table 17 SRF comparison

	SRF 1	SRF 2	SRF 3	Pesh. SRF 4	Isb. Site	Isb. Yard
Calorific Value (kJ/kg)	13160	15200	17800	18800	16443	15089
Ash Content Test (%)	25	17	19	15	19	22.2
Moisture Level Test (%)	6.70	12	12	9	9	9
EMISSIONS						
HC (ppm)	176	180	92	49	55	40
CO (%)	0.08	0.09	0.07	0.07	0.025	0.026
CO^2(%)	2.80	2.30	2.61	2.70	3.4	4.9

4.12 Comparison SRF with other fuels

Comparison of SRF with other fossil fuels used locally. As shown in Table 18 the suitable option of SRF comparison with coal as the calorific value of SRF is 80% close to that of coal, and 90% to wood. The moisture of SRF is lower than coal and wood, however, the ash content is higher in SRF. The calorific value changes because of the carbon percent availability. The Sulphur content is much lower in SRF as compared to coal and wood so it is more environment-friendly. Also, the nitrogen quantity which is less in SRF as compared to coal it means that it will produce less NOx as compared to coal. Consideration of SRF with that of Coal and Wood because of NOx and Sox, the SRF is cleaner fuel and it is environmentally cleaner. While on the other hand, SRF reduces the volume of MSW as a result of the reduction of Greenhouse emission gases methane gas and carbon dioxide, cleaning city solid waste and saving the land from landfills. So, it is quite promising to get the same energy content from MSW that is renewable and also saving of fossil fuel reserves and the environment.

4.13 Cost-benefit analysis

The price setting of SRF mainly involve the transportation of MSW from generation to dumpyard. The reports of WSSP was analyzed and looking the details of administrative staffs, vehicles fueling, O&M cost of vehicles, salaries of drivers, helper, supervisors, purchase of safety equipment's, uniforms. The three months data of each 4 zones were analyzed. The all zones 3 months that is (Feb, March, April) data average was find out. All zones data was then average, and a figure was obtained on each tone which is 5798 Rs/ton. Whereas this cost is bare by WSSP to clean their city.

Table 18 SRF comparison with local fossil fuel

	SRF (Isb.)	SRF (Pesh.)	Coal (Thar)[1]	Wood[2]	Furnace oil[3]	Natural gas
Calorific Value (Btu/Lbm)	7069.2	8182.4	10103	7738-9028	18200	1067
Ash Content (%)	19	15	10	0.08-2.5	0.1	-
Moisture (%)	9	9	15	20-45	0.5	-
Carbon (%)	40.67	48	51.89	50.20		
Hydrogen (%)	31.24	7.50	4.90	6.20		
Sulphur (%)	0.25	0.06	2.40	0.10	3.5	
Nitrogen (%)	0.51	0.61	0.90	0.10		
EMISSIONS						
HC (ppm)	55	49				
CO (%)	0.0255	0.07	0.37	0.18		0.01
CO^2(%)	3.4	2.70	2.30	0.12		0.50

In one tone up to 650 kg is useful for SRF production then cost of 650 kg is 7.2 Rs/kg. As utility charges was assumed of 1 Rs and 1.2 Rs for binders. The price of SRF per kg is set to be 9.45 Rs/kg. This price is set based on per ton cost of waste incur from generation to dump yard if the plant is to be set at yard. The cost which is not included in pricing is capital cost and O & M cost of SRF manufacturing plant. The comparison of SRF with fossil fuels used in local industries as shown in Figure 22. The value of monthly bills is based on the amount of energy company consumed. The total energy per month used by factory A that is 5766 MMBtu which cost of 3114010 Rs. Upon replacement with SRF of same energy will cost the of 3057907 Rs that is savings of 56103 Rs/month. Similarly, the factory B uses natural gas as energy source, the total energy consumed 300 MMBtu. This energy consumption cost the factory bare was

1 M. A. M. Munir, G. Liu, B. Yousaf, M. U. Ali, and Q. Abbas, "Enrichment and distribution of trace elements in Padhrar, Thar and Kotli coals from Pakistan: Comparison to coals from China with an emphasis on the elements distribution," *J. Geochemical Explor.*, vol. 185, pp. 153–169, 2018.

M. A. F. Choudry, Y. Nurgis, M. Sharif, A. A. Mahmood, and H. N. Abbasi, "Composition , trace element contents and major ash constituents of Thar coal , Pakistan," *Am. J. Sci. Res.*, vol. 11, no. 11, pp. 92–102, 2010.

2 P. Quinteiro *et al.*, "Life cycle assessment of wood pellets and wood split logs for residential heating," *Sci. Total Environ.*, vol. 689, pp. 580–589, 2019.

A. Price-Allison *et al.*, "Emissions performance of high moisture wood fuels burned in a residential stove," *Fuel*, vol. 239, no. August 2018, pp. 1038–1045, 2019.

K. W. Ragland, D. J. Aerts, and A. J. Baker, "Properties of Wood for combustion analysis pre-exponential factor for hydrocarbons pre-exponential factor for pyrolysis," *Bioresour. Technol.*, vol. 37, pp. 161–168, 1991.

3 A. R. Limited, "Furnace fuel oil," 2012.

180000 Rs. Upon replacement with SRF the bill leads to 159100 Rs/month. That means the factory savings is 20900 Rs/month. The factory C utilization of natural gas for their operational needs the total consumption of fuel that is natural gas was 1500 MMBtu. The bill/month which was paid by company 900000. The factory fuel replacement case the cost of 795501 Rs/month showing the difference of 104499 Rs/month which is a very handsome amount which will be saved by the factory.

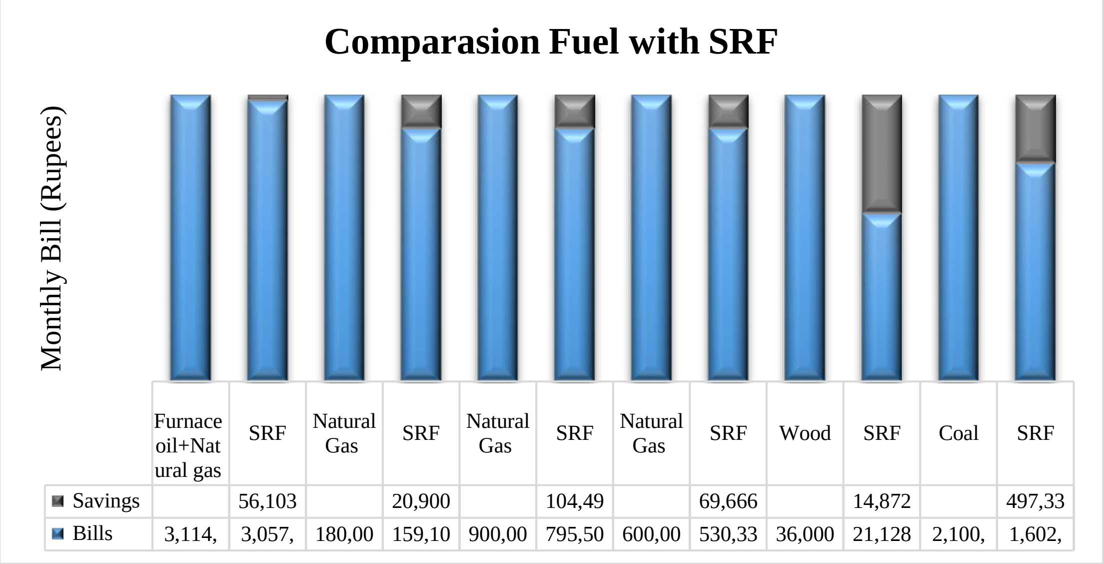


Figure 22 Cost-Benefit analysis

The farmer factories that is factory E which are using pure wood for their need. The energy contains which was consumed was 13.28 MMBtu which cost was 36000 Rs/month. The difference is 14872 Rs/month, which is saving when replace it by SRF which cost the factory 21128 Rs/month. The factory F which main source of energy is coal the coal which consumed by the factory was 4041.2 MMBtu. This energy cost the factory 2100000 Rs/month this figure is reduced when SRF is implemented the cost factory would bare is 1602669 Rs/month that is the saving of 497331 Rs/month. Upon comparison of fossil fuels, monthly bills (in Pakistani Rupees) with SRF is shown in Figure 22. The replacement of wood with SRF will give savings of up to 41%. 24% savings if Coal-burning industries shift its kiln fuel from coal to SRF. For industries which are using Natural gas to meet their energy demand will save up to 12% upon shifting to SRF. For furnace oil using company saving will be 2%.

Summary

The results of the MSW management audit are presented. The results of the feasibility of WtE are explained in detail which represents that WtE is feasible. The combustion analysis along with cost-benefit analysis is also presented in detail.

References

[1] G. of P. M. of Statistics, "Population Census 2017," 2017.

[2] M. J. S. Zuberi and S. F. Ali, "Greenhouse effect reduction by recovering energy from waste land fi lls in Pakistan," *Renew. Sustain. Energy Rev.*, vol. 44, pp. 117–131, 2015.

[3] Ministry of Planning, "Long term plan for China-Pakistan Economic Corridor (2017-2030)," 2017.

[4] Ministry of Planning, "China Pakistan Eorridor Corridor Quarterly," 2018.

[5] Government of Pakistan, "Policy for development of renewable energy for power generation," Islamabad, 2006.

[6] Alternative Energy Development Board, "Frame work for power co-generation 2013," *Ministry of Energy, Power Division, Governament of Pakistan,* 2013. [Online]. Available: http://www.aedb.org/ae-policies/policy-bioenergy.

[7] G. of Pakistan, "Alternative and renewable energy government of Pakistan," Islamabad, 2019.

[8] M. A. M. Munir, G. Liu, B. Yousaf, M. U. Ali, and Q. Abbas, "Enrichment and distribution of trace elements in Padhrar, Thar and Kotli coals from Pakistan: Comparison to coals from China with an emphasis on the elements distribution," *J. Geochemical Explor.*, vol. 185, pp. 153–169, 2018.

[9] M. A. F. Choudry, Y. Nurgis, M. Sharif, A. A. Mahmood, and H. N. Abbasi, "Composition , trace element contents and major ash constituents of Thar coal , Pakistan," *Am. J. Sci. Res.*, vol. 11, no. 11, pp. 92–102, 2010.

[10] P. Quinteiro *et al.*, "Life cycle assessment of wood pellets and wood split logs for residential heating," *Sci. Total Environ.*, vol. 689, pp. 580–589, 2019.

[11] A. Price-Allison *et al.*, "Emissions performance of high moisture wood fuels burned in a residential stove," *Fuel*, vol. 239, no. August 2018, pp. 1038–1045, 2019.

[12] K. W. Ragland, D. J. Aerts, and A. J. Baker, "Properties of Wood for combustion analysis pre-exponential factor for hydrocarbons pre-exponential factor for

pyrolysis," *Bioresour. Technol.*, vol. 37, pp. 161–168, 1991.

[13] A. R. Limited, "Furnace fuel oil," 2012.

Chapter 5

Conclusion and Recommendation

Conclusion

The basic objective of this study was to do a techno-economic feasibility study of using MSW fuel instead of fossil fuels. To better understand the situation, firstly the waste management system of Islamabad and Peshawer city were analyzed. On ground surveys were done to determine the gaps in waste management system. The second step was to estimate the potential to generate electricvity from the MSW in both cities. Third step in the study was to make solid fuel from the waste collected from dumping stations of both cities. The fuel was then analyzed for its properties as a fuel. Finally, the cost benefit analysis was done to compare it with current fuels used by different industrires. The following conclusions were made for the analysis and experitmentation done during this study.

Survey: The primary collection that is from households and shops to bins is the main issue by looking at the map of bins installed, first, they are very few as compared to the population as 17000 people per bin.

- The most common practice as the distance of bin from household is more so people mostly placed their waste at the roadside or through it to empty plot nearby.
- Improper location of bins is the cause of open dumps around the city. Second due limit resources with WSSP in terms of staff due to which most of the vehicles are not running at full capacity.
- Due to low wages of staff specifically drivers due to which most of the drivers found suspicious in stealing oil and dumping waste illegally at roadside or river or plots instead of dumping it in the dump yard. Such a list of drivers is given to WSSP but due to security issues, we are not authorized to publish it here.
- The sanitary workers are also inexperienced or barely educated and untrained. Low salaries of workers are the main cause of illegal practices like selling recyclables, selling fuel issued for the vehicles and doing part-time private jobs

during duty hours. The sanitary workers lack self-respect and social acceptability and are poorly motivated to perform their duty. The sanitary staff, compared to sanitary workers, is educated but neither trained nor motivated.

- According to analysis says if WSSP improves its management and increases its vehicle utilization up to 60% the whole waste collection problem of the city will be solved.

Feasilbility Study: The municipal solid waste generation potential of the Islamabad and Peshawar was evaluated in the current study. The available MSW of both cities should be termed as a beneficial resource not as waste and it can be converted into energy through incineration technology. For the WtE technology adaptation, two scenarios were considered; Mass burn and mass burn without Recycling Materials for the two cities of Islamabad and Peshawar.

- The finding of the mass-burn scenario verifies that it will meet 0.964 % of the total expected electricity demand of the country by 2025 only through one WtE facility. The analysis showed that Mass Burn with recycling has the potential of producing 178 MW and 141 MW of electricity for Peshawar and Islamabad respectively.
- During the comparison of two scenarios, the Mass Burn was found 8.8 times more effective than Mass Burn without recycling materials.

Experimental Validation: The conversion of MSW to SRF of the two cities were evaluated in this study. The experimental tests of SRF were conducted according to ASTM standards and the results of SRF were compared to coal, wood and natural gas. The SRF have almost very low content of Sulphur and Nitrogen as compared to coal and wood, so it has almost negligible amount of SOx and NOx emissions along with CV which is close to coal and wood.

- The energy content of SRF which was found out for Peshawar and Islamabad taking that actual value electricity forecast was found out which is shown in figure 21.
- The result shows the difference of 11% and 30% in values of Peshawar and Islamabad respectively.

- The difference is because of a certain fraction of waste that is toxic and is not considered in making SRF fuels and of higher energy content that's tyres, leather, rubber, hard plastics.

Cost Benefit: The result of final comparisons leads to savings of investment on fossil fuels.

- The replacement of wood with SRF will give savings of up to 41%.
- The 24% savings of Coal-burning industries by shifting its kiln fuel from coal to SRF.
- Industries which are using Natural gas to meet their energy demand will save up to 12% upon shifting to SRF.
- Furnace oil using company saving will be 2%.

Recomendatations

- According to WSSP data, they collect 45%-55% of the total waste generated in Peshawar city while the rest 40%-50% left there and remain uncollected. If managed properly, the resources present is quite enough to carry and collect all the waste produced in the city. According to analysis says if WSSP improves its management and increases its vehicle utilization up to 60% the whole waste collection problem of the city will be solved.
- To improve the city waste management system training session should be conducted for sanitary workers and proper education should be given to them in order to perform their work in a better way.
- The minimum wages of the labor should be increase and ethical education to be provided through conducting seminars, conferences that motivate the drivers and labors to perform their work with honesty.
- City wise campaign to be conducted in which awareness is to be provided to the public regarding waste management by reducing, reusing and recycling.
- It is recommended and mandatory that GoP should come forward to commission the WtE Plants for the metropolitan cities to fulfill the local energy demand that will also reduce greenhouse gas emissions with a cleaner environment and optimal waste management.

- The MSW should be considered as a renewable fuel and could be used in local industries, it not only save the land but also the environment from GHG emissions. It is recommended and mandatory that GoP should come forward to commission the SRF manufacturing plant for the metropolitan cities to fulfill the local energy demand and to recover the operational cost and admirative cost of municipalities.

Summary

In this chapter, the present research findings are concluded. Also, some recommendations are also proposed to better implement the MSW management waste to energy techniques at commercial level.

Status of Solid Waste Management in Peshawar, Pakistan

Waqas Ahmad[1*], Muhammad Hassan[1], Tahir Nawaz[1], Muhammad Ashfaq[2], Muhammad Assad Khan[1]**

[1]US Pakistan Center for Advanced Studies in Energy, NUST, Islamabad 44000, Pakistan.

[2]Department of Mechanical Engineering, UET Peshawar, Peshawar 25000, Pakistan.

Abstract:

Pakistan faces both an energy crisis on one hand and difficulty in transporting waste from generation to final disposal because of a quickly expanding population. The number of inhabitants in Pakistan was recorded as 208 million in 2017 census and constantly expanding with the growth rate of 2.4%, making it one of the world's most crowded nations and further exacerbating waste management issues. The main objective of this article is to examine the present waste management procedure of Peshawar city and what should be done to improve it. A major part of the Peshawar population belongs to the low and middle-class income region and based upon this fact, squander generation rate per capita fluctuates in various parts of the city. To achieve the goal of information gathering of waste generation daily, quantitative analysis survey was being performed in Peshawar city along with WSSP and interviews conducted with household. Besides, every zone's garbage collecting vehicles were monitored and their performance was tracked which demonstrates that 2208 tons/day waste is generated every day. Municipal solid waste collection and disposal services in the city are not in the same class as it should've been. On the grounds that roughly 60 percent of the solid waste is collected and the remaining are present there at gathering points, or in streets, where it radiates a large amount of contaminants into the surrounding environment, making it unsuitable for human interaction. A noteworthy part of the waste is dumped in an old furnace misery around the southern side of the city. This analysis represent that limited number of bins, as 17000 people per bin. Substandard design and location of bins make it difficult to proper utilize it. Underutilization of vehicles as the total maximum potential trips it could make is 1908 but on ground only 562 trips are made weekly which is 31% of it, it should be utilized at full capacity. Firing of suspicious drivers and, recruit new staff along with proper training and ethical awareness should be provided to them. Further analysis should be performed like budgetary costing of every ton waste from the waste generation site to a landfill site, social, technical, political and environmental.

Keywords: Pakistan, MSW, Solid waste Management, Peshawar strategy

*First author: Waqas Ahmad , Tel: +92-316-0095592, email: waqasahmad000713@gmail.com

**Corresponding author: Dr.Muhammad Hassan, Tel: +92-51-90855275, email: hassan@uspcase.nust.edu.pk

Status of Solid Waste Management in Peshawar, Pakistan

Waqas Ahmad[1*], Muhammad Hassan[1], Tahir Nawaz[1], Muhammad Ashfaq[2], Muhammad Assad Khan[1]

[1]US Pakistan Center for Advanced Studies in Energy, NUST, Islamabad 44000, Pakistan.
[2]Department of Mechanical Engineering, UET Peshawar, Peshawar 25000, Pakistan.

1st Author: Waqasahmad000713@gmail.com, Corresponding Author: hassan@uspcase.nust.edu.pk

Abstract

In the present-day world, the energy crisis and the transportation of the waste to a proper disposal site are two of the major problems that Pakistan is facing with its growing population. The number of inhabitants in Pakistan was recorded as 208 million in 2017 census and constantly expanding with the growth rate of 2.4%, making it one of the world's most crowded nations and further exacerbating waste management issues. This study was carried out to examine the waste management procedures, its limitations and possible solutions to it. With the collaboration of governing body Water and Sanitation Services in Peshawar (WSSP) a quantitative survey analysis is being performed. Interviews with drivers and household were conducted, and, garbage collecting vehicles in each zones was also monitored. The results show that around 2208 tons/day waste is generated. On grounds, roughly 60% of solid waste is collected and the rest are lifted there at gathering points, or in streets, where it radiates many containments into the surrounding environment, making it undesirable for humans. The results of this study also represent, that limited numbers of bins are installed as 17000 people per bin. Substandard design and location of bins make it difficult to properly utilize it. Underutilization of vehicles as the total maximum potential trips it could make is 1908 but, on the ground, only 562 trips are made weekly which is 31% of it. The recommendation to fulfill this gap is; proper design of the bin and at least install 200 more bins. The vehicles present with WSSP are sufficient, only increase their utilization by up to 61%. Proper training and ethical awareness should be provided to driver staff. Further analysis like budgetary costing of every ton of waste from the waste generation site to a landfill site is to be performed.

Keywords-Pakistan, MSW, Solid waste Management, Peshawar strategy

1. Introduction

Most developing countries highly ignore the overall environmental impact of managing there MSW (Municipal Solid Waste). Developing countries have acquired a worrying attitude towards the effects that can be caused by improper handling of MSW [1]. Managing the MSW in many poor nations takes a substantial share of the Municipal budget, yet existing practices pose a great danger to the environment and to public health and well-being [2]. Waste management planning is a subset of environment planning through limiting, reusing, recycling and getting rid of resources in a way that minimizes overall biophysical and socioeconomic effects [3].

In developing countries like India which includes 42% of the urban population lives in metropolitan cities which are Delhi, Mumbai, Kolkata, and Chennai [3], [4]. Due to the high occupancy rate, its production of MSW is also high. The total waste generation of the Indian cities in 2009 was 90 million tons and it is expected to increase up to 300 million tons in 2047

[5]. While the collection of this waste at the generation site is very poorly managed that is in most

part of urban areas the MSW storage facility is absent, while the collection bins which are even present in various areas are neither properly designed nor properly located and maintained. The consequence of this is poor collection efficiency [6]. For a collection of decomposable and no decomposable waste, toxic and nontoxic waste all are collected in a common bin [7]. Only 6%-7% of MSW converted into compost while the rest of MSW i-e 90% is disposed of through landfilling [8]. An only minor portion of MSW is used in waste to energy.

In neighbor Iran, a developing country [9], has a population of 81 million according to 2017 data [9], [10]. The total MSW generation only 71.2% of waste is collected from the capital city, Tehran. According to [11] 83.6% of Tehran waste ends up in landfills, while 10.5% in composting and only about 5.9% is recycled. There is, currently no proper management and handling rules applied in the area, also, lack of policy even capital city MSW and hospital hazardous waste are collected in the same bin and transfer to the dumpsite [9].

According to the China Statistical Yearbook, 2018 says that the end of 2017 the total urban population was 58.52% [13], [14]. The total urban waste generation of China 350 million tons in 2017 [15]. The total MSW 60.16% ends up in landfills, while 29.84% in incineration and 8.21% untreated discharge and 1.79% in other treatments [16].

Pakistan, a developing nation [17], having a population of 207 million according to 2017 [18]. Out of which 36.38% are urban population [18]. An estimation of around 25.420 million tons of MSW except perilous wastes is produced per annum [19]. The collection of waste from generation site is only 60% in most of the cities while the rest lies in topographic depressions, vacant plots, along streets, roads, railway lines, drains, storm drains, and open sewers within overall urban areas [1].

The area targeted for this study has Peshawar situated in KPK (Khyber Pakhtunkhwa) province with a total population of 4.3 million [20]. this study mainly focuses on the total amount of waste generated in Peshawar and per capita waste generation in Peshawar city; mainly include composition, primary storage, secondary storage, transportation, disposal.

2. Methodology

Peshawar consist of low, middle, high economic classes, based on the area of houses, and income of a household. Collection of information from generation site. The approach which is used in this study are interviews with companies specifically WSSP (Water and Sanitation Services Peshawar), the waste management governing body. Observation of the management system at ground level from waste generation to disposal.

2.1 Status of MSW

Capital of KPK, Peshawar a city of extreme hospitality, with a population of 4.2 million people. People of Peshawar enjoy four seasons because of geographical location. During summer mean temperature 42.7 degrees Celsius while in winter the temperature reaches 2.5 degrees Celsius [21]. A Google map as shown in figure 2 the Peshawar district in which WSSP is working divides the city into 4 zones. The WSSP is government water and solid waste management body working in Peshawar. Private companies like Blue Skies a composting company give services to a very limited household area.

2.1.1 Solid waste storage

After the generation of waste, there is no such system of proper storage of solid waste. Every household specifically low-income area where housewives and shopkeepers clean their houses and shops respectively and put their waste outside of their main gate which is then discarded erratically into the streets.

Figure 23 (a) Board Bazar where bin is located along with open dumps, (b) Open dumps at Police colony

In Peshawar, the household placed their garbage outside their residences and all the waste is collected by the collection service provider.

2.1.2 Location of storage bins

The map shows the areas which are under WSSP is shown in figure 2. According to WSSP, they install 315 waste bins at different sites of different shapes and sizes. With the help of GPS, the areas were visited here the is installed.

2.1.3 Storage of waste outside the house

The house put their waste in a shopper or in a bin and put them outside at their home for waste collectors. Different colonies have different arrangements for their waste services. Some have donkey cart figure 2 services, daily they come and collect waste from household upon knocking each door.

2.1.4 Open dumps

The practice of open dumping is very common in Peshawar city like dumps on the roadside, walkways, vacant plots, stormwater drains, and open sewers, and streets in figure 1(b). Which causes serious environmental and health hazards problems like sight pollution, odor pollution, diseases producing vectors like dengue, malaria-causing flies. The open dumps also found near the container bins.

2.1.5 Containers

Onsite storage of waste in some place WSSP placed containers as shown in figure 1(a). These containers are lifted off mechanically and emptied mechanically at the site. Two types of containers are used one 5 cubic meters and the others are 22 cubic meters.

Figure 25 Some sectors like Professor Colony and Police Colony a Donkey cart collecting waste

The problem with the containers is height as 22 cubic meters have 1.75-meter height as a result user throw their waste outside of the containers. Which leads to open dumps. The total operating number of that 5cubic meters arm roll is 19. Whereas heavy arm roll which is 22 cubic meters are 5 in numbers.

2.2 Collection of Solid Waste

In the collection process, the waste is collected from these bins and it is transferred to the dump yard. Before transport the waste reached to these bins by three means which are;

- Household members like children and housewives, servants and shopkeepers after cleaning shop at morning collect waste put it down in near placed bin.
- Private sweepers and sweeper of government collect the household’s garbage from outside of their residences with their handcart/donkey carts and dump that waste into a waste bin.
- Private companies like Blue skies use garbage trucks to collect waste from the house to house.

2.3 Garbage Trucks and their timings

The machinery used for a collection of waste from storage points includes; Compactor, Hino Arm Roll, Hino Arm Roll heavy, Suzuki Mini Dumper, Tractor Trolley, Rickshaw. In Peshawar the collection system is a stationary container system, here the garbage vehicles move around in its specific location until it is filled and then move towards the disposal site for offloading.

2.3.1 Suzuki mini dumper

The most affordable and common in Peshawar is SUZUKI mini dumper it approximately collects up to 800kg of waste from generation site. The

Figure 24 In University Town collection made through SUZUKI mini dumper

volume of the container is 2.5 cubic meters.

2.3.2 Compactor

The compactor vehicle compact waste. It has the capacity to compact waste up to 5.6 tons. WSSP has the compactor total numbers are 41. The solid waste bin is lifted off by the compactor and it is emptied in the compactor. The main issue with a compactor is foul-smelling liquid fell off it while it moves around lift, compact, and unload, the garbage it collects.

2.3.3 Arm roll Trucks

The arm roll truck takes the containers by itself with the help of an arming jack. In a single round trip, it takes one container and brings it back to its location after offloading it at the dumpsite. Based on this, two-arm roll trucks are used which are Arm roll 5 cubic meters and 22 cubic meters.The 5 cubic meter arm roll can carry MSW up to 2 tons per trip. While 22 cubic meter can carry up to 9 tons per trip.

2.3.4 Mazda truck

Mazda truck operate manually means it can be loaded with the help of labor by using shawl. The main issue with that is during the moment along their route to the dumpsites the solid waste falls from it because it is uncovered. The capacity of that truck is up to 2 tons.

2.3.5 Tractor trolley

Tractor trolley is generally used in Peshawar city and easily convince for carrying solid waste. They are also used to lift garden waste. It can carry up to 4 tons of waste. The same problem of falling of solid waste and liquid from it, as with truck and compactor.

2.4 Temporary Storage Sites

Temporary storage sites are used to remove, and transfer collected solid waste from residences through small vehicles to large transport vehicles. Currently, there is no transfer station in the city of Peshawar, and this model also doesn't have any specifications for such location.

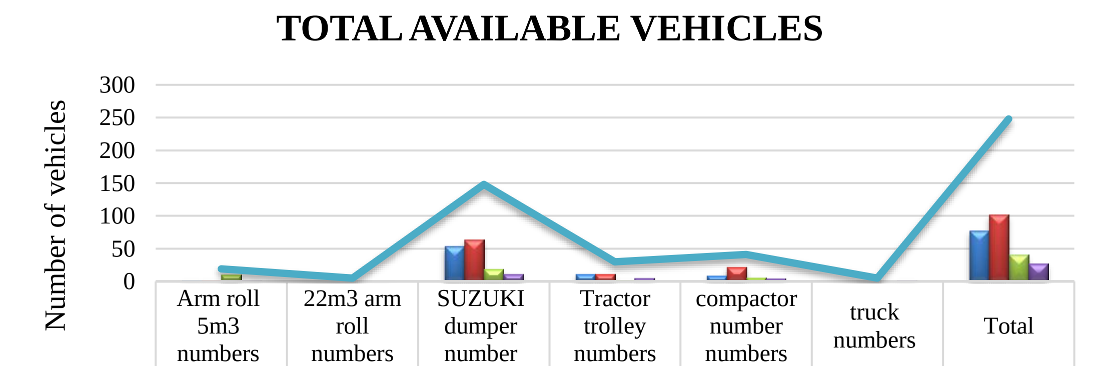
2.5 Recovery of recyclables

Waste being produced on-site consist of different fractions like organic, demolition waste, tins, steels, hard plastic, soft plastic, napkins, pampers, bones, glass, papers, foam, textiles, paints, oil, etc. Out of which the potentials recyclables are PET bottles, jars, tins, glass bottles, papers. Their segregation starts at the generation sources. Scavengers wander around in the streets and call for recyclable waste, they get it either free of cost or even pay some money for it. Scavengers sort out the materials placed in dustbins, skips and other pickup points. They also collect the recyclables from disposal sites. These materials then sold out to the junk dealers (Kabariys) in the market by these scavengers at low rates.

2.6 Solid waste disposal

Disposal of solid waste means landfilling. The landfill sites are not properly managed, but it involves open dumping at multiple unplanned locations inside and around the city. The official dumpsite currently decides by government and WSSP is 12 Km radius away from city zones the dumpsite name as Shamshatto dumpsite and Chowa Gujjar Gari site. The field survey shows that open dumping is carried out in the open empty plots of governments, back swamps, slum areas, and

Table 19 Summary of available vehicles with WSSP for each Zones (A, B, C, D)



	Arm roll 5m3 numbers	22m3 arm roll numbers	SUZUKI dumper number	Tractor trolley numbers	compactor number numbers	truck numbers	Total
A	3	1	54	11	9	0	78
B	3	2	64	11	22	0	102
C	10	1	19	3	6	2	41
D	3	1	11	5	4	3	27
Total	19	5	148	30	41	5	248

rivers. With the presence of an official dumpsite driver still disposes waste illegally in order to steal oil. This illegal dumping practices causes complex and serious environmental problems, and adversely affects public health.

3. Results and Discussions

3.1 Total waste generation

The total population of Peshawar city is 4.3 million. Which on average produces 0.4-0.8 kg/capita/day waste. If we take 0.5 kg/capita/day average, then it leads to 2208 tons of waste generated per day. Whereas in an interview with WSSP finance they say that a maximum of 1000 tons/day waste is collected. Up to 250 tons/ day lifted off by privates' companies like Blue Skies and Scavenger and Junk dealers. While the rest lay there, that is 960 tons/day.

3.2 Result of vehicles availability

The total vehicles available with WSSP are present in table 1 in detail.it shows that the SUZUKI dumper number is high in each zone, where tucks and 22 cubic meter arm roll are minimal in number.It is a common observation that each zone not fully utilizing its vehicles. They use limit numbers of vehicles for waste collection while the rest stand there at the garage. Each zone trip detail to dump yard is present in the given tables.

There is no precise account of distances that each vehicle traveled because in most machines the speedometers are not working properly. This promotes the dumping of waste at dumpsites located closer to the collection sites other than specified disposal locations. This requires a GPS-based control system to be installed in the vehicles for tracking purposes. It is very uneconomical as wells as inefficient to load and unload the vehicles manually in terms of time and effort. In areas with limited space for storage, it requires the more frequent collection of waste by smaller vehicles due to limited space is an uneconomical practice.

Table 20 Trips details of each vehicle in zone A for a week (WSSP Verified)

Zone A	Trips/Day 6/6/19	Trips/Day 7/6/19	Trips/Day 8/6/19	Trips/Day 10/6/19
Arm roll-11(5m^3)	3	2	2	4
Arm roll-15(5m^3)	5	1	5	4
Arm roll-8(5m^3)	0	2	4	5
Trolley 47	2	2	2	4
Arm roll(22m^3)	4	0	2	4
Comp.-79(7m^3)	0	0	1	0
Comp.-82(7m^3)	1	1	1	1
Comp.-85(7m^3)	1	1	1	2
Comp.-90(7m^3)	1	2	0	1
Comp.-91(7m^3)	1	1	1	1
Comp.-92(7m^3)	0	0	0	0
Comp.-94(7m^3)	1	1	0	2
Comp.-177(4m^3)	1	1	2	1
Comp.-180(4m^3)	1	1	0	1
Comp.-187(4m^3)	1	1	0	1
Trolley-76	2	1	2	1
Trolley-77	2	2	1	1
Trolley-1 messi	2	0	1	5
Dumper 3	1	2	1	2
Dumper4	2	1	0	2
Total	**31**	**22**	**26**	**42**

Table 21 Trips details of each vehicle in zone B for a week (WSSP Verified)

Zone B	Trips/Day 6/6/19	Trips/Day 7/6/19	Trips/Day 8/6/19	Trips/Day 10/6/19
Arm roll-large 1	2	3	4	4
Arm roll-large2	2	3	4	4
Comp.-01(4m^3)	2	1	2	0

Comp.-64(7m^3)	1	1	1	1
Comp.-65(7m^3)	2	1	2	2
Comp.-80(7m^3)	2	1	1	2
Comp.-84(7m^3)	2	1	1	1
Comp.-97(7m^3)	0	0	0	0
Comp.-98(7m^3)	1	1	1	1
Comp.-99(7m^3)	1	0	0	0
Comp.-156(7m^3)	0	0	0	0
Comp.-174(7m^3)	1	1	1	2
Comp.-175(4m^3)	2	1	2	2
Comp.-178(4m^3)	2	1	1	2
Comp.-181(4m^3)	0	0	0	0
Comp.-182(4m^3)	2	1	2	2
Comp.-183(4m^3)	1	1	0	0
Comp.-184(4m^3)	1	1	1	1
Comp.-185(4m^3)	2	1	1	2
Comp.-186(4m^3)	1	1	1	2
Comp.-188(4m^3)	1	2	0	2
Comp.-189(4m^3)	2	1	2	2
Comp.-190(4m^3)	2	1	0	0
Comp.-191(4m^3)	1	1	1	2
Comp.-193(4m^3)	2	2	1	2
SUZUKI damper1	4	4	4	4
SUZUKI damper2	4	0	4	0
SUZUKI damper3	5	3	5	4
Trolley Messi4	5	5	5	6
Multi Loader	5	0	0	0
Arm roll large 1	3	0	0	0
Arm roll large 2	2	0	0	0
Arm roll 7	5	3	6	3
Arm roll 8	5	5	5	5
Arm roll 16	4	5	6	6
Trolley 44	0	0	0	0
Trolley 48	3	2	3	3
Trolley 45	0	0	3	0
Trolley 51	2	1	5	1
Trolley 52	3	1	0	3
Trolley 53	4	4	3	4
Trolley 54	0	0	0	2
Trolley 55	5	5	5	5
Trolley 56	0	0	0	0
Trolley 57	6	1	4	0
Truck 29	0	0	0	0
comp.52	1	0	1	1
Total	**66**	**39**	**59**	**47**

Table 22 Trips details of each vehicle in zone C for a week (WSSP Verified)

Zone C	Trips/Day 6/6/19	Trips/Day 7/6/19	Trips/Day 8/6/19	Trips/Day 10/6/19
Arm roll-1(5m^3)	6	3	5	5
Arm roll-2(5m^3)	0	0	0	0
Arm roll-6(5m^3)	3	3	5	5
Arm roll-8(5m^3)	5	5	4	6
Arm roll-10(5m^3)	2	1	0	2
Arm roll-12(5m^3)	3	1	1	0
Arm roll-13(5m^3)	6	0	2	0
Arm roll-14(5m^3)	0	0	0	0
Arm roll-17(5m^3)	4	1	3	5
Arm roll-20(5m^3)	1	1	0	0
Arm roll(22m^3)	2	1	2	0
Comp.-96(7m^3)	1	1	1	1
Comp.-86(7m^3)	1	1	1	1
Comp.-179(4m^3)	2	1	1	1
Comp.-03(4m^3)	1	1	0	0
Comp.-165(7m^3)	1	1	1	1
Comp.-93(7m^3)	1	1	0	1
Truck-06	0	0	0	0
Truck-10	2	1	2	2
Trolley-13	0	0	0	0
Trolley-46	0	0	0	0
Trolley-03	0	0	0	0
Multi loader(5m^3)	0	0	0	0
Total	**41**	**23**	**28**	**30**

Table 23 Trips details of each vehicle in zone D for a week (WSSP Verified)

Zone D	Trips/Day 6/6/19	Trips/Day 7/6/19	Trips/Day 8/6/19	Trips/Day 10/6/19
Arm roll-3(5m^3)	3	3	3	4
Arm roll-4(5m^3)	3	4	4	3
Arm roll-5(5m^3)	3	3	3	3
Arm roll2(22m^3)	2	2	2	2
Comp.-192(7m^3)	2	1	2	1
Comp.-02(7m^3)	2	1	2	1
Comp.-176(4m^3)	1	1	1	1
Comp.-95(4m^3)	1	1	2	1
Trolley-04	6	4	2	2
Trolley-37	1	2	1	1
Trolley-15	3	1	0	2
Trolley-57	3	2	3	2
Multi loader(5m^3)	2	0	1	2
Total	**32**	**25**	**26**	**25**

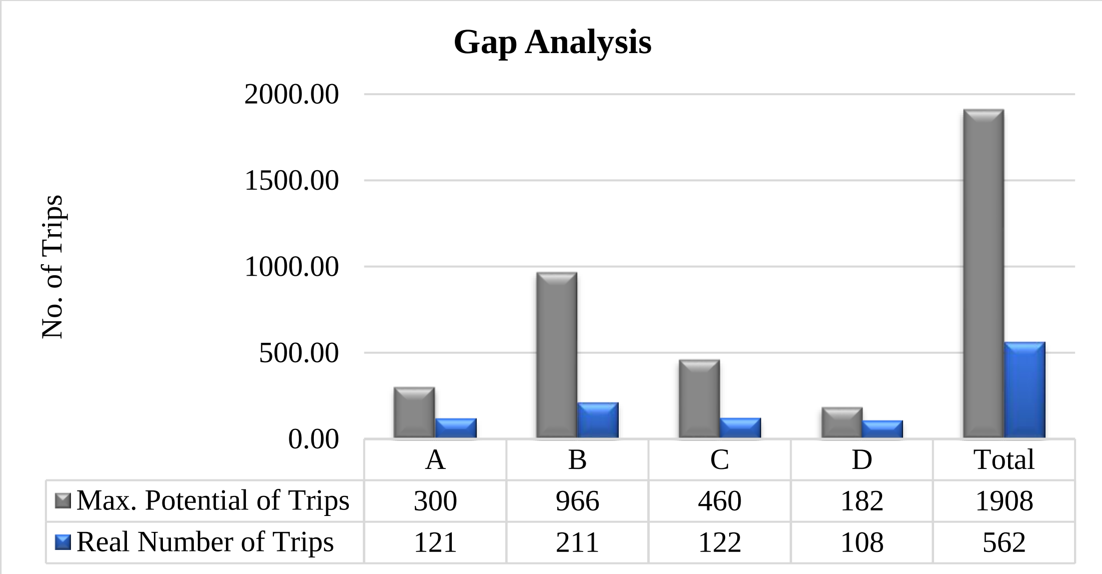


Figure 26 Gap analysis summary of four zones of Peshawar city

4. Conclusions

The primary collection that is from households and shops to bins is the main issue by looking at the map of bins installed, first, they are very few as compared to the population as 17000 people per bin. The most common practice as the distance of bin from household is more so people mostly placed their waste at the roadside or through it to empty plot nearby which more commonly seen in Professor colony and Board Bazar, Police colony, Town, etc. Improper location of bins is the cause of open dumps around the city. Second due limit resources with WSSP in terms of staff due to which most of the vehicles are not running at full capacity. Also due to low wages of staff specifically drivers due to which most of the drivers found suspicious in stealing oil and dumping waste illegally at roadside or river or plots instead of dumping it in the dump yard. Such a list of drivers is given to WSSP but due to security issues, we are not authorized to publish it here.

According to WSSP data, they collect 45%-55% of the total waste generated in Peshawar city while the rest 40%-50% left there and remain uncollected. If managed properly, the resources present is quite enough to carry and collect all the waste produced in the city. According to analysis says if WSSP improves its management and increases its vehicle utilization up to 60% the whole waste collection problem of the city will be solved.

Public awareness is another issue as the public generally do not cooperate with the staff and are not entirely familiar with the health and social issues associated with solid waste management. The sanitary workers are also inexperienced or barely educated and untrained. Low salaries of workers are the main cause of illegal practices like selling recyclables, selling fuel issued for the vehicles and doing part-time private jobs during duty hours. The sanitary workers lack self-respect and social acceptability and are poorly motivated to perform their duty. The sanitary staff, compared to sanitary workers, is educated but neither trained nor motivated.

To improve the city waste management system training session should be conducted for sanitary workers and proper education should be given to them in order to perform their work in a better way. The minimum wages of the labor should be increase and ethical education to be provided through conducting seminars, conferences that motivate the drivers and labors to perform their work with honesty. City wise campaign to be conducted in which awareness is to be provided to the public regarding waste management by reducing, reusing and recycling.

Acknowledgments

The authors acknowledge the assistance of Sheraz Khan, Manager Finance at Head Office of Water and Sanitation Services Peshawar Khyber Pakhtunkhwa. The author also thanks, the site supervisors and drivers for their support.

References

[1] S. A. Batool and M. N. Chuadhry, "The impact of municipal solid waste treatment methods on greenhouse gas emissions in Lahore, Pakistan," *Waste Manag.*, vol. 29, no. 1, pp. 63–69, 2009.

[2] R. Joshi and S. Ahmed, "Status and challenges of municipal solid waste management in India: A review," *Cogent Environ. Sci.*, vol. 2, no. 1, pp. 1–18, 2016.

[3] S. Oduro-Appiah, K., Aidoo, D.O. and Graham, "Fee-based solid waste collection in economically developing countries: The case of Accra metropolis," *Int. J. Dev. Sustain.*, vol. 2, no. 2, pp. 629–639, 2013.

[4] R. Ghosh and A. Kansal, "Urban Challenges in India and the Mission for a Sustainable Habitat," vol. 2, no. Vesilund 1982, pp. 281–304, 2014.

[5] T. TERI, "Energy data directory and yearbook (teddy) 2001–2002," *Tata Energy Res. Institute, New Delhi, India*, 2002.

[6] S. Saxena, R. K. Srivastava, and A. B. Samaddar, "Sustainable Waste Management Issues in India," vol. III, no. 1, 2010.

[7] S. Rathi, "Alternative approaches for better municipal solid waste management in Mumbai, India.," *Waste Manag.*, vol. 26, no. 10, pp. 1192–1200, 2006.

[8] R. Reddy, "Secured Landfills for Disposal of Municipal," vol. 1, no. 1, 2013.

[9] P. F. Rupani, R. M. Delarestaghi, and H. Asadi, "Current Scenario of the Tehran Municipal Solid Waste Handling Rules towards Green Technology."

[10] Iran Population, "Iran population," 2019. [Online]. Available: https://www.worldometers.info/world-population/iran-population/.

[11] M. R. Alavi Moghadam, N. Mokhtarani, and B. Mokhtarani, "Municipal solid waste management in Rasht City, Iran.," *Waste Manag.*, vol. 29, no. 1, pp. 485–489, Jan. 2009.

[12] P. Agency, "(Draft) Guideline for Solid Waste Management," *Pakistan Environ. Prot. Agency*, pp. 1–142, 2005.

[13] B. Zhou, C. Sun, and H. Yi, "Solid waste disposal in Chinese cities: An evaluation of local performance," *Sustain.*, vol. 9, no. 12, pp. 1–20, 2017.

[14] China, "China Statistaical Year Book 2018," 2018. [Online]. Available: http://www.stats.gov.cn/tjsj/ndsj/2018/indexeh.htm.

[15] Y. Geng, Q. Zhu, and M. Haight, "An overview of municipal solid waste management in China.," *Waste Manag.*, vol. 27, no. 1, pp. 716–24, 2007.

[16] M. M. Mian, X. Zeng, A. A. N. Bin Nasry, and S. M. Z. F. Al-Hamadani, "Municipal solid waste management in China: a comparative analysis," *J. Mater. Cycles Waste Manag.*, vol. 19, 2016.

[17] Finance Division Govement of Pakistan, "Pakistan Economic Survey," 2019.

[18] G. of P. M. of Statistics, "Population Census 2017.pdf," 2017.

[19] M. S. Korai, R. B. Mahar, M. A. Uqaili, and K. M. Brohi, "Assessment of Municipal Solid Waste Management Practices and Energy Recovery Potential in Pakistan," *14th Int. Conf. Environ. Sci. Technol.*, no. September, pp. 3–5, 2015.

[20] Pakistan Bureau of Statistics, "Population and household detail from block to district Level-Peshawar KPK," 2017.