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Review

A Review on Sustainable Framework for Food Based Solid Waste Energy Management in Karachi

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Abstract. The paper focuses to introduce a sustainable Food Waste (FW) management framework to facilitate an efficient FW segregation from other types of waste in Municipal Solid Waste (MSW) through an optical sorting system, valorization to biogas *via* Anaerobic Digestion (AD) and further for power generation considering Karachi as a case study. For sustainable resolution to the acute waste disposal issue, a frame work for food waste collection, sorting and recycling is proposed considering the current waste management practices and local government policies. The process for obtaining biogas fuel from food waste has been widely practiced by many countries like Norway, Sweden and France. This study indicates the forecast for energy production from biogas which may reach to 994 GWh by the year 2030 in Karachi. Thus, this proposed management framework can bring the epitome of the waste to wealth concept for the sustainable collection and recycling of food waste to renewable energy in order to facilitate the clean environment and may result in reduction of reliance on landfills, promote circular economy and lessen the energy gap between power demand and supply in Karachi city.

Keywords: sustainable framework, food waste, solid-waste conversion, waste to energy technologies, renewable biogas, waste management, waste segregation

Introduction

Globally, the population is escalating annually with the growth rate of 1.05% and with this rapid growth, the quantity will exceed 10 billion by the year 2057 (Khan *et al*., 2022). Thus, the MSW generation per annum is approximately 2.01 billion tons, out of which the un-managed MSW amount is 33% (Nadeem *et al*., 2022). The amount of Municipal Solid Waste (MSW) outputted is rising due to industrial activities, urban movement and increase in population. Segregation, collection, transportation, processing, recovering and dumping of MSW needs multidisciplinary skills with active participation of the public authorities, policy makers, the community and members of municipalities (Batista *et al*., 2021). The different kinds of MSW have different environmental and health impacts depending on the dumping and disposal method (Chen *et al*., 2020). The Intergovernmental Panel on Climate Change says that MSW has a significantly large fraction of organic waste mainly food waste (FW) (25-70%) that has a great potential to become a source of renewable energy through any waste to energy (WTE) conversion technologies. The annual total quantity of food waste produced is around 1.6 giga tons (Chhandama *et al*., 2022). About one third of the generated food which is supposed to be consumed by living beings is lost every year (Persson *et al*., 2022). It is projected that from 2005 to 2025, the quantity of FW in different countries of Asia could increase from 278 to 416 million tons (Paritosh *et al*., 2017). The demand for food globally is projected to enhance by 70% in order to sustain a human population and is expected that by 2050, it will reach 9.8 billion. This calls for an immediate action and plans to reduce food waste through sustainable consumption and renewable practices (Ananno *et al*., 2021).

Research problem. Karachi, a metropolitan city of Pakistan is currently facing a situation of an un-precedented increase in municipal solid waste (MSW) generation due to rise in human capital growth, economic development and industrialization. Karachi is considered to be the largest and most populated city of Pakistan. The most important reason of this population growth is due to rapid industrial growth, rural to urban migration due to push-pull factors, cross regional migration of different types of skilled people and unprecedented rise of population as part of human capital growth (Khan *et al*., 2019). This has led to large scale design of

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industrial and commercial growth, including development of business focused projects as well as formation of residential neighborhoods. Progress and urbanization are also followed closely with increased human presence as well as human consumption leading to paramount issues related to MSW propagation and raised energy demands. Karachi, the commercial and industrial heart of Pakistan is in the midst of power and energy crises that results in long and frequent power outages. The existing power decline is heavily destroying the economic and commercial activities and its effects are penetrating in each domain of life cycle as generated power (including all the sources of renewable energy) is not enough to meet the energy demand (Sohoo, *et al*., 2021a&b).

Research objectives

- To propose a sustainable Food Waste (FW) management framework to facilitate an efficient FW segregation from other type of wastes in Municipal Solid Waste (MSW) through an optical sorting system
- Valorization of food waste to renewable biogas *via* Anaerobic Digestion (AD) process.
- Generation of electricity from biogas to bridge the gap between energy demand and supply and reduction in energy shortfall

Literature review. ***Definition of food waste.*** The food waste that is generated is categorized into avoidable and un-avoidable sub-categories. There are certain possibilities where a third option is also available which is referred to in healthy habit enabled cultures. These are seen as prohibited by some and un-prohibited by others. Some of the examples are bread and starch based vegetables residue. Presently, categories related to organic waste generated by two separate categories are utilized (Bernstad and Andersson, 2015). The food waste consist of organic waste and biodegradables (Onyeaka *et al*., 2022). A typical organic food waste comprises of fruits and vegetables, meat, cooked and other kitchen wastes. The Food and Agriculture Organization (FAO) defines food waste as “any healthy or edible matters that are wasted, lost or degraded throughout the food supply chain, including organic waste generated from various sources such as food processing plants, household and commercial kitchens (Chhandama *et al*., 2022).

Food waste generation and composition around the globe. This world generates adequate food for living beings; however, due to the massive food loss, one in nine people remains malnourished, as 821 million people experiences hunger on daily basis (Ananno *et al*., 2021). As a result of the COVID-19 pandemic, world hunger has actually escalated by 1.5% in 2020, reaching a hunger level around 9.5%. The report depicts that about 2.7 billion people did not had access to sufficient food in the year 2020 and about 12% of the global population suffered from immense food insecurity. In the same year 2020, 420 million undernourished individuals were from Asia and 280 million were from Africa (Rosenberg, 2021). Another research report says that approximately 88 million tonnes of food are wasted per year in the European Union. A United States (US) study reports 70 million tonnes of annual edible food loss (Dou *et al*., 2016). A study on British households reports around 61% of food waste could be effectively consumed if handled through any sustainable management approach (Dagiliute and Musteikyte, 2019). The European Union has declared the food waste as one of the ten (10) major indicators of the circular economy monitoring framework that targeted the decrease food loses as one of the Sustainable Development Goals (SDGs) priorities adopted in agenda 2030, for sustainable production and consumption.

The amount of food waste (million tons per year) generated by different countries are provided in Table 1. The composition of food waste varies and depends on the source, region, climate, culture, yearly time period and economical condition of the country. Around 70~80% of food waste was observed as moisture content, total solids were around 20-30%. The organic ingredients of food wastes consists of proteins, polysaccharides (hemicelluloses, cellulose, lignin and starch), organic acids and oil/lipids. (Chhandama *et al*., 2022).

The major food ingredients leading to solid waste are proteins, fat, carbohydrates, lipids and others. The amount of different food products wasted globally and in Asian countries is shown in Fig. 1 and 2 respectively (Paritosh *et al*., 2017).

Around 46% of the total MSW produced globally consist of organic content. The typical global composition of MSW is depicted in Fig. 3 which shows the that major part is covered by the organic content (46%) (Ayodele *et al*., 2019).

The World Bank reported the typical composition of MSW containing mainly organic content (67%),

Table 1. Food waste global generation and background (Chhandama *et al*., 2022)

Country	Amount of food waste	Number of projects for valorizing food waste
China	169 million tons/year	≤
46	Zhou *et al*., (2014)	
South Korea	4.28 million tons/year	≤ 31
India	11 billion tons/year	NA
United Kingdom	15 million tons/year	≤ 30
United States of America	60 million tons/year	≤ 44
Germany	4-5 million tons/year	≤ 38
France	5.8-9.0 million tons/year	≤ 11
Brazil	12.9 million tons/year	≤ 2
Turkey	12.3 million tons/year	≤ 49
Australia	2.2 million tons/year	≤ 17
Nigeria	25 million tons/year	≤ 60
Hong Kong	36,000 million tons/year	NA

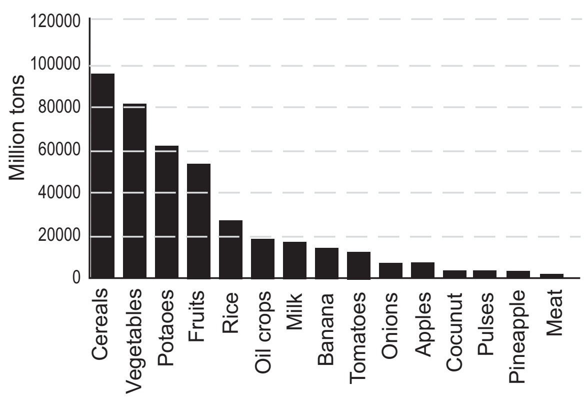

Fig 1. Food products wasted globally (Paritosh *et al*., 2017)

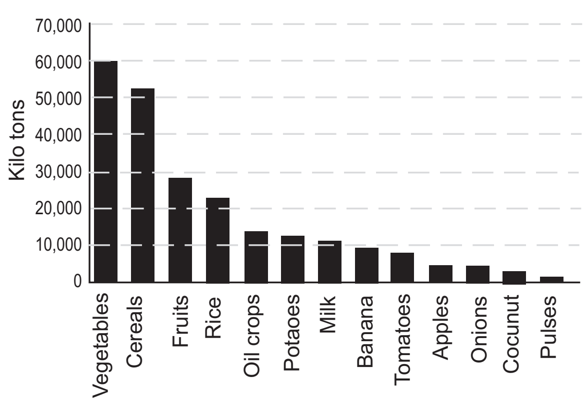

Fig 2. Food products wasted in Asian countries (Paritosh *et al*., 2017)

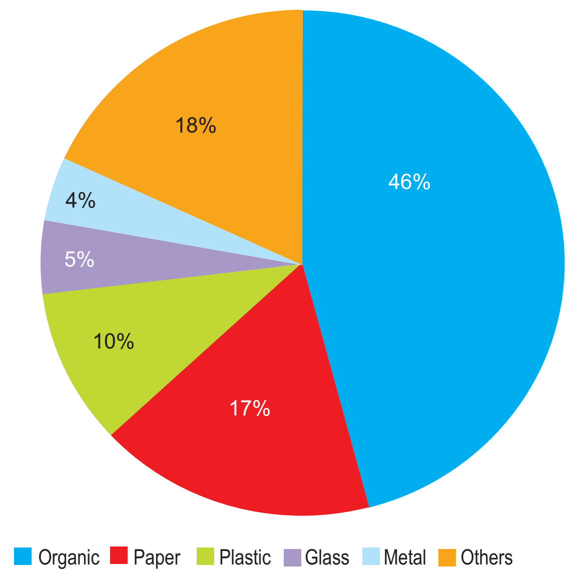

Fig 3. Typical global composition of MSW (Ayodele *et al*., 2019)

inorganic (26%) and others (7%) as depicted in Fig. 4 (Zuberi and Ali, 2015).

Solid waste and Pakistan. In Pakistan, approximately 67,500 tons of solid waste is produced daily out of which more than half of the waste is picked up and discarded in open dumps and disposition sites located outside the metropolis. Remaining discarded products are thrown as garbage on the sides of the roads, in storm drains and underground channels, sewerage lines and open plots leading to potential problems of public medical emergencies (Zuberi and Ali, 2015). An average rate of 150 Kg/c/y (Kg per capita per year) (0.41 Kg/c/d), and the waste generation rate in the overall urban areas, rural areas and in the few populated cities were 232 Kg/c/y (0.63 Kg/c/d), 103 Kg/c/y (0.28 Kg/capita/day) and 238 Kg/c/y (0.65 Kg/c/d) respectively. The data related to solid waste generation in some populated cities of Pakistan is mentioned in Table 2 (Sohoo *et al*., 2021a&b).

Solid waste in Pakistan usually consists of paper and cardboard, plastic, glass, textiles, metals, stones, wood, green waste (leaves, grass, straws and fodder) the food waste, animal waste, bones, rubber and inert waste including fines. The average composition of MSW in Pakistan consists of 64% and 36% organic and inorganic waste respectively. The physical composition of solid waste in major cities of Pakistan is provided in Table 3 (Sohoo *et al*., 2021a&b).

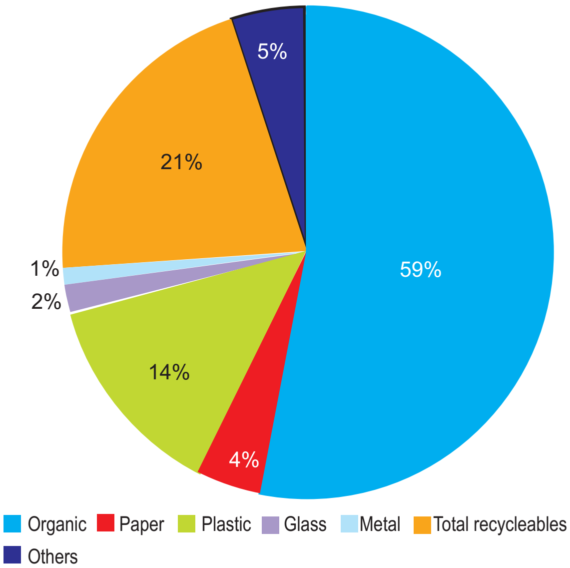

Fig 4. MSW composition reported by World Bank (Zuberi and Ali, 2015)

Apart from commercial output, solid waste is composed primarily of biomass, which is sourced as kitchen waste. Most of the local organic waste referred as MSW in Pakistan is discarded in large places where wild animals and under-age scavengers hunting for leftovers are seen seeking recyclable items. This may lead to serious environmental and further epidemiological problems. There exists due to the fact that Pakistan has a reduced capacity of incinerators for sufficient efficient waste disposal factories or outlets (Ali *et al*., 2018). Overall, Pakistan lacks a sound infrastructure for solid waste which results in serious health and environment problems for millions of citizens of Pakistan.

Solid waste and Karachi city. ***Waste generation.*** Karachi being one of largest cities of Pakistan as well as a large metropolis, is producing solid waste at an enormous rate. Karachi city has a population of around 22 million with seven districts and six cantonment boards. Karachi city generates around 12,000 to 16000 tons/day of municipal solid waste (Khatri *et al*., 2021; Shaikh and Hussain, 2019). Out of total 8,500 to 9000 tons / day of MSW reached at the official landfill sites (Shahid *et al*., 2021).

***Waste collection, transportation and dumping*.** The existing SWM system in Karachi is inefficient and inadequate to ensure environmental maintenance. The city's waste is mainly collected by two major institutions, one being the Sindh Solid Waste Management Board (SSWMB) and the other being the district municipal committee (DMC). These two bodies have hired private third-party contractors to collect the solid waste of Karachi. Their network works in a manner that the waste is collected through front end collection points and stored at a garbage transport facility prior to dumping into two main landfill areas (legal landfill site) namely Jamchakro and Gondpas. (Ahmed *et al*., 2021).

Table 2. Amount of MSW generation in some of the populated Pakistani cities

City	Population (Million)	MSW generation rate (k/c/d)	MSW quantity (t/day)	MSW quantity (Mt/year)
Karachi	14.91	0.761	11,347	4.14
Lahore	11.12	0.75	8340	3.04
Faisalabad	3.20	0.48	1538	0.56
Rawalpindi	2.09	0.453	950	0.35
Gujranwala	2.07	0.51	1034	0.38
Peshawar	1.97	0.489	963	0.35
Multan	1.87	0.32	599	0.22
Hyderabad	1.72	0.7	1213	0.44
Islamabad	1.01	0.81	822	0.3
Quetta	1.00	0.378	378	0.14
Remaining urban areas	34.63	0.612	21,193	7.74
Rural areas	132.184	0.283	37,408	13.65
Total	**207.77**		**85,425**	**31.18**
Including 5% hazardous waste			4271	1.56
Grand total			89,696	32.74

Note: Kg/c/y; Kg/c/y; Kg/c/d; Kg/c/d; t/d millionstons

Table 3. Physical composition of solid waste in some of the major cities of Pakistan .

MSW Components [%]	Karachi	Lahore	Faisalabad	Gujranwala	Peshawar	Multan	Hyderabad	Quetta	Islamabad
Plastic & Rubber	8	12.6	4.8	5	3.7	4.3	9.85	8.2	3
Metals	1.1	0.1	0.2	0.3	0.3	0.3	3.66	0.2	
Paper	8	2.4	2.1	2.5	2.1	2.4	5.89	2.2	10
Cardboard			1.6	1.8	1.9	-	6.70	1.3	
Textile	7.6	9.1	5.2	3.2	4.3	6.9	2.07	5.1	5
Hazardous waste		1.5							
Glass	5.6	0.8	1.3	1.5	1.3	0.8	6.08	1.5	3
Bones			2.9	3.2	1.7	1.3	-	2	
Food waste	26.1		17.2	14.7	13.8	32.4	30.82	14.3	58
Organics		64.8							
Animal waste			0.8	1	7.5	2.7	-	1.7	
Combustibles		2.1							
Green waste	17		15.6	12.8	13.6	20.2	13.85	10.2	
Tetra pack	10	1							
Wood	3.1		0.7	0.8	0.6	1.3	1.84	1.5	20
Fine	3.7		43	47.5	42		18.13	44	
Stones			4.6	5.7	7.2	27.4	-	7.8	
E-waste			0.3						
Others	9.8	5.3					1.11		1
Total	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**

Karachi Metropolitan Corporation (KMC) along with the district Municipal Councils (DMCs) is responsible for the management of municipal solid waste in the metropolitan Karachi city. Initially, only DMC was responsible for handling and management of solid waste but at present, the responsibility has been transferred to Sindh Solid Waste Management Board (SSWMB). Out of the total amount of municipal solid waste, 50% of the municipal solid waste (MSW) is dumped on the landfill sites and rest of 50% remain in the city dumped sites. Karachi is divided into six zones or districts (north, east, west, south, central and Malir), eighteen (18) towns and one seventy-eight (178) union councils. According to the Director Operations of SSWMB, Karachi has twelve (12) Garbage Transfer Stations (GTSs) out of which only five (05) Garbage Transfer Stations are operational. These five (05) are GTS-Imtiaz, EMB Cosway shift to Imtiaz (district east), Sharafi goth (district Malir), Gutter Baghicha is temporary GTS in West from where the MSW is shifted to GTS Baldia / Kasba (district west) 100 quarters (district Korangi) and Dhobi Ghaath (district south). The Four Garbage Transfer Stations (04 GTSs) out of total are planned to be used for renewable energy production, where anaerobic digestion will be used to produce electricity but this target is yet to accomplish. (Shahid *et al*., 2021).

Waste segregation and treatment. This mixture of MSW that contain all forms of waste is just dumped at the official landfill site lacking proper plan and without attempting any technique of segregation and treatment for sustainable management. The ongoing and continuous dumping of the waste at the official landfill site results in huge heap that are higher than 12 feet. These landfill sites are operational from the year 1986 till present and in this duration the condition of the landfill site has become pathetic for the human and environmental health. The organic fraction that remained on every nook and corner of the city causes naturally degrade, contaminate our resources, spreads unpleasant odour and causes diseases and unhealthy environment (Shahid *et al*., 2021).

Waste physical composition. The physical composition of Karachi solid-waste comprises of food waste, green waste, plastic, paper, metal, cardboard, glass, metal, wood, etc. The complete physical composition of the generated waste in Karachi can be depicted in Fig. 6 (Sohoo *et al*., 2021a&b).

Technologies for converting waste to energy. There are various techniques that are used to convert waste to energy. Some of them are described below:

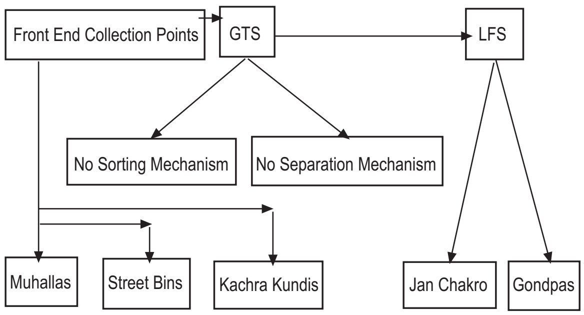

Fig 5. Solid waste network in Karachi (Ahmed *et al*., 2021)

Incineration process. This is a fully defined technology that involves combustion and used to generate electrical and heat energy. The output from the combustion process is used to run steam turbines used for energy production, or for heat exchangers used to heat up process streams in industry. Incinerators reduces volume of the solid up to 80–85%, thus, significantly reducing the required volume.

In this process, the waste is combusted to produce heat or biogas. The produced heat is directly used for residential and industrial purposes. Further heat can be transformed to another form of energy *i.e.* electricity (Pham *et al*., 2015)

Gasification and pyrolysis. Gasification is the conversion of an organic compound into a gas mixture (syngas) and a solid byproduct (char). Char is a mixture of organic carbon and ash. There are a lot of gasification techniques that exist and distinguishes between them using different operations realized as such (Perrot and Subiantoro, 2018). The major benefit of gasification is that the

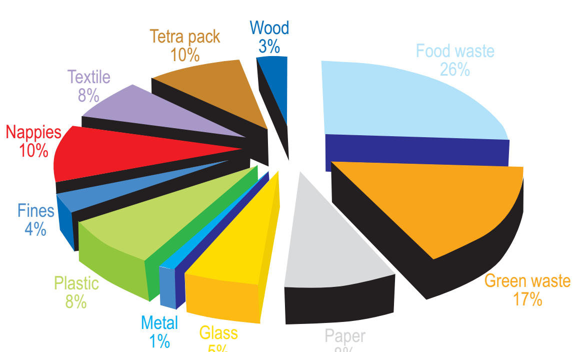

Fig 6. Karachi's MSW physical composition (Sohoo *et al*., 2021a&b)

product gas can be used directly, after significant cleaning though, in gas turbine or in any other use. The disadvantage is that there are many more items in the waste that are needed to be separated and the capital investment is correspondingly higher (Kayes and Tehzeeb, 2009).

Pyrolysis involves the thermal degradation with anaerobic presence of oxidizing agent at a temperature of between 400 °C and 1000 °C. However, the methods are less developed as compared to anaerobic digestion and incineration (Perrot and Subiantoro, 2018).

Anaerobic digestion (AD). One of the most commonly used waste to energy technology (mainly for organic waste treatment and food waste utilization) is Anaerobic Digestion process. In such biological process, the micro-organisms breakdown biodegradable wastes and organic matter in the food waste is converted into biogas (comprising mainly methane and carbon dioxide) used to produce natural gas, heat and electricity. The process takes place in the absence of oxygen. This method has been widely used in north America and European countries (Ngoc Bao Dung THI, 2017) . The major advantages of this process are the lower emissions of CO_2, the possible utilization of organic waste for soil conditioners and minimum pollution. The major drawback is that it is a slow process. It is not practical to rely solely on anaerobic process to eliminate all the waste from the country. Furthermore, it can only be used to treat biodegradable waste or organic part of municipal solid waste. (Perrot and Subiantoro, 2018).

Theoretically, 847 kWh electricity and 247 m^3 methane can be produced from one ton of food waste (Thi *et al*., 2016). In the real world, considering a case study of United Kingdom, the methane production from wet food waste was about 98 m^3 per ton, which consist of 62% of the total biogas production. The power generation from food waste was around 405 kWh per ton. For commercial treatment of food waste, the facilities can produce electricity upto 220 kWh per ton of food waste. Thus anaerobic method is considered to be the most commercial method for food waste treatment and biogas recovery and production that gives maximum energy, environmental and energy benefits (Ngoc Bao Dung THI, 2017).

Power generation, demand and supply in Karachi. Karachi, a mega city, faces daily load shedding of average of 4 to 8 h due to maintenance issues and electric power failure. The K-Electric (KE), previously known as Karachi Electric Supply Company (KESC) is one and the only utility company that supplies power in all the districts of Karachi. The power demand of Karachi is 2,900 MW but KE generation capacity is 2,267 MW. This results in energy gap between power demand and supply of 633 MW. This huge power gap is compensated by KE by obtaining power from the National Transmission and Dispatch Company (NTDC) and other Independent Power Producers (IPP's) (Khatri *et al*., 2021).

Biogas, a renewable energy source. The energy generated from the solid waste is considered as biogas. In Pakistan, annual biogas production can be reached to 17.2 billion m^3. In Pakistan, around 3,500 low scale production plants for biogas have been built in remote areas to meet the domestic energy requirements of 3,500 households. Similarly, three biogas plants have been built in Islamabad to meet energy needs of around twenty houses in remote areas. Biogas generation from any kind of waste results in reducing the waste management and disposal problem along with energy deficiency problem. The government of Pakistan started Biogas Support Program in the year 2000. Approximately 1200 units have been installed and 10,000 biogas plants are under construction as per plan (Latif and Ramzan, 2014). The typical composition of biogas is mentioned in Table 4 (Uddin *et al*., 2016).

Table 4. The composition of Biogas

Gases	Percentage (%)
Methane (CH_4)	50-75
Carbon dioxide (CO_2)	25-50
Nitrogen (N_2)	0-10
Hydrogen (H_2)	0-01
Hydrogen sulphide (H_2S)	0-03

Materials and Methods

Proposed optic bag system for source segregation. Food waste (FW) includes local food waste, food-processing left overs, households, canteens and restaurant residue. Consumer habits are mainly considered to be the major element of food waste. The minor change in consumer behavior can create an impact in reduction of food waste production at households and public places (González-Santana *et al*., 2020). The separation of source materials is an important step with issues of food waste that happen before moving the leftover consumables to deposits. As far as Karachi is concerned, the food waste is not separated and sorted out from other MSW. If the food waste is not sorted at source, it will be contaminated and recycling process cannot be done. On the other hand, a complicated sorting process can demotivate citizens from sorting their generated waste. A simple sorting method requiring less behavioral change by citizens is a critical part in order to motivate the citizens to sort the food waste at source so that it can be successfully utilize and treated for energy recovery and production. Thus, to achieve this objective, an optic bag system is proposed.

The food waste generated particularly at households and restaurants will be packed in an optical bag (green color plastic bag) and other solid waste will be packed in bags of different colors. The awareness for waste segregation at source among the consumers must be enhanced by promoting MSW segregation awareness programs. The cost of a green optic bag is approximately 22 PKR/bag. Table 5 lists the different cities of the developed countries that uses colorful bags and optic bag for FW segregation with other mixed waste (Woon *et al*., 2021).

Waste collection, sorting and segregation. The packed waste bags will then be placed at existing designated collection bins that can be picked by the daily waste vehicles and transported to respective refuse transfer stations. This waste collection system can be executed without any amendment to the current waste bins system in Karachi.

At refuse transfer stations, all the collected waste bags will be unloaded into a receiving pit and then sent to a main conveyor belt that uses the application of optic sensors for separation of bags. The green wavelength of the reflective surface of the optic bag helps in differentiating the said from other non-biologically degradable bags. Upon detection of an optical bag (which is food waste), a command will be generated to move the optical bag from the current conveyor belt to another belt. Now to remove the FW from optical bag, an Enviflex system can be used. In this system, the optical bag will be opened by hydraulically driven roller and stretched open in a long conveyor belt or path. The solid residue will be synthesized and made into small chunks of approximately 35 – 50 mm. The bag and the food waste will then be separated. The compacted small pieces of separated and sorted food waste will be placed in special containers and transported to food waste recycling units (Woon *et al*., 2021).

Table 5. Optic bag implementation for segregation system in different cities of the world

Country	City	Colour of bag	Waste category
Denmark	Aarhus	Green	FW
		Black	Residential waste other than food waste
Norway	Oslo	Green	FW
		Blue	Plastics
		Other colours	Combustible waste
Norway	Tromse	Green	FW
		Red	Newspaper
		Orange	Paper
		Blue	Plastic
		Other colours	Combustible waste
Sweden	Boras	Black	FW
		White	Flammable waste
Sweden	Halmstad	Green	FW
		Other colour	Combustible waste
Sweden	Linkoping		Green FW
		Other colour	Combustible waste

Food waste valorization to renewable energy. Among all the technological options, anaerobic digestion is the most efficient one that can recover energy from food waste. In China, over 100 food waste treatment plants have been built in the last 10 years and most have adopted anaerobic digestion as their core technology (Liu *et al*., 2019). In Singapore, 45,000 m^3 of biogas produces 78 MWh energy per day. Table 6 lists the treatment capability and application of anaerobic digestion plants for FW treatment in various countries like China, UK, Australia, Japan etc. In majority developed and developing countries, the accumulated biogas is recovered for electricity and heat generation. Fig. 7 and Fig. 8 illustrates the proposed framework for FW source segregation, waste collection, waste segregation and waste treatment (Woon *et al*., 2021). The project investment for AD plant will be 86 million PKR and net present value will be (Huiru *et al*., 2019)

Global application of optical technology for food waste segregation and cost of optical sorting plant. This approach of sorting and segregation of FW from other waste *via* optical bag system in a sorting plant has been used by various countries like Sweden and Norway. The financial cost of the plant that can handle approximately 30,000 tons capacity annually for separation of waste (mainly FW and other waste) using optical sensor technology is around 30 million SEK (equivalent to 651.8 million PKR) based on Swedish plant installed in 2011. Norway's optical sorting plant is currently considered to be the largest in the world that can annually handle 150,000 tons FW (Woon and Lo, 2016).

The capital cost for the two-fraction (FW and MSW) optical bag sorting system having yearly treatment capacity of 210 kt is fourteen (14) million Malaysian Ringgit which is equivalent to 720 million PKR (Woon *et al*., 2021).

Results and Discussion

Quantification of food waste generation in Karachi. The Table 7 summarizes that the waste generation escalates in Karachi with the escalation in population. Like in the year 1972, the population was 3.51 million and the amount of waste tons per day was nearly 1884 td^{-1}, whereas in the year 2017, the population reached to 14.91 million and the amount of waste tons per day was around 11319 td^{-1} and the estimated population based on 2.5% growth rate will be approximately 20.63 million by the year 2030 and the quantity of waste generated would be around 25669 td^{-1} (Shahid *et al*., 2021).

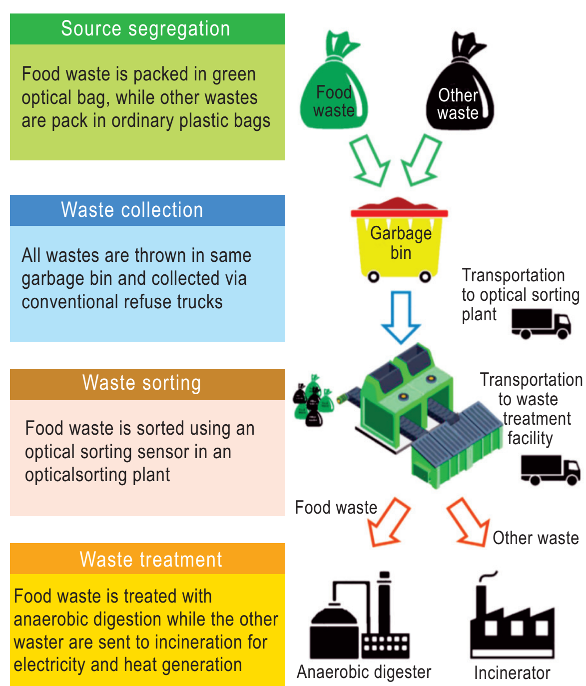

Fig 7. The proposed sustainable framework for FW segregation at source and utilization (Woon *et al*., 2021)

Table 6. Optic bag implementation for segregation system in different cities of the world

Country	City	Substrate	Capacity (t/y)	Application
Australia	Melbourne	FW	33,000	8,030 MWh/y of electricity
China	Qingdao	FW	73,000	2,200 t/y of grease for biodiesel: 1.46 M Nm^3/y of natural gas for cooking purpose
China	Wuhan	FW	3,300	1,136 MWh/y of electricity
Czech Republic	Benesov	FW, commercial and industrial organic waste	38,000	4.38 M Nm^3/y of natural gas for electricity generation
Denmark	North Jutland	FW and livestock manure	365,000	13 M Nm^3/y of biogas fuel for vehicle use
Japan	Fukuoka prefecture	FW and human waste	6,600	Two 30 kW of combined heat and power units to generate electricity
Japan	Niigata prefecture	FW	3,285	94 kW of combined heat and power units to generate electricity and heat for heating roads
Norway	Oslo	FW	51,100	5.1 M Nm^3/d of liquified biogas fuel for vehicle use
Singapore	Singapore	FW	109,000	28,470 MWh/y of electricity
South Korea	Busan	FW	73,000	7.5 M Nm^3/y of biogas for electricity
The United Kingdom	Hertfordshire	FW	45,000	17,640 MWh/y of electricity
The United States	New Jersey	FW	109,500	29,000 MWh/y of electricity

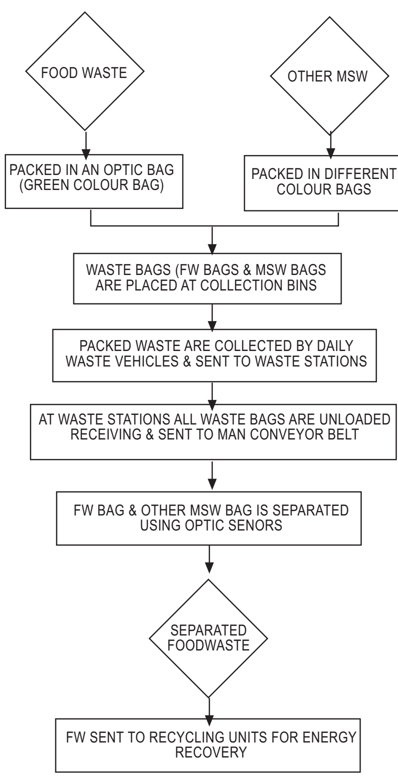

Fig 8. Process flow diagram for food waste segregation, sorting, collection and recycling (Woon *et al*., 2021)

Therefore, using the estimated population and MSW generation results in Karachi as mentioned in the research study (Shahid *et al*., 2021), estimated figures are calculated for food waste generation per year for the year 2023 to 2030 in Karachi as illustrated in Table 8, considering that 26% of the total solid waste consist of food waste as per physical composition of solid waste in Karachi (Sohoo *et al*., 2021a&b).

Quantification of biogas and electricity generation in Karachi. Under ideal condition, 200 m^3 biogas is produced per ton of food waste via anaerobic digestion process and 600 kwh of electricity can be yield from 180 m^3 biogas (Ali *et al*., 2019).

For quantification in this study, it is considered that 200 m^3 biogas is produced per ton of food waste *via* anaerobic digestion process and 1 m^3 of biogas could generate 2.04 kWh of electricity with 35% of generation efficiency (Pham *et al*., 2015). The Table 9 is generated that provides biogas generation and electricity generation estimations in Karachi for the year 2023 to 2030.

Conclusion

The solid waste management including food waste management in various cities of Pakistan and particularly in Karachi city, has become a universal problem due to

Table 7. Solid waste generation (ton per day) in Karachi (Shahid *et al*., 2021)

Years	Population in Karachi in millions	MSW Generate in Karachi		
		Wt. (t/d)	Wt. (Kg/c/d)	Wt. (Kg/h/d)
1972[a]	3.515	1884.04	0.536	3.216
1973[E]	3.618	1939.408	0.536	3.216
1974[1]	3.724	2000	0.536	3.216
1998[b]	9.269	5561.90	0.600	3.6
2001[2]	9.999	6000	0.600	3.6
2006[3]	11.329	6113	0.539	3.237
2007[4]	11.616	9000	0.774	4.648
2012[6]	13.162	10,000	0.759	4.554
2017[c]	14.913	11319.33	0.759	4.554
2019[6]	15.67	12,000	0.765	4.59
2020[E]	16.072	20,000	1.244	7.464
2021[E]	16.072	20,434,58	1.244	7.464
2022[E]	16.479	21019.121	1.244	7.464
2023[E]	17.323	21550.807	1.244	7.464
2024[E]	17.762	22095.928	1.244	7.464
2025[E]	18.211	22654.857	1.244	7.464
2026[E]	18.672	23228.025	1.244	7.464
2027[E]	19.144	23815.635	1.244	7.464
2028[E]	19.628	24418.169	1.244	7.464
2029[E]	20.125	25035.880	1.244	7.464
2030[E]	20.634	25669.193	1.244	7.464

Note: Wt. (t/y)= Weight ton per year; Wt.(t/d)= Weight ton per day; Wt. (Kg/c/d)= Kilogram per capita per day; Wt. (Kg/h/d)= Kilogram per house per day; b, and c= Population Census Organization, Federal Bureau of Statistics; 1= Karachi Plan 1974-85; E=Estimated

lack of planning, insufficient management policies and resources. Energy recovery from food waste by anaerobic digestion process is an important pathway for municipal waste management, treatment and renewable energy development.

Considering Karachi city as a case study, this paper introduces a sustainable Food Waste (FW) management framework in this city to facilitate an effective and efficient FW segregation from other type of wastes in Municipal Solid Waste (MSW) with least requirements on behavioral amendments among the consumers through an optical sorting system and valorization to biogas via Anaerobic Digestion (AD). The capital cost for the two fraction (FW and MSW) optical bag sorting system having yearly treatment capacity of 210 kt is 720 million PKR and AD plant investment requires 86 million PKR. This research may also help the city of Karachi for generation of electricity from biogas *i.e.*, 994 GWh energy can be generated by the year 2030 to alleviate the power gap between consumer demand and supply and facilitate the clean environment.

Table 8. Estimated food waste generation in Karachi

Year	Waste generated (million tons/year)	Food waste generation (million tons/year)
2023	7.87	2.05
2024	8.07	2.10
2025	8.27	2.15
2026	8.48	2.20
2027	8.69	2.26
2028	8.91	2.32
2029	9.14	2.38
2030	9.37	2.44

Table 9. Estimated biogas and electricity generation in Karachi

Year	Estimated biogas generation (million m^3/ million tons/year)	Electricity generation (GWh/year)
2023	409.03	834
2024	419.38	856
2025	429.99	877
2026	440.87	899
2027	452.02	922
2028	463.46	945
2029	475.18	969
2030	487.20	994

Conflict of Interest. The authors declare they have no conflict of interest.

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