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The feasibility of municipal solid waste for energy generation and its existing management practices in Pakistan

Muhammad Safar Korai[a,*], Rasool Bux Mahar[b], Muhammad Aslam Uqaili[c]

[a] Institute of Environmental Engineering and Management, Mehran UET, Jamshoro, Sindh, Pakistan
[b] US-Pakistan Center for Advance Studies in Water (US-PCASW) Mehran UET, Jamshoro, Sindh, Pakistan
[c] Electrical Engineering Department, Mehran UET, Jamshoro, Sindh, Pakistan

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ABSTRACT

Energy crisis and growing amount of solid waste at alarming rate have remained a challenge for every governing body of Pakistan. This study has been performed in order to evaluate the feasibility of municipal solid waste for energy generation and to assess its existing management practices. The study finds that solid waste is not properly managed in Pakistan. Throughout the country, it has been observed that the generated waste is directly either dumped in low lying areas or burned in open environment without any engineered way of disposal. On the other hand, the solid waste generated in Pakistan has significant potential to produce energy by bio-chemical and thermo-chemical process upto 50.35 million m^3/year and 265 million m^3/year respectively. The contribution of energy from solid waste has been estimated that is 0.07% through bio-chemical and 0.34% through thermo-chemical in the total primary energy supply of the country. Moreover, results of study revealed that about 70% of imported energy can be reduced by bio-chemical and completely can be replaced by thermo-chemical process of solid waste. Not only this but also burden on energy from other primary sources of the country would be reduced upto 1.86% cumulatively by adopting thermo-chemical process of waste. The study concludes that lack of pre-planning, infrastructure, public awareness and many other factors have become root factors for worsening municipal solid waste in Pakistan. Solid waste is capable to yield energy in the country, if it is treated either by bio-chemical or thermo-chemical process. The findings of study lead to recommend that waste to energy concept should be promoted in the country for sustainable environment and economic growth.

1. Introduction

At present, Pakistan is seriously under energy crisis and facing various environmental as well as social issues which are associated with mismanagement of municipal solid waste (MSW). Both have acquired alarming dimensions in the country nowadays similarly as in other developing countries. Mismanagement of waste leads not only to degrade environment but also public health becomes at risk [1]. The major reason of generating waste and the shortage of energy at alarming rate are industrialization, over population, non-utilization of enormous indigenous energy resources and lack of proactive as well as integrated planning for production of energy. Increasing of population as well as economic activities and lack of training in modern MSW management have become responsible factors due to which efforts for improving MSW management system have remained more complicated [2]. The urbanization is globally accelerating which leads to generate huge quantity of solid waste. Approximately, six billion people would settle in urban areas in 2050 [3,4]. It has been predicted that global population would be more than tripled to almost nine billion by 2050 as it has become more than doubled since 1960 [3,5]. The developing countries will observe 55% and 99% of urbanization and population growth rate respectively as estimated [3–6]. The urbanization is expected continuously to grow, therefore the world would observe one third (34%) rural and two thirds (66%) urban population [7,8]. Fig. 1 shows the increasing urbanization as rural population decreases upto year of 2050.

The population of urban and rural areas of developing regions are increasing and declining respectively at alarming rate as compared to the developed regions as reported in Fig. 1. Pakistan also becomes under developing region where population growth is fairly high as in other developing countries. The population of Pakistan is 188.02 million with urban and rural population share of 72.50 and 115.52 million respectively [9]. Presently, Pakistan stands at sixth position with respect to population in the world but its population is expected to become 363 million by retaining same sixth position in 2050 [9]. The change in population is mostly described by population growth rate

* Corresponding author.
E-mail address: safar.korai@faculty.muet.edu.pk (M.S. Korai).

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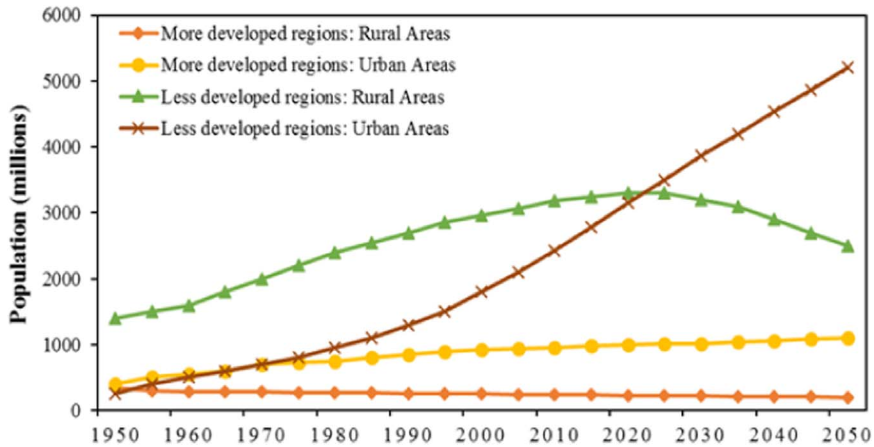


Fig. 1. Worldwide urban and rural population percentage [7,8].

(PGR) which plays vital role in the economic development of country. According to the [9,10], PGR (i.e. 1.92%) of Pakistan is higher than the regional and Muslim countries except Afghanistan and Egypt as mentioned in Fig. 2. For searching jobs, facilities, to provide better education for children and because of many other factors, the people are migrating from rural areas to cities which results growing urbanization rapidly in Pakistan. The share of urban population in Pakistan has been increased from 38.6% in 2014 to 39.2% in 2015 [10] which is at 3rd number among the regional countries as shown in Fig. 2.

If current trend in urbanization remains continuous then the urban population of country will cross the 122 millions in 2030 [9,11] that implies significant impacts on energy consumption [12]. Growing population needs energy source for their survival. As, from a brief review of history and particularly industrial revolution, energy is considered as the lifeline of an economy and plays a significant role to sustain industrial, commercial and domestic activities. In Pakistan, the primary energy consumption (PEC) grown at the annual compound growth rate (ACGR) of 3.6% and stood at 66.8 million ton oil equivalent (MTOE) including use for transformation (23.6 MTOE) and non-energy purpose (3.4 MTOE) in the year 2014 [10,13]. At stated ACGR, the total PEC has been estimated that is 69.21 MTOE and 71.7 MTOE upto to the year 2015 and 2016 respectively as shown in Fig. 3 along with percentage of different sources and compared worldwide as illustrated in Fig. 4.

Fig. 4 represents that Pakistan has been remaining dependent upon the extraction of energy from non-renewable sources whereas, energy from biomass is extracted in other countries of world [9]. The Pakistan's appetite for energy is expected to grow at an ACGR of 4.37–6.09% depending upon the gross domestic product (GDP) growth and would be in the range of 116–148 MTOE by 2022 as mentioned in Fig. 5 [13,15,16]. Moreover, Pakistan's energy requirement is continuously mounting while primary energy supply decreasing as estimated in Fig. 6.

Fig. 6 reports that the gap between energy supply and demand is increasing rapidly day-by-day. The energy crisis in the country is accelerating at the alarming rate and energy sector is facing many challenges presently. Consequently, increasing gap between energy demand and supply has become main reason of economic crises in Pakistan [17]. The energy scarcity is contributed by major limitations including reliance on fossil fuels since beginning, declining gas production, less usage of renewable energy resources (i.e., solar energy, wind energy, energy from waste), circular debit etc [18,19]. Additionally, fragile financial situation of energy supply firms, limited utilization of cheap coal and hydel resources, unexploited power production capacity are main reasons to energy scarcity in the country [9,20]. Energy consumption is significantly and positively affected by financial development through economic growth [20].

Also because of over population, solid waste is generated more and more globally which pollutes environment either directly or indirectly if not properly disposed of. Secondly, urbanization requires industrial growth and agricultural demand which ultimately needs energy sources. The non-renewable sources have remained the choice of world for centuries. Now the resources of fossil fuels are decreasing due to rapidly growth in population and industrialization. Consequently,

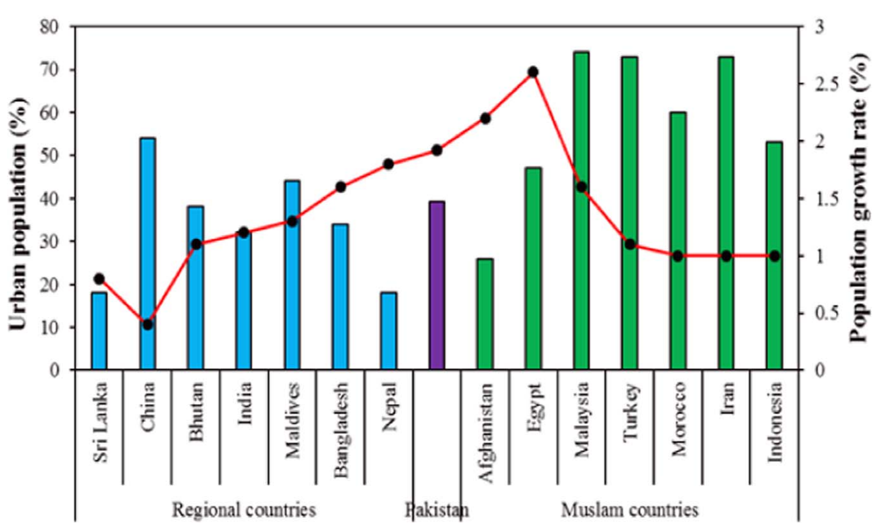


Fig. 2. Urban population and population growth rate of various countries [8–11].

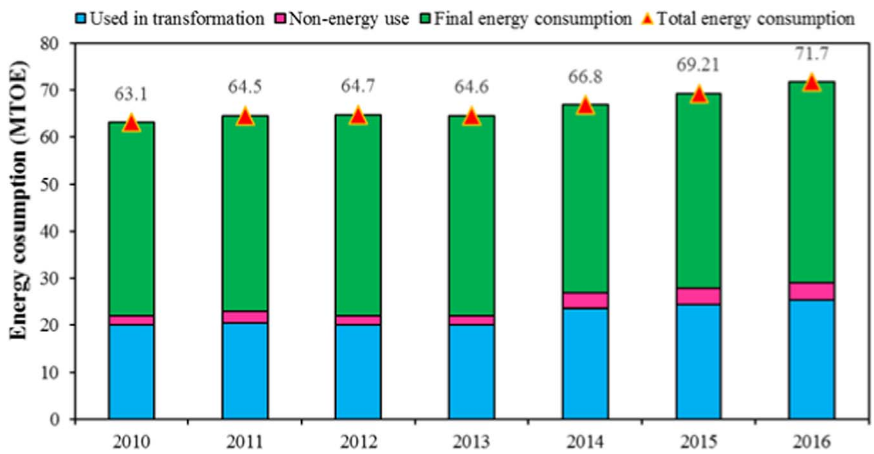


Fig. 3. Primary energy consumption [10,13].

depletion of fossil fuels results loss of economy. Moreover, the energy consumption pattern has mounted generally in Asian economies and particular in Pakistan because of population growth and industrial expansion [21]. Pakistan is low middle income country and energy crisis has been reaching to worst situation for the past few years. Therefore, economic and population growth have become root causes to increase energy demand continuously in the country [20]. The key pillars of any energy system are economic growth and development, sustainability and energy security, and access [10]. There is about 6.5% per year economy's long run growth potential which has been decreased upto 2% due to power shortage in the country [11,20]. This shows that international competitiveness and exports, employment and poverty in Pakistan have been negatively affected by power shortage [22]. Thus the shortage of energy effects social cohesion in the society and results unemployment.

To save resources and environment from degradation are the needs of present as well as future for sustainable life in the world. Since beginning, world has been depending upon fossil fuels. Currently, global warming is burning environmental issue which refers to rise in global surface temperature due to climate change induced by ongoing human activities and systems using fossil fuels [23]. Various greenhouse gases (GHG) like CO_2, CH_4, oxides of nitrogen and others have been led by different energy systems based upon fossil fuels causing severe environmental degradation. Releasing of GHG from different sources including transportation, forestry and waste generation to final disposal etc, has been increased since 1970 that is largely contributed by 80% from CO_2 and 40% by CH_4 from its initial value [24]. Previous studies [17,25,26] reveal that MSW is the 4th largest contributor of global emissions by sharing 550 Tg global methane emissions per annum. According to the findings of other studies [27,28], the uncontrolled MSW landfills are the 3rd largest sources of methane emissions and estimated to rise up to 816 $MtCO_2$-eq by 2020 in case of little or no efforts taken against their reduction. Pakistan stands on 135th position by contributing 0.8% of total GHG globally and expected would be increased by 2030 due to depending upon non-renewable energy sources [17,26,29]. Huge quantity of MSW generation due to changing lifestyles, technology development and economic expansion of developing countries is leading to environmental issues because of its improper management [30–32]. Pakistan is also facing challenging issues in MSW management like other developing countries due to urbanization and limited by lack of an effective recycling organic wastes into valuable material, poor waste management and handling infrastructure [26,33,34]. Developing countries despite of abundant quantity of MSW generation, are facing energy crises which have posed to their socio-economic development [34]. Thus releasing of emissions from system working on non-renewable energy sources and burning of MSW have become responsible factors to generate environmental problems like greenhouse effect leading to climate change. Here is the pressure point known as hotspot of conflict as illustrated in Fig. 7 which is globally challenge of all stakeholders.

In this regard, there has been a growing world opinion in favor of looking alternatives to a non-renewable sources that would ensure eco-friendly sustainable development on the one hand and energy security on the other hand. Moreover, the increasing in cost associated with conventional energy generation and improper waste disposal has globally compelled to move towards waste to energy concept, as a more attractive and viable solution now-a-days [23,35].

Nobody can deny the availability of various renewable energy

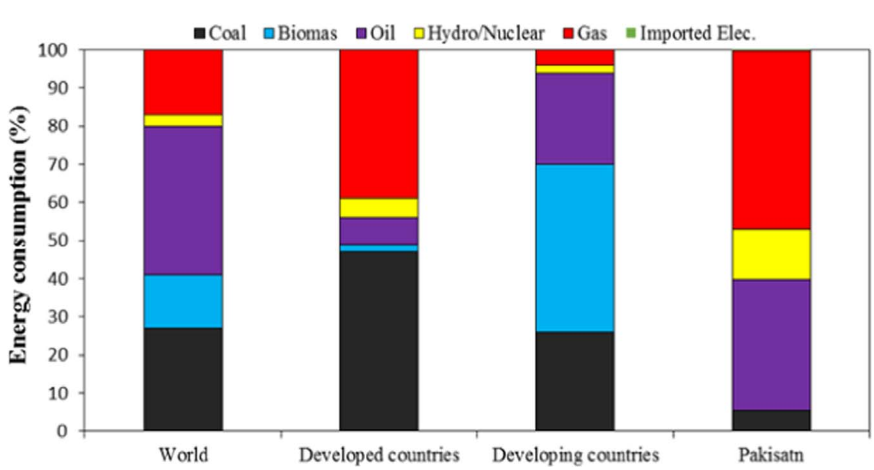
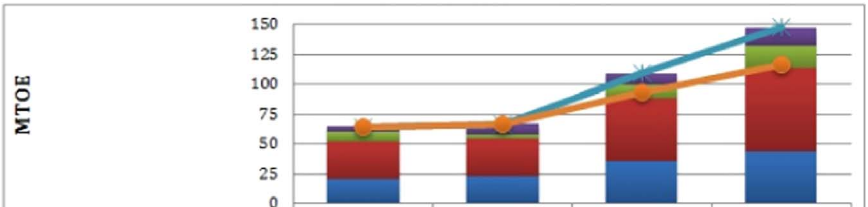


Fig. 4. Estimated total primary energy supply of Pakistan and worldwide [10,13,14].



	2013	2014	2017	2022
Coal	3.86	8.9	9.8	15.7
Hydro-Nuclear-Imported	8.31	3.6	11	18.4
Gas	31.45	31.3	52.3	69.4
Oil	20.97	23.0	36.2	44
Total at GDP growth Rate 6.5% (ACGR 6.09%)	64.59	66.80	109.3	147.5
Total at GDP growth Rate 4.5% (ACGR 4.37%)	64.59	66.80	93.5	116

Fig. 5. Projected energy demand [13,15,16].

sources including solar energy, wind energy and energy from waste in Pakistan. Instead of that, Pakistan is under energy crisis and has been facing many challenges for the past few years [20]. Therefore, there is urgent need to exploit energy from these sources. In this study, estimation of energy from MSW along with its existing management practices is focused. MSW is generating at the alarming rate with annually growth rate of 2.4% [36]. Proper disposal of MSW is a seriously challenging issue for Pakistan [9,26]. By taking into account these facts, current study was formulated in order to analyze existing practices of MSW management in Pakistan and to find out energy generation potential from it.

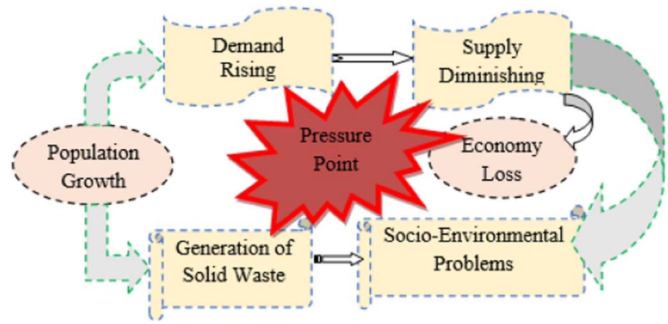


Fig. 7. Solid waste management conflict.

2. Methodology

2.1. Study area

Pakistan is the 6th most populous country and covers an area of 803,940 km^2 by standing at 36th position with respect to total area in the world. In Pakistan, there are five provinces (i.e Punjab, Sindh, Baluchistan, Baltistan and Khyber Pakhtunkhwa) along with capital territory known as Islamabad and Federal Administrative Tribal Areas (FATA) in the northwest of the country [37]. Major twelve cities such as Karachi, Hyderabad, Sukkur, Quetta, Peshawar, Islamabad, Rawalpindi, Sialkot, Gujranwala, Lahore, Faisalabad, and Multan were considered as represented in Fig. 8.

There are approximately 50.59 millions people which settle in these cities and are generating huge amount of MSW daily. Generally, solid waste is the result of human activities. According to the observation of [38] that there is similarity in problems associated with improper management of MSW in developing countries except little bit variances between parameters like regions based on geographic locations, industrial, infrastructure, legal, socio-cultural and environmental factors etc. From literature survey data regarding management of MSW practices of selected cities was obtained. Also, information regarding collection, transportation and disposal practices of MSW was got from Municipal Authority, Pakistan Environmental Protection Agency (PEPA) and by visiting dumping as well as burning sites. However, Hyderabad city was selected for collection of waste samples in order to characterize MSW.

2.2. Sample collection and analysis

From residential areas including high, medium and low rise dwellings as well as from commercial areas, various waste samples were

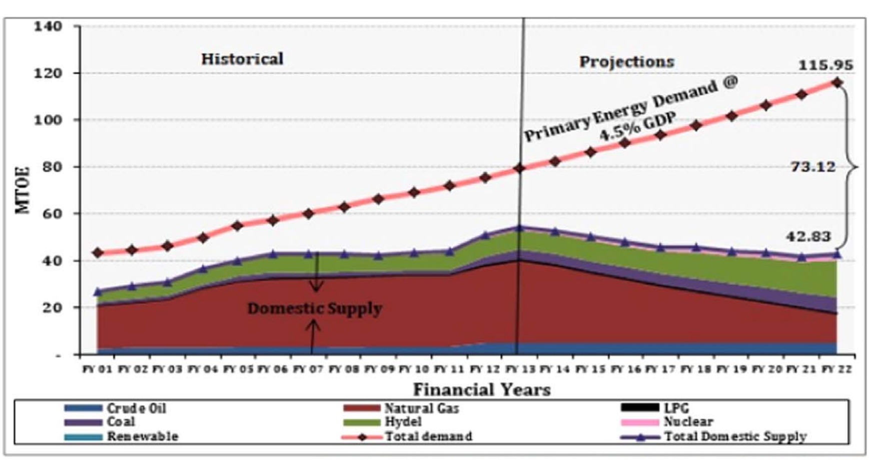


Fig. 6. Energy supply and demand projection [13,15,16].

Fig. 8. Locations of study sites.

collected weekly and monthly for characterization of MSW. After that, samples of each organic fractions of municipal solid waste (OFMSW) for proximate and elemental analysis were prepared on the basis of quartering method [39,40]. Proximate and elemental analysis of represented samples were performed according to the standard methods [41,42]. Data with regard to elemental analysis and calorific value of inorganic fractions (metals, glass and ash/dirt/fines etc) of MSW was taken from literature [38]. Whereas, calorific value of OFMSW was determined by Gallenkamp ballistic bomb calorimeter [26].

2.3. Energy generation potential

In light of fact, all of solid waste engineers and other stakeholders concerned with energy recovery mechanism are well familiar that heterogeneous mixed MSW has great tendency to yield energy in terms of either heat energy or biogas leading to power generation. There are number of methods and techniques by which hidden energy can be extracted from mixed MSW. Some of them are being used according to empirical models and others are experimental approaches [43] such as calorimetric measurement for heat recovery and biochemical methane potential test system for biogas production. In present study, theoretical biogas potential (TB_P) and energy recovery potential (ERP) of MSW were estimated by using modified Boswell's [44] molecular formula and various equations (Table 1) respectively.

3. Results and discussion

3.1. Generation and quantification of MSW

As compared to the developed countries, the generation rate of MSW in Pakistan is much lesser like other developing nations. However, the ability of Pakistan like other developing countries with regard to handle, collect, transfer, transport, process, dispose, reuse and recycle of solid wastes is neither economical nor socio-environment friendly as compared to the developed nations [38]. Total quantity (TQ) of MSW was determined from the generation rate of MSW and population of major cities of Pakistan as given in Tables 2–4 along with findings of different previous studies, conducted in the country at different times. Pakistan environmental protection agency [48] carried out a study to quantity MSW in eight selected cities of the country and estimated about 20.04 MT/year on the basis of population for 2004 by considering PGR of 2.61% per year (Table 2). This data was also cited [17] who analyzed GHE reduction by recovering energy from waste landfills in Pakistan. World Bank [49] jointly conducted a study

Table 1
Formula and equations for energy generation estimation.

Energy generation potential	Equation	Refs.
Biochemical potential/process	$ERP = \frac{BG \times NCV}{0.042}$	[45]
	$PGP = \frac{[BG \times NCV \times \quad]}{1008}$	[46]
(Bio-Ch.P)	$BG = TB_p \times \ _d \times OBF \times VM \times MSW_q \times 1000$	[47]
Thermochemical potential/process	$ERP = 1.16 \times NCV \times MSW_q$	[45]
(Th-Ch.P)	$PGP = \frac{[0.048 \times NCV \times MSW_q \times \ _{Th}]}{1000}$	[46]
$TB_p = \left[\frac{\left\{\frac{(4n + x - 2y - 3z)}{8}\right\} CH_4 \times Sp.Wt.of CO_2 + \left\{\frac{(4n - x + 2y + z)}{8}\right\} CO_2 \times Sp.Wt.of CH_4}{C_nH_xO_yN_z \times Sp.Wt.of\ Biogas} \right] \times 1000$		[26,44]

Where; ERP=Energy recovery potential (kW h/tMSW); PGP=Power generation potential (MW/tMSW); MSWq=Municipal solid waste dried quantity (Tons/day); BG=Biogas generation (m^3/tMSW); NCV=Net calorific value (Kcal/kgMSW) for thermochemical potential (Th-Ch.P) and 0.242 kW/m^3 of biogas was considered in this study, whereas NCV of biogas lies between 0.194–0.242 kW/m^3 [45,46]; η=conversion efficiency of biochemical process (Bio-Ch.P) that is mostly considered to be 30% [26,45,46]; η_d=Digestion efficiency (60%) as considered; OBF=Organic biodegradable fractions (55%) as considered. Actually, η_d and OBF values lies in the range of 45–70% and 35–60% respectively [47]; VM=Volatile matter (% on dry basis); TBp=Theoretical biogas potential (m^3/kgVS); η_{Th}=Conversion efficiency of Th-Ch.P (30%) considered, about 25–30% is usually taken into consideration for Th-Ch.P throughout the world [26].

Table 2
Quantity of MSW generated in major cities of Pakistan in 2005 and 2007.

City Corporation	2005 [17,48]			2007 [49]		
	Population (millions)	Generation rate (kg/capita/day)	Total quantity (MT/Year)	Population (millions)	Collection rate (%)	Total quantity (MT/Year)
Karachi	10.818	0.613	2.421	0	0	0
Lahore	0	0	0	6.4	76	1.825
Faisalabad	2.307	0.391	0.329	2.5	0	0.427
Hyderabad	1.343	0.563	0.276	0	0	0
Peshawar	1.153	0.489	0.206	0	0	0
Gujranwala	1.312	0.469	0.225	1.4	43.24	0.338
Quetta	0.654	0.378	0.09	0	0	0
Bannu	0.054	0.439	0.009	0	0	0
Sibi	0.095	0.283	0.009	0	0	0
Multan	0	0	0	1.5	0	0.328
Sialkot	0	0	0	0.5	60	0.183
Sargodha	0	0	0	0.6	0	0.11
Rawalpindi	0	0	0	1.7	85.56	0.341
Bahawalpur	0	0	0	0.5	0	0.058
Deraa Ghazi Khan	0	0	0	0.3	0	0.042
Total	17.736	3.625	3.565	15.4	66.2	3.652
Remaining urban area	31.818	0.453	5.261	0	0	0
Rural area	102.853	0.283	10.625	0	0	0
Sub-total	152.407	4.361	19.451	15.4	66.2	3.652
Hazardous wastes (3%)		0	0.584	0	0	0
Grass Total			20.035			3.652

in nine cities of Punjab and about 3.65 MT/year of MSW was roughly estimated on the basis of population and average waste generation rate of 0.6 kg/capita/day (Table 2).

In 2010 [50], estimated about 6.15 MT of MSW per year in ten cities of Pakistan (Table 3). Later on in 2012 [51], estimated 9.42 MT of MSW per year in 12 cities of Pakistan (Table 3). Another study in 2013 performed [52] who estimated about 4.25 MT/year of MSW generated in ten largest cities of Pakistan according to the population, generation rate and collection rate of MSW in each city (Table 3).

The results of another latest study in 2014 conducted [53] on management of MSW generated in eight cities of Pakistan show 5.32 MT of MSW per year generate in selected cities of Pakistan (Table 4). In present study, approximately 30.76 MT of MSW except hazardous waste per year in the selected cities of Pakistan was estimated on the basis of population (estimated in 2016) by [54] and generation rate MSW (obtained from latest studies) as shown in Table 4.

The results of all studies show that MSW generation in Pakistan is increasing as population and urbanization increase. The huge quantity of MSW needs management properly but here in the Pakistan it is openly dumped into low lying areas, water bodies and even along the road sides. Like in other developing countries, proper attention is not mostly given to solid waste management and socio-environmental issues due to its mismanagement in Pakistan. Behind the improper attention given to waste management, there are various reasons including the lack of financial, human, infrastructure and concerned resources to make effective efforts for management of MSW in developing countries [62]. In developing countries, MSW management has multidimensional issues such as institutional, political, environmental and socio-economic aspects [63]. Municipalities have been traditionally functioned to provide waste management services in developing countries [64]. However, efforts have been made by many municipalities to make waste management in a sustainable manner in developing countries. These efforts oftentimes either become ill managed or even cease to exit due to various technical, social and institutional constraints [63]. Recently, some non-government organizations (NGOs) and community based organizations are functioning

Table 3
Quantity of MSW generated in major cities of Pakistan in 2010, 2012 and 2013.

City corporation	2010 [50]			2012 [51]	2013 [52]		
	Population (millions)	GR (kg/capita/day)	TQ (MT/Year)	TQ (MT/Year)	Population (millions)	GR (kg/capita/day) [Collection rate %]	TQ (MT/Year)
Karachi	13.38	0.613	2.354	3.688	11.62	0.61 [53]	1.378
Lahore	7.21	0.7	2.419	2.149	6.29	0.61 [68]	0.953
Faisalabad	2.91	0.48	0.427	0.775	2.5	0.39 [65]	0.296
Hyderabad	0	0	0.073	0.449	1.39	0.56 [72]	0.375
Peshawar	0	0.5	0.183	0.286	1.24	0.49 [67]	0.149
Gujranwala	1.67	0.469	0.301	0.436	1.44	0.47 [52]	0.128
Quetta	0	1	0.274	0.222	0.73	0.38 [75]	0.1
Bannu	0	0.445	0.014	0	0	0	0
Sibi	0	0.57	0.014	0	0	0	0
Multan	0	0	0	0.462	1.45	0.45 [60]	0.325
Sialkot	0	0	0	0.123	0	0	0
Sargodha	0	0	0	0.134	0	0	0
Islamabad	1.049	0	0	0.155	0.74	0.53 [91]	0.225
Rawalpindi	2.01	0	0	0.543	1.77	0.58 [86]	0.32
Bahawalpur	0	0	0.091		0	0	0
Total	28.229	4.777	6.15	9.422	29.17	5.07 [69]	4.247

Table 4
Quantity of MSW generated in major cities of Pakistan in 2014 and 2016.

Citycorporation	2014 [53]			2016 [present study]		
	Population (millions)	Generation rate (kg/capita/day)	Total quantity (MT/Year)	Population (millions)	Generation rate (kg/capita/day)	Total quantity (MT/Year)
Karachi	14	0.572	2.92	22.825	0.572 [53]	4.765
Lahore	0	0.151	0.507	10.355	0.75 [55]	2.835
Faisalabad	2.7	0.53	0.522	3.675	0.45 [56]	0.604
Hyderabad	9.2	0	0	2.99	0.8 [57]	0.873
Peshawar	0	0	0	1.785	0.38 [58]	0.248
Gujranwala	1.85	1.08	0.73	2.195	1.08 [53]	0.865
Quetta	0	0	0	1.14	0.378 [52,59]	0.157
Multan	2.06	0.53	0.402	1.95	0.53 [53]	0.377
Sialkot	0	0	0	0.58	0.313 [60]	0.067
Islamabad	0	0	0	0.74 [52]	0.53 [52]	0.143
Rawalpindi	2.5	0.21	0.192	1.77 [52]	0.21 [53]	0.136
Khariyan	0.035	2.57	0.033	0	0	0
Lala Musa	1	0.027	0.01	0	0	0
Sukkur	0	0	0	0.585	0.45 [61]	0.096
Total	33.345	5.67	5.316	50.59	6.443	11.166
Remaining urban area	0	0	0	23.11	0.84 [17,31]	7.086
Rural area	0	0	0	114.32	0.30 [17,31]	12.518
Sub-total	33.345	5.67	5.316	188.02	7.583	30.764
Hazardous wastes		0	0	0	0	1.538
Grass Total			5.316			32.3

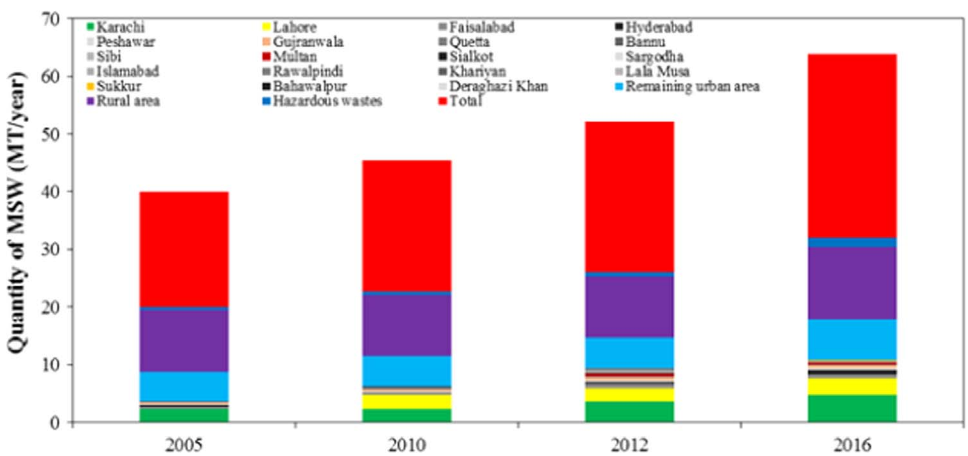


Fig. 9. Quantification of MSW generated in various cities of Pakistan.

together to manage solid waste in major cities of the countries. Instead of that until there is a need to manage MSW for energy recovery in a sustainable way. There is neither engineered landfill nor any other disposal facility even in major cities such as Karachi, Lahore, Quetta, Peshawar and Rawalpindi. Moreover, no well-designed incinerator has been installed in hospitals where about 2.5×10^5 tons of waste having 20% as infectious waste is generated per year [9]. The findings of previous studies and present study regarding the quantification of MSW generated in various cities of Pakistan are shown in Fig. 9.

About 20.03 MT (2005), 22.7 MT (2010), 26.07 MT/year (2012) and 32.3 MT/year (2016) estimated by Pakistan environmental protection agency [48], Federal Bureau Statistics [50], Mahar [51] and present study respectively (Fig. 9) by including remaining urban area, rural area and hazardous waste. The generation of MSW is highly influenced by population growth and pattern of urbanization of any country. Population was estimated on the basis of PGR of 1.92 [10] from 2014 to 2030 as in Fig. 10. The share of urban population in Pakistan has been increased from 38.6% in 2014 to 39.2% in 2015. Whereas, the rural population decreased from 61.4% in 2014 to 60.8 in 2015 [10]. The difference between urban population in 2014 and 2015 is 0.6, according to that further urban population was estimated (Fig. 10). According to the findings of [48], the generation of all types of waste varies from 0.283 kg/capita/day (or 1.896 kg/house/day) to 0.613 kg/capita/day (or 4.29 kg/house/day) in Pakistan. In comparison to above [31] , reported that MSW generation in Pakistan varies from 0.30 kg/capita/day to 0.84 kg/capita/day with expectation to increase up to 1.05 kg/capita/day by 2025. In this study, quantity of MSW generation in Pakistan projected by considering 0.84 kg/capita/day in urban areas and 0.3 kg/capita/day in rural areas and total amount of solid waste would be about 52.13 MT in 2030 as shown in Fig. 10.

Fig. 10 reports quantity of MSW generated increases as population and urbanization increase. Per capita MSW generation is strongly associated with national income and it varies from country to country [65]. According to [66] that countries with lower GDP generate less quantity of solid waste. Lilliana et al. [67] by neglecting that statement, explains that solid waste generation is collected from information provided in cities by several sources including municipalities, NGOs, research centers, universities or even reported by first author. Whereas GDP is an indicator of an economic situation at an national level. MSW generation of several regions and countries is given in Table 5.

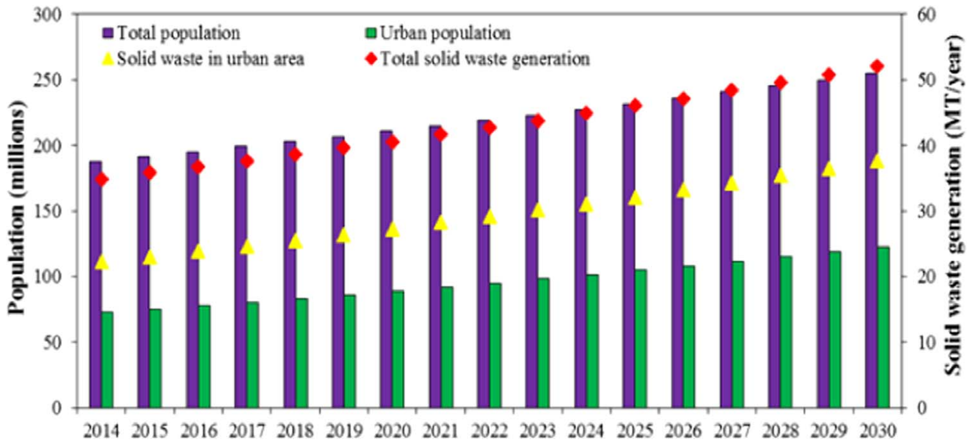


Fig. 10. Projection of Population and MSW generation in Pakistan.

Table 5
Generation rate MSW in various countries.

Refs.	Study year	Region/Country	GR (kg/capita/day)
[31]	2015	High Income	2.1
		Upper Middle	1.2
		Lower Middle	0.79
		Lower Income	0.6
		African	0.74
		Arabs States	0.77
[68,69]	2011, 2015	Asia	0.79
		Latin America	0.82
		Industrial Nations	1.4
		Transition Nations	1.34
		All cities Average	0.96
[70]	2011	Beijing (China)	1.2
[71]	2010	Singapure (Singapure)	0.96
[72]	2015	Kocaeli (Turkey)	0.92
[73]	2011	Seoul (Korea)	0.89
		Kano (Nigeria)	1.61
[74]	2012	Dutse (Nigeria)	0.97
		Katsina (Nigeria)	1.12
		Denmark	2.04
		France	1.45
		Netherlands	1.44
[75]	2016	Kuwait	1.4
		United Kingdom	1.32
		Sweden	1.25
		Romania	0.74
[17,31]	2012, 2015	Pakistan	0.57
		Mumbai	0.45
		Kolkata	0.58
[76]	2013	Ahmedabad	0.37
		Lucknow	0.22
		Jkochi	0.67

3.2. MSW composition

Composition of MSW plays vital role for selection of proper disposal and/or treatment method to recover valuable resources which are hidden in the heterogeneous mixture of various organic as well inorganic substances. The composition of MSW generated in any country is very important for proper waste management and mostly effected by various factors such as economics status, culture, living standard, energy consumption and climate change etc [77]. Due to the heterogeneity nature of MSW, its classification is very difficult. According to the [78], MSW is classified on the basis of its biodegradability nature. On that basis, MSW generated in the major cities of the Pakistan are classified and percent by weight of its each component was averagely estimated as mentioned in Fig. 11 by getting basic information from [48,52,53,55,57,60,61,79–82].

MSW generated in Pakistan contains 64 and 36% of organic and inorganic wastes respectively as illustrated in Fig. 11. Further, 64% of organic waste is contributed by 67 and 33% of putrescible and non-putrescible (also combustible) waste material respectively (Fig. 11). Similarly, 36% of inorganic waste is more composed of 8% and 92% of degradable and non-degradable waste respectively (Fig. 11). Moreover, Fig. 12 shows quantity of different components of MSW in major cities of Pakistan. It was observed that MSW generated in the country is averagely shared by degradable (3%), non-putrescible (22%), non-degradable (33%) and putrescible (42%) as mentioned in Fig. 12.

Figs. 11 and 12 realize that huge quantity of energy from putrescible and non-putrescible (combustible) wastes can be exploited in terms of biogas and heat energy correspondingly which would be enough for power generation potential in Pakistan. On that account, there is an urgent need to analyze various disposal and/or treatment methods (i.e anaerobic process, thermal treatments etc) properly by considering engineering and scientific principles. The comparison between composition of MSW in pakistan with other countries [65] is illustrated in Fig. 13.

There is difference between the composition of MSW generated in Pakistan as compared to the other income countries because of various reasons. From which one very important reason is the poverty. Due to which, mostly recyclables items (i.e, paper/cardboard, plastics, metals etc) are collected in the urban areas of the country and sold by needy persons for their survival at various stages from generation to final disposal of MSW. This leads to contribute their lesser quantiy in the composition of MSW (Fig. 13) like other low and lower middle income countries.

3.3. Evidence of MSWM practices

Solid waste is not properly managed in Pakistan like other developing countries and the country is facing serious environmental issues due to the mishandling of waste [83,84]. Over all findings and observations of MSW management practices in Pakistan are summarized in Table 6.

Further disposal practice of MSW in the Pakistan is compared with the other countries as mentioned in Fig. 14.

Obviously, Pakistan is away from proper disposal of MSW, only 40% of wastes is disposed off by using landfill in the country (Fig. 14), whilst no any well designed incinerator is currently functioning. Very small quantiy of MSW is informally recycled because of lack of any recycling regulation in the country [51,55]. Additionally, if any where in the country, solid waste is disposed by landfill and composting that is not in an engineering way, further both disposal methods require improvement [55,102]. Mostly, the entrance and exit of cities of Pakistan are accumulated with burning and dumping of MSW.

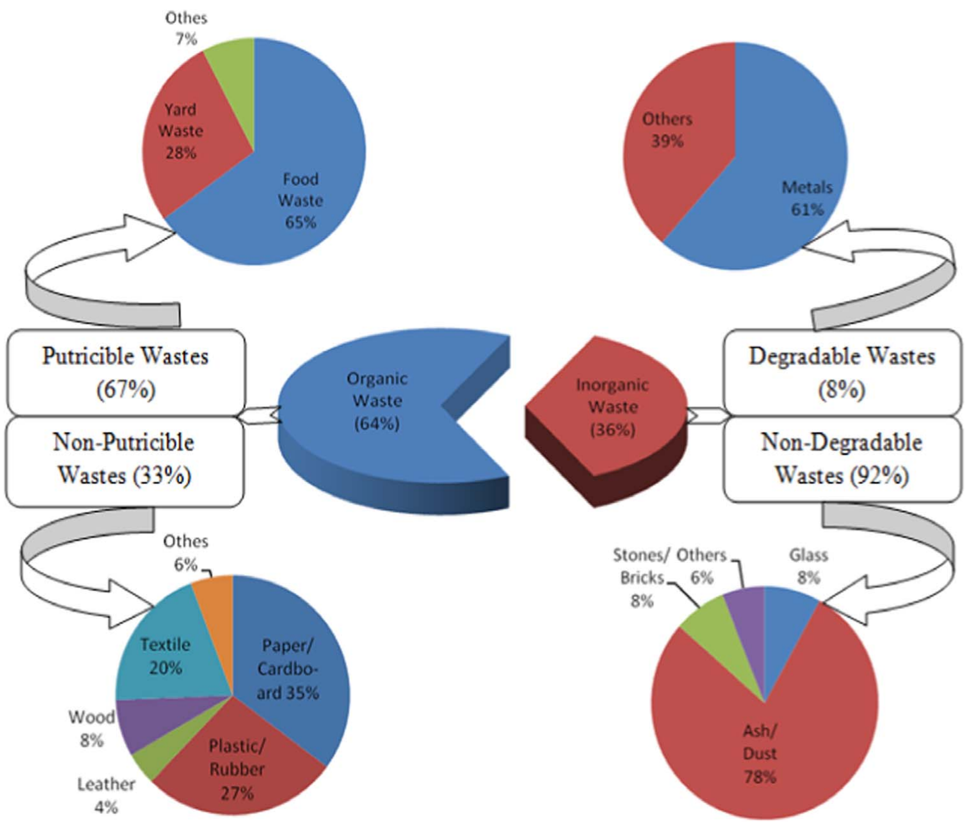


Fig. 11. Average MSW physical composition in Pakistan.

3.4. MSW characterization

Every city of Pakistan observes equally four seasons of a year. As upper parts of country (i.e Islamabad and some area of Khyber Pakhtunkhwa province) are facing cold climate where as lower parts (i.e. south Punjab, Sindh and some areas of Baluchistan) are observing hot climate in the year. All cities observe same pattern of change if any natural phenomena by chance happens. Therefore, there may be little variation in the characteristic of MSW generated in different areas of country. By considering this fact, only samples of OFMSW from residential and commercial areas of Hyderabad city were collected in summer season and characterized as shown in Table 7. Then on that basis, characteristics of mixed MSW generated in selected cities were determined as shown in Table 8. Also characteristics of MSW from previous studies in Pakistan and other region of the world are described in Table 8. On the bases of this decision makers as well as

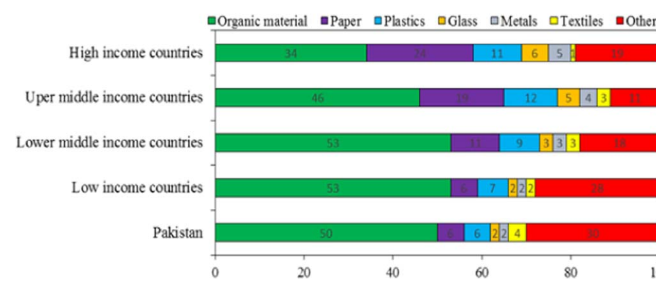


Fig. 13. Composition of MSW in Pakistan and different income countries [65].

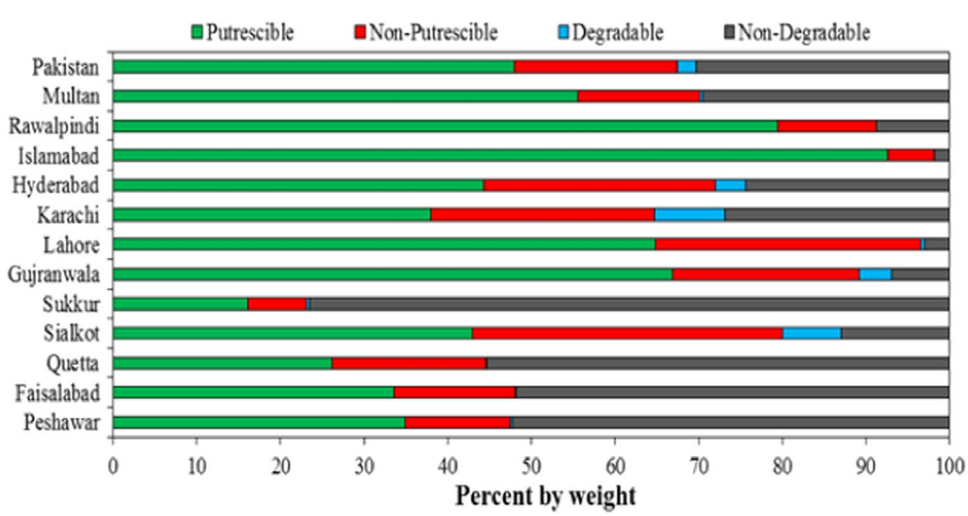


Fig. 12. Average quantity of MSW components generated in selected cities of Pakistan.

Table 6
Findings and observations of MSW management practices in the Pakistan.

Element	Findings and observations
Legislation	Pakistan has developed laws, established government agencies and accepted technical assistance from donors like the World Bank in order to respond environmental problems. Despite of that, the response remains fragmented and environmental laws, regulations and other initiatives have not solved the problem [85]. Muhammad [55] reported that there are plethora of regulations in Pakistan but their applications are still far from becoming the reality for the country and they are only at implementation stage across the country. The major weakness lies in the enforcement of regulations [86]. The sustainable waste management is one of the serious and challenging task because of regulatory issues in the country [87].
Implementing Institutions	Environmental protection agency (EPA) has been functioned in each province of Pakistan to monitor environmental problems such as air pollution, water pollution, management of solid waste etc. Instead of provincial of EPAs, there is a lack of implementation of laws even in major cities of the country [88]. The lack of technology & human resources, insufficient funding for waste are mainly factors which have made the MSW as a challenging problem in Pakistan [87,89]. According to [90], funds were allocated for two new SWM projects for Karachi city which are still awaiting to release of funds. Same study also elaborates that the government lacks the political will in the most important projects.
Planning and political concentration	Throughout the country, no any proper planning of SWM has been done. The SWM issue is highly neglected in most of the cities of the country [91]. Muhammad [55] and Ahmad et al. [89] reported the lack of interest from government and local bodies has hampered advancement of MSW management. The main causes of mismanagement of solid waste in Pakistan are lack of urban planning, infrastructure and lesser political will [1,55,91,92].
Generation rate of MSW	The generation rate of MSW varies from city to city and area to area of the country depending upon income level of people. The studies [17,31] reported that MSW generation in Pakistan varies from 0.31 to 0.84 kg/capita/day and would increase up to 1.05 kg/capita/day by 2025.
Composition of MSW	Waste composition varies from city to city in the country. Mostly, from 40 to 65% of waste is biodegradable waste in Pakistan [55]. According to the study [26], MSW generated in Hyderabad is composed by 45% organic and 55% inorganic waste. In Lahore, about 65% of waste is biodegradable [86]..
Onsite storage and processing	There is no any well designed container for storage of MSW and improper storage at the source in the cities of Pakistan is mostly observed [53]. Same study also stated that no any activity has been performed at onsite processing of MSW due to unawareness and lack of onsite processing equipments. According to the studies [93,94], the improper storage of MSW is a grave concern in Lahore and the storage containers are placed without considering their effectiveness and suitability. Moreover [95] , reported that capacity of container is less than incoming waste thus resulting waste overflow and containers are lifted without collecting the fallen waste material.
Sources segregation	Biowaste is mostly disposed of along with other wastes in open environment without any biological process and segregation at sources of generation [53]. Shahid et al. [92] reported that transported waste by uncovered vehicles is dumped at disposal sites in Karachi without any segregation system.
Collection	Generally, Pakistan is facing environmental problems due to the conventional system of waste collection [96]. Improper collection rate of 70 and 30% in large cities and small towns have been reported respectively [55]. Taluka municipal authority (TMA) is responsible to collect MSW and dispose of, but collection of MSW is still not satisfactory in Pakistan [53,95]. According to the [86,91] in Lahore, 100% collection rates are not obtained yet by Lahore Waste Management Company (LWMC) instead of involving 10,000 field workers in waste collection and disposal. Also in Karachi being a largest city of the country, until no any perfect collection system for MSW has been mechanized [97].
Collection equipment	There are limited collection equipments/vehicles. Lack of well-designed equipments and skilled labour are main reasons to remain waste material on open roads and streets of cities of the country. The TMA of Bahawalpur, Pakistan is unable to achieve primary and secondary collection of MSW successfully due to the faulty and limited equipments [98]. Kamran et al. [94] reported that about 57 vehicles are engaged to collect waste in Lahore but most of them are not properly maintained and even some remain often out of order. Bhatti et al. [99] reported that in Abbottabad, there are insufficient sanitary workers for collection of waste material.
Collection method	No any proper method of collection even in major cities of the country has been found. Due to lack of standardized laws for waste collection, the existing collection method in Lahore is not much impressive instead of investing lot of money [86]. The collection bins such as masonry dust bins, containers etc of very limited numbers and low capacity are installed and not properly located to accommodate MSW of cities [53,95].
Frequency of collection	Collection frequency varies from city to city. Masood et al. [86] reported that there is no regular interval for collection of waste and it varies for every city. Bhatti et al. [99] carried out study in Abbottabad, Pakistan and stated that due to lack of manpower and public participation, the waste is collected in certain areas after several days which creates a nuisance and risk of spreading diseases.
Transfer and transport	There is no any well designed transfer station even in major cities of the country. The transportation of MSW is carried out mostly by open body type trucks, tractor-trailers etc and left uncovered during hauling leading to scatter waste material. In Pakistan, existing method of transportation of waste is unsatisfactory [95]. In Karachi, the mixed MSW is transported to disposal sites by uncovered vehicles from different areas of city [92]. Abbasi et al. [97] highlighted that existing waste transportation in Karachi city of Pakistan is not environment friendly due to lack of long term plans.
Energy recovery facility	No any well designed energy recovery facility is available throughout the country. Even long ago, feasibility studies of waste to energy plants on the basis of MSW were conducted for installation in selected cities such as Karachi, Quetta, Peshawar and Lahore. Unfortunately no any single system has become under operation [100]. One latest study [95] showed that there has been little interest in getting energy from waste or material recovery even after privatization of MSW in Lahore.
Disposal method	Open dumping of MSW is common in Pakistan [96] and mostly waste is dumped in empty plots and on bank of canals passing through cities of the country. Existing disposal method of MSW in Pakistan is not satisfactory [95]. Dumping and burning of waste on road sides is frequently sighted [101]. In Lahore, there is no any controlled or even semi-controlled disposal facility based upon engineering principle [55,86,95,102]. Masood et al. [86] further reported that, all of three existing disposal facilities in Lahore are no more than dumpsites and insufficient for generated waste. Karachi is the metropolitan city of Pakistan, where only 60% of MSW is dumped at the dumping site and remaining 40% is not collected [92]. Siddiqui [103] reported that about 13,500 tons per day MSW generated in Karachi, out of which 16.85; 29.63 and 53.52% per day are informally recycled, dumped and left on street corners as well as in open drains respectively.
Recycling	Because of lack of fundamental recycling rules, only 20–30% of solid waste is recycled [104]. There is no any systematic mechanism for recycling of waste and mostly scavengers are engaged to collect recyclable materials such as paper, plastic, tin etc [88]. About 27% of waste recycled informally and 8% of waste is converted into compost product by composting plant in Lahore city [86,91].
Awareness	Awareness is a basic tool by which public is motivated to get desired objectives. To convert MSW into valuable product in order to protect environment is one of the global issue. Therefore, awareness about basic principles of MSW management is necessary for any country. In Pakistan, lack of public awareness, unplanned city growth and high generation rate are the major factors which lead to mismanage MSW [1,55,87,89,99,105].
Socio-economic constraints	The management of solid wastes have been constrained by various financial and socio-economic factors. In order to meet increasing demand of rapidly urbanization, mechanization of latest rules and regulations are the need of present time [106,107]. The findings of

(continued on next page)

Table 6 *(continued)*

Element	Findings and observations
	study [63] identified major types of constraint that have been usually observed to influence waste management system in developing countries such as (1) culture, knowledge & microeconomics; (2) social provisions, infrastructure & technology and (3) institutions, policy & macroeconomics. Pakistan is one of the developing country where population and urbanization has led to generate huge quantity of MSW and the country is facing same issues like other developing countries.
Environmental impacts	Deterioration of soil quality, underground water resources, reduction in plant diversity and decrease in vegetation abundance are grave consequences of open waste dumping in one of the renowned green city (i.e, Islamabad), of Pakistan [96]. Abbasi et al. [97] reported that air quality deterioration, quality of resources, disturbances of small mammals and wildlife are the major environmental impacts of disposal sites of MSW in Karachi. Munir et al. [108] estimated 4.09×10^7 kg of CO_2, 9.86×10^6 kg of CH_4 and 2.69×10^2 kg of N_2O released into environment with a cumulative global warming potential of 2.48×10^8 kg from the collection and landfill operation of MSW generated in Ravi town, Lahore. Mohsin et al. [98] found that almost 95% of waste is thrown openly in the fields and streets which is creating severe environmental and health problems in Bahawalpur city of Pakistan. The beauty of Gilgit city of Gilgit Baltistan, Pakistan is also worsening due to the open dumping and burning of MSW [88,109]. Ahmad et al. [89] identified that, waste material is mostly dumped in open spaces which decreases the attraction and beauty of Swat Valley in Pakistan.

well-wishers of the country may take action to recover energy from MSW by managing it properly.

Table 8 reports that MSW generated in selected cities contains density, MC, TS, VM and FC in the range of 185–337 kg/m^3, 14.07-58.2%, 41.81-85.93%, 15.43-84.04% and 1.69–13.54% with an average of 256 kg/m^3, 31.48%, 68.52%, 51.8% and 6.9% in Pakistan respectively. From lower moisture content of MSW generated in Pakistan, it can be realized that MSW is more favorable for combustion process rather than other as it reduces the ignition temperature and rises the calorific value of fuel [114]. Moreover, cost of drying process during combustion is minimized because of low moisture content and vice versa in case of MSW have high moisture content as it needs drying process for enhancing calorific value [114,115]. There is generally inverse relationship between volatile solids and fixed carbon. The trend of inverse relation between volatile solids and fixed carbon of present study has been observed similarly as reported [115]. Whilst, pure biomass such as forest residue, oak wood and pine contains volatiles solids of 79.9%, 78.1% and 83.3% respectively [116]. Rapidly burning of a fuel has been generally observed due to having high volatile as well as low fixed carbon and vice versa as in case of coal which requires more time for burning on a grate if it is not pulverized to a very small size [117]. Therefore, MSW generated in Pakistan is more suitable for combustion process as it contains high volatile and low fixed carbon.

The elemental analyses of MSW in different cities show that the concentration of C, H, N, S, O, AC and C/N ratio lies in the range of 29.49–44.78%, 3.27–6.53%, 0.31–1.07%, 0.09–0.18%, 8.38–40.46%, 10.84–48.30% and 39–116 with an average of 36.31%, 4.53%, 0.55%, 0.13%, 24.68%, 33.76% and 67 in Pakistan respectively (Table 8). According to the (Table 8), the concentration of sulfur in MSW is lower than the 1.1% of sulfur of bituminous coal analysis [118]. The lower average amount of nitrogen and sulfur in MSW generated in the country indicates that emissions would be reduced during combustion process [115]. Elemental analysis of MSW is mostly used to determine C/N ratio for biological conversion process of MSW and important to design selected technology [119]. Elemental composition of MSW also plays significant role to calculate the amount of air required and the flue gas produced during combustion process [120].

The NCV of MSW generated in selected cities were observed to be in the range of 1028–4127 kcal/kg with an average of 2569 kcal/kg in Pakistan (Table 8). The characteristics of MSW mostly depend upon composition of waste and vary region to region, country to country, time to time. The calorific value (CV) of MSW is highly associated with its composition. The amount of biogenic and non-biogenic components alter the MC and CV of MSW. Increasing non-biogenic components over biogenic indicates the growing amount of CV of MSW. Higher MC & inert fractions and consequently low CV of MSW make least favorable for Th-Ch.P [121]. There are various treatment technologies, adopted in all over the world. The selection of technology depends upon desirable range of various characteristics of MSW as tabulated in Table 9.

From Table 9, it can be justified that the average characteristics of MSW generated in Pakistan (Table 8) are within the range of Th-Ch.P and can be autogenously incinerated as compared to MSW generated in center part of Nigeria [74]. Therefore, Th-Ch.P is more favorable option to treat MSW in Pakistan rather than Bio-Ch.P.

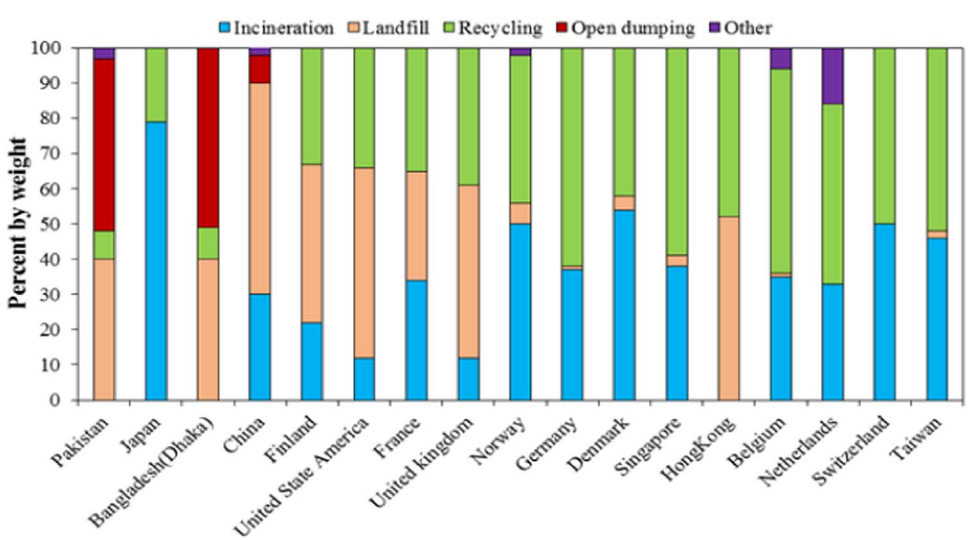


Fig. 14. Disposal methods of MSW in various countries [51,77,110–113].

Table 7
Characteristic of MSW components.

Waste Components	Density (kg/m^3)	Proximate analysis				Elemental analysis						NCV
		MC	TS	VM	FC	C	H	N	S	O	AC	
Cardboard	50.26	3.91	96.09	76.44	23.56	20.86	0	0	0.1	57.12	22.02	6784
Food waste	323.18	75.02	24.98	83.01	17.1	35.56	6.43	1.53	0.18	48.67	7.81	10
Leather	162.14	0.71	99.29	73.49	27	36.86	5.48	0.15	0.26	37.15	20.36	7457
Paper	82.69	4.82	95.18	85.12	15	40.98	7.44	0	0.08	39.13	12.45	7221
Plastics	64.85	0.24	99.76	97.01	3.72	71.92	0	0	0	23.15	4.93	17960
Rubber	129.71	0.18	99.82	91	9.73	58.34	0	0	0.17	15.23	26.43	15192
Textile	64.85	1.34	98.66	93	7.01	49.5	6.45	0	0	37.92	6.13	8016
Wood	243.21	4.71	95.29	88.43	12.81	44.73	2.92	0	0.15	49.29	3.06	6521
Yard waste	159.44	30.38	69.62	91.95	8.04	45.36	8.03	1.04	0.12	37.44	8.13	1352
Ash/bricks, etc	486.42	8	92	0	0	26.3	3	0.5	0.2	2.2	68	1375
Glass	196.19	2	98	0	0	5	0.1	0.1	0	4.1	98.9	18
Metals	575.6	8	92	0	0	4.5	0.6	0.1	0	4.3	90.5	211

MC (moisture content %); TS (total solid %); VM (volatile matter %); FC (fixed carbon %); C (carbon %); H (hydrogen %); N (nitrogen %); S (sulfur %); O (oxygen %); AC (ash content %); C/N (carbon to nitrogen ratio) and NCV (net calorific value in kcal/kg).

3.5. Energy generation potential assessment

Solid waste is not a waste but it is a precious renewable resource which has capacity to generate energy in terms of biogas and heat energy. These both can be used to produce electricity to enlighten some area of the country. Energy generation potential in terms of Bio-Ch.P and Th-Ch.P of MSW generated in selected cities of Pakistan was estimated through stoichiometry analysis and NCV of MSW respectively as elaborated in Table 10.

Promoting waste to energy in Pakistan is the need of current time when it is under severe energy crisis. Table 10 shows that TBp, BG, ERP and PGP through Bio-Ch.P lye in the range of 0.142–1.129 m^3/kgVS, 7–313 m^3/tMSW, 42–1804 kW h/tMSW and 0.25–80.78 million m^3 in selected cities with 0.566 m^3/kgVS, 97 m^3/tMSW, 557 kW h/tMSW and 50.35 million m^3 in Pakistan respectively. By Th-Ch.P, the ERP and PGP obtained in the range of 358–1436 kW h/tMSW and 4.79–460.96 million m^3 in selected cities with an average of 888 kW h/tMSW and 265 million m^3 in Pakistan accordingly (Table 10). Muhammad et al. [52] estimated PGP from OFMSW of different cities through Bio-Ch.P in the range of 5.00–72.00 million m^3 with 244 million m^3 in Pakistan (Table 10). The results of this study are little bit different than the findings of present study; especially the PGP is higher and lower than PGP through Bio-Ch.P and Th-Ch.P respectively of present study. In present study, mixed MSW was considered while [52] assumed only OFMSW for PGP. The higher result of ERP through Th-Ch.P than Bio-Ch.P denotes that all biodegradable and non-biodegradable components of MSW contribute to generate energy during Th-Ch.P of MSW. Whereas, during Bio-Ch.P of MSW, only biodegradable fractions become active to yield energy. Zuberi et al. [17] estimated 1.8 million m^3/day as biogas potential from waste landfills through first order decay model (developed by intergovernmental panel for climate change) in Pakistan by considering 24.64 million tonnes of MSW per year. Later on using biogas potential of 1.8 million m^3/day, 9.9 million m^3/day and 18.0 million m^3/day, Jibran et al. [123] estimated power generation potential in Pakistan that is 68.55 million m^3/year, 1900 million m^3/year and 4487 million m^3/year from waste landfills, bagasse and livestock respectively.

3.6. Contribution of energy from MSW in total energy supply of Pakistan

In today's world, the fear about the depletion of fossils fuels has become very common and the cost of energy is increasing continuously [124]. Another study [125] reported that, the cost of electricity is increasing due to the reduction in local fossil fuel reservoirs in Pakistan and the country observes a daily power shortfall about 12–14 h. Like

Table 8
Characteristics of MSW generated in selected cities of Pakistan and other countries.

Studies	Selected cities	Density	Proximate analysis				Elemental analysis							NCV
		(kg/m^3)	MC	TS	VM	FC	C	H	N	S	O	AC	C/N	
Present study	Peshawar	262	20.39	79.61	69.27	3.57	32.53	3.83	0.52	0.16	14.65	48.30	62	2372
	Faisalabad	256	22.18	77.82	65.82	3.81	33.66	3.93	0.53	0.15	15.78	45.94	63	2490
	Quetta	232	18.81	81.19	67.3	3.31	34.60	3.51	0.47	0.15	14.46	46.81	73	3154
	Sialkot	194	34.16	65.84	38.96	9.39	36.25	3.27	0.31	0.09	27.15	32.92	116	4127
	Sukkur	337	14.07	85.93	84.04	1.69	29.49	3.48	0.51	0.18	8.38	57.97	58	1927
	Gujranwala	213	39.62	60.38	27.9	10.29	36.81	5.79	0.59	0.10	33.70	23.01	62	2314
	Lahore	318	56.04	43.96	21.54	13.54	39.11	5.49	0.68	0.13	40.46	14.13	57	1810
	Karachi	222	25.57	74.43	53.25	5.43	34.43	3.99	0.46	0.12	21.06	39.95	75	2969
	Hyderabad	185	29.88	70.12	44.84	7.91	34.96	3.48	0.44	0.11	25.78	35.24	79	3436
	Islamabad	401	58.2	41.81	15.43	11.32	41.64	6.53	1.07	0.13	39.79	10.84	39	1028
	Rawalpindi	187	24.81	75.19	18.04	7.09	44.78	6.32	0.80	0.11	31.86	16.13	56	2909
	Multan	261	34.09	65.91	48.44	5.7	37.49	4.78	0.63	0.14	23.11	33.85	60	2296
	Pakistan (average)	256	31.48	68.52	51.8	6.9	36.31	4.53	0.59	0.13	24.68	33.76	67	2569
[94]	Lahore	–	72.21	27.79	23.14	5.41	48.72	6.37	2.41	0.29	40.15	1.34	20	1348
[74]	Kano	–	32.6	67.40	25.26	10.0	21.47	0.46	0.68	0.56	12.1	32.15	32	1354
	Dutse	–	29.66	70.34	20.46	16.6	21.0	0.12	1.38	0.09	14.5	33.26	16	1275
	Katsina	–	26.74	73.26	23.41	15.1	20.96	0.34	1.1	0.29	15.9	34.75	19	1285

MC (moisture content %); TS (total solid %); VM (volatile matter %); FC (fixed carbon %); C (carbon %); H (hydrogen %); N (nitrogen %); S (sulfur %); O (oxygen %); AC (ash content %); C/N (carbon to nitrogen ratio) and NCV (net calorific value in kcal/kg).

Table 9
Desirable range of various characteristics of MSW for selection of waste to energy technology [121,122].

Important Parameters	Waste treatment technologies	
	Bio-chemical treatment technologies such as biomethanization/ anaerobic digestion	Thermo-chemical treatment technologies such as incineration, pyrolysis, and gasification
Moisture content	> 50%	< 45%
Volatile matter	> 40%	> 40%
Carbon to nitrogen ratio	25–30	–
Fixed carbon	–	< 15%
Total inert/ash content	–	< 35%
Net calorific value	–	If, > 2400 kcal/kg (incinerated autogenously) If, between 1500 and 2400 kcal/kg (incinerated with the aid of an auxiliary fuel). If, lies in the range of 1200–1500 kcal/kg (incineration becomes unfavorable option)

Table 10
Energy generation potential from MSW in selected cities of Pakistan.

Selected cities	Chemical formula	Biochemical process (Bio-Ch.P)				Thermochemical process (Th-Ch.P)		Previous study [52]
		TBp	BG	ERP	PGP	ERP	PGP	PGP
Peshawar	$C_{72}H_{101}O_{24}N$	0.843	193	1110	7.79	825	19.17	7.00
Faisalabad	$C_{73}H_{102}O_{26}N$	0.788	171	986	16.85	867	49.00	14.00
Quetta	$C_{79}H_{95}O_{25}N$	0.840	187	1075	4.77	1098	16.13	4.00
Sialkot	$C_{67}H_{72}O_{38}N$	0.408	52	302	0.57	1436	9.01	0.00
Sukkur	$C_{71}H_{99}O_{15}N$	1.129	313	1804	4.90	671	6.03	0.00
Gujranwala	$C_{62}H_{116}O_{43}N$	0.261	24	138	2.29	805	44.11	5.00
Lahore	$C_{109}H_{182}O_{85}N$	0.194	14	79	6.37	630	167.20	64.00
Karachi	$C_{72}H_{99}O_{33}N$	0.592	104	599	80.78	1033	460.96	72.00
Hyderabad	$C_{69}H_{81}O_{38}N$	0.473	70	403	9.96	1196	97.74	21.00
Islamabad	$C_{49}H_{91}O_{35}N$	0.142	7	42	0.17	358	4.79	22.00
Rawalpindi	$C_{94}H_{158}O_{50}N$	0.189	11	65	0.25	1012	12.89	14.00
Multan	$C_{69}H_{105}O_{32}N$	0.532	85	490	3.96	799	21.40	21.00
Pakistan	$C_{67}H_{97}O_{32}N$	0.566	97	557	50.35	888	265	244

TBp (theoretical biogas potential in m^3/kgVS); BG (biogas generation in m^3/tMSW); ERP (energy recovery potential in kWh/tMSW) and PGP (power generation potential in million m^3/ year).

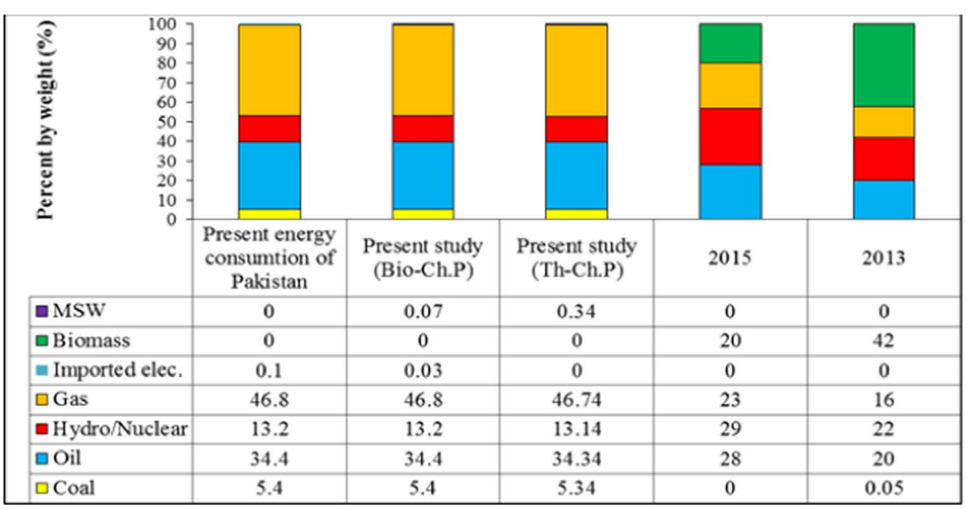


Fig. 15. Contribution of energy from MSW/biomass in total energy supply by present and previous studies [10,123,126].

other developing countries, Pakistan needs clean and cheap energy source. The contribution of energy from MSW (present study) into the total primary energy supply of Pakistan has been estimated as shown in Fig. 15 along with findings of previous studies, conducted in 2015 [123] and in 2013 [126]. Jibran et al. [123] investigated three biomasses including livestock, bagasse and MSW as energy resources available in Pakistan. Jibran et al. [123] concluded approximately 20% (Fig. 15) of energy could be contributed by selected biomasses in the power portfolio of Pakistan, when the country become self-sufficient to produce 29.7 million m^3 of biogas annually. Zuberi et al. [126] assessed biomass energy resources potential in Pakistan. Findings of this study showed that 42% of energy could be shared by fully utilization of livestock and bagasse for power generation in Pakistan (Fig. 15).

During present year out of total, 46.8% of energy needs are met with indigenous gas while oil accounts for 34.4%, imported elec. (0.1%), hydro/nuclear (13.2%), coal (5.4%) [10]. The share of imported elec. would be reduced from 0.1–0.03%, if energy is obtained by bio-Ch.P of MSW which can contribute upto 0.07% (Fig. 15). In case of Th-Ch.P of MSW, the contribution of MSW would be 0.34% followed by gas (46.74%), hydro/nuclear (13.14%), oil (34.34%) and coal (5.34%) as shown in Fig. 15. The energy from Bio-Ch.P and Th-Ch.P of MSW would be enough to reduce 70% share of imported energy and to replace completely imported energy respectively (Fig. 15). Not only this, but also burden on energy supply from gas, hydro/nuclear, oil and coal can be reduced upto 0.13%, 0.45%, 0.17% and 1.11% respectively when MSW treated by Th-Ch.P. Fig. 15 also reveals that the replacement of imported energy and dropping the percentage of other energy resources would be helpful to reduce country's dependency on imported energy. Moreover, the country can become self-sufficient to extract energy from MSW which is nowadays burning environmental issue in all over the world and especially in developing countries. The waste to energy would be surely beneficial for the better environment as well as economic growth of the country.

4. Conclusion

Being a precious renewable energy source, MSW is highly neglected in Pakistan. Whereas, developed countries are getting benefits from waste to energy by adopting proper management system of MSW. Rapidly growing population leading urbanization generates abundant quantity of solid waste at alarming rate in Pakistan. Approximately, 32.0 million tonnes of MSW per year are generated by major cities of the country. MSW is composed of 36% and 64% by inorganic and organic wastes correspondingly. Moreover, the share of putrescible, non-putrescible, degradable and non-degradable has been estimated, that is 42%, 22%, 3% and 33% respectively. Informal collection rate of MSW has been observed, that is approximately from 30 to 70% in rural to urban areas respectively. Lack of engineered landfill or any other environment friendly treatment facility is found even in major cities of the country. Moreover, unawareness of source segregation, lack of well-designed onsite storage as well as processing equipment, informal waste collection and improper collection route have been commonly observed in each and every city of the country. On the other hand, energy generation potential of MSW through bio-chemical and thermo-chemical processes has been found significantly, that is 50.35 million m^3/year and 265 million m^3/year respectively. This means that huge quantity of energy from MSW can be harnessed either by bio-chemical or thermo-chemical conversion process. Moreover, the results of study lead to conclude that the share of bioenergy (i.e 0.07% by bio-chemical and 0.34% by thermo-chemical) from MSW would be enough to replace imported energy and to reduce the burden on fossil fuels.

5. Recommendations

According to the findings of study, various remedial measures have been suggested for better management of MSW generated in each city of Pakistan for recovery of energy. By adopting these, that urban environment of each city would be sustainable for citizens as well as energy crises would be resolved to some extent.

- The implementation of new policies & regulations regarding SWM at town, district and provincial level and also development of commission at national level is the need of an hour.
- Strengthen capability of institutions by allocation of sufficient funds according to current needs to manage MSW.
- Strict punishment for the violation of law.
- Fundamental awareness of social and environmental problems which are generated because of dumping and burning of MSW.
- Providing guidelines for environment friendly onsite handling, storage & processing, collection, transfer, transport and disposal of MSW.
- Promoting source segregation for selection of disposal and/or treatment method of solid wastes
- Development of environmental performance indicators.
- Implementation of life cycle assessment approach.
- Awareness regarding adaptation of 3Rs principle.
- Hiring of skilled staffs.
- Enhancing recycling system by providing education and adopting basic recycling rules.
- Proper selection of disposal and/or treatment method by considering various parameters including waste volume reduction efficiency, need of infrastructure, operating as well as installment cost etc.

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