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Municipal solid waste management: A Case Study of Saudi Arabia provinces

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Abstract. The rapid increase in pollution and waste in Saudi Arabia is primarily due to rapid urbanization and industrial development. Local governments and government agencies are faced with the problem of waste disposal on a daily basis. The League of Arab States has called on researchers to develop solid waste management projects for the Arab region at the national level. The aim of the study is to critically analyze and study the current state of solid waste in the Saudi Arabia provinces, which should help in identifying the most promising approaches to solid waste management, which will ultimately improve the level of environmental safety. It was found that the annual volume of solid waste in Saudi Arabia, which is calculated per capita, is 1.4 kg/day/person, which is significantly higher than the world average. According to the forecast, about 3545 thousand tons of waste will be generated by 2030, which requires a global approach to waste management to mitigate the long-term impact on the environment and health. The study found that the Mass Burn scenario provides the potential to generate 61.3, and 180.0 MW, respectively in Medina, and Jeddah, which is higher than the Mass Burn's recycling power scenario and the RDF with the biomethane scenario. Joint in-depth analysis and practical research of the current situation in the field of solid waste management made it possible to identify the strengths and weaknesses of the current MSW management systems, as well as to identify promising areas for the country to reach a higher level of waste management in accordance with the set goals.

Keywords: waste management, regional level, municipality, environmental safety, energy potential.

1. Introduction

The population growth in Saudi Arabia and the rapid economic growth are contributing to the acceleration of urbanization and the improvement of living standards, which in turn is accompanied by an annual increase in municipal solid waste (MSW) (Bhada-Tata & Hoornweg, 2016). This is generally also observed in both Asian and

European countries (Salam et al., 2023; Vambol et al., 2023). The current volume of MSW is estimated at approximately 64-72 million tons, while waste generation is predicted to reach approximately 125 million tons by 2031 (Hoornweg & Bhada-Tata, 2012). The most common components of MSW, regardless of the country, are food and textile waste, cellulose in the form of paper and cardboard, sometimes wood waste and completely non-degradable goods in the form of broken glass, metal elements, rubber and leather waste (Themelis et al., 2002; Cucchiella et al., 2018; Sharma et al., 2024; Vambol et al., 2024). Figure 1 illustrates the concept of generated waste.

Regular neglect of responsibilities regarding rational and safe waste management provokes a decrease in public awareness and, as a result, a decrease in environmental quality (Pearson et al., 2015; Hanoshenko et al., 2022). The most responsible processes for waste accumulation are the lack of an effective system for collecting solid waste in a city (or other administrative unit) and its transportation to disposal or recycling sites (Hoornweg & Bhada-Tata, 2012). Due to unscientific waste management generated in municipal organizations and institutions, as well as among the population, problems with public health and well-being arise (Vambol et al., 2024; Karlova et al., 2017; Hrynzovskyi et al., 2018). A scientifically based approach to waste management is necessary to maintain a safe environment, health and well-being of the population.

Due to a variety of issues in different areas, waste management is generally poorly regulated in developing countries, and Saudi Arabia is one of these countries.

The League of Arab States has called on researchers to develop solid waste management (SWM) projects for the Arab region at the national level. The projects should contribute to the creation and implementation of a comprehensive plan for the management of hazardous materials and waste. Some cities do not have information on the best waste management practices and existing opportunities for improvement in this area. Researchers have only conducted a few active case studies on the involvement of local and private sectors in solid waste management in developing countries.

In this regard, the aim of the study is to critically review and study the current state of solid waste management in Saudi Arabia provinces, which should help in identifying the most promising approaches to solid waste management, which will ultimately improve the level of environmental safety.

2. Research background

Despite the significant number of scientific publications in the field of MSW management, which increases annually, studies assessing the effectiveness of existing MSW management systems are still insufficient, unlike other infrastructure services. Thus, the authors investigated multi-criteria decision making (MCDM) approach involving facility location or management strategy in waste management (Goulart Coelho et al., 2017). It was found that the most frequent and deeply discussed issues were the assessment of the environmental impact of different waste management technologies, social impact assessment, the choice of location for a sanitary waste landfill and types of waste processing plants.

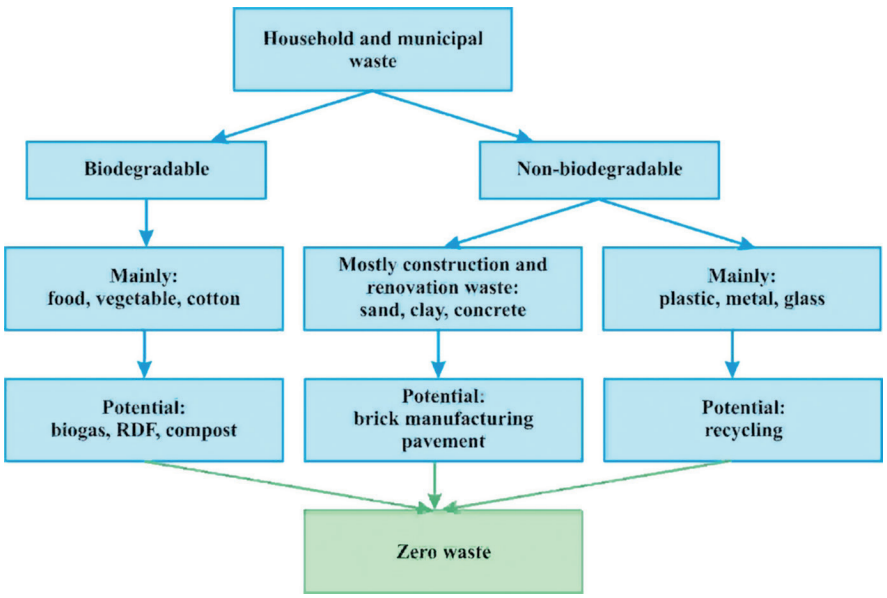


Figure 1. The generated waste concept

A simple cross-sectional comparison was conducted by Sequeiros (2012) of 39 municipal waste systems in Portugal to improve the performance of MSW management programs. Eighteen performance indicators (PIs) were used for a driver pressure-state impact-response model, where the outcome of each PIs was estimated by classical addition. Through regional/global comparisons of a large number of municipalities, the performance of a specific component from several studies was assessed. In 40 municipalities in Verona (Italy), Guerrini et al. (2016) investigated the performance of MSW management systems using non-parametric methods, found that (i) integrating waste collection services of small municipalities does not improve performance; (ii) innovative waste collection methods need to be introduced in densely populated areas. A study conducted in Poland (Vambol et al., 2023) revealed that waste collection systems, including waste segregation at source, can be effectively stimulated and improved by implementing appropriate legislation and raising public awareness, which should develop into a tradition of effective waste management. Anestina et al. (2014) analyzed 30 enterprises that implemented a private sector approach to SWM in Nigeria and recommended that the regulator enforce its statutory functions more aggressively.

In previous studies, the specificity of the municipal solid waste management system (MSWM system) was protected by a smaller number of PIs. A significant number of participating municipalities used detailed data sets of past results. Moreover, there were no considerations regarding uncertainties due to observational errors or limited data. Without prior information, the issue is more serious for qualitative PIs or newly formed PIs. In addition to this, the establishment of a desired level of service (LOS) based on expert experience, indigenous expertise and available literature generates a range of potential uncertainties in the performance appraisal process, for instance, lack of expert assessment, Limited information, data inconsistencies due to limited measurement numbers and equipment potential and human errors.

Therefore, this study attempts to answer two research questions, namely:

RQ1. What are the performance indicators (PIs) to move to a new level of MSW management in Saudi Arabian provinces?

RQ2. What are the best practices for the desired LOS in the MSWM system?

The first research question provides a basis for the development of the MSWM system in Saudi Arabian provinces by analyzing the publication of articles that discuss the factors affecting the dynamics of waste generation and management. Meanwhile, the second research question provides the value obtained from reducing the environmental impact of waste through the most sustainable practices according to the PIs. Together, these research questions contribute to revealing the impact of the PIs to evaluate the MSWM system effectiveness on the choice of waste management approaches.

3. Methodology

This paper is a combination of a systematic literature review and a bibliometric analysis to answer the research questions. The combined use of these two case studies contributes to a deeper understanding of the problem raised in the current study (Awasthi et al., 2023). Bibliometric analysis is used to identify performance indicators to evaluate the MSWM system effectiveness in Saudi Arabian provinces. Meanwhile, a systematic literature review was used to identify the best approaches to meet these performance indicators. The focus was on publications indexed in Scopus, the largest database of peer-reviewed scientific publications with a wide geographical coverage and open access. Cross-referencing was also used where necessary to benefit the current study.

The methodology for selecting publications for analysis is the following sequence of actions:

Step 1: Identification of articles was carried out in the Scopus database by keywords: municipal solid waste, waste management, Saudi Arabia.

Step 2: Automatic selection of articles in English from 2014 to the present day was provided.

Step 3: Directly bibliometric analysis.

At the same time, to identify the most effective approaches to solid waste management corresponding to the current situation in the provinces of Saudi Arabia, another research methodology is used, for which the search for publications is the same as in the previous one, using the same keywords. The main difference is that the filtering of results is not based on the previous restrictions but is based on reading first the abstract and then the full study if it is of interest to the current study, after which the research results are compared with each other to get an answer to the second question of the current study.

In addition to the theoretical study based on relevant publications, physical random sampling was conducted, 400 samples of household waste were collected from 60 unreliable landfills in the Western Region and the Eastern Region.

The Eastern Province is a strategic gateway for international trade and tourism. Significant economic growth of this region began in the early 20th century after the discovery of oil fields. In addition, the agricultural sector, electric power and other industries are actively developing in the province. The Eastern Province is also considered the

most industrial region of Saudi Arabia, where more than 86% of the main industries are located. All this contributed to the active population growth. Thus, in 2017, the population of the Eastern Province was 4,900,325 people: Saudi Arabian citizens – 3,140,362; foreign citizens 1,759,963. The governorate with the largest population and the largest governorate in terms of land area is Al-Ahsa (or Al-Hasa).

The Western Region has an active industrial development as the Eastern Region, but this region greatly attracts tourists and pilgrims due to its spiritual and historical value. Jeddah can be called the commercial centre of the Kingdom, which has a seaport and an international airport. As of 2022, there was a population of about 3,751,722 people, making Jeddah one of the largest cities and the second largest city in Saudi Arabia. Jeddah City has a heterogeneous population density, differences in economic strata and lifestyle of the population. Medina is the second holiest city for Muslims after Mecca. Its current population is 1,152,991 people.

In the current study, waste management is understood as any waste operations that reduce their harmful impact on the environment and public health. This concept also includes operations related to the prevention of waste generation.

The samples were sorted manually, and the ingredients were weighed according to the groups indicated in Figure 2. Then, each group was further sorted into the waste ingredients that were weighed: food waste; cellulose waste (cardboard, paper); polymer waste (plastic separately, rubber separately); glass; metal elements (aluminium separately, all other types of metal separately); timber; hazardous waste; broken household items such as furniture or its parts, electrical appliances, etc.

4. Results and discussion

In accordance with the request, 32 documents were found according to the first method. The distribution of documents by year is presented in Figure 3. The statistics indicate a growing interest of scientists in the problem under study, although this interest cannot be called very active. Among the research topics raised in the found documents (Fig. 4), Environmental Science demonstrates a significant advantage – 22 papers (28.2%) and energy – 15 papers (19.2%).

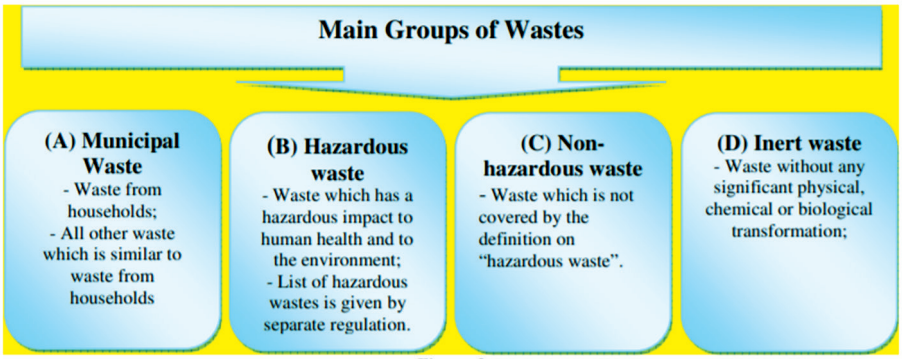


Figure 2. Waste groups of the current study

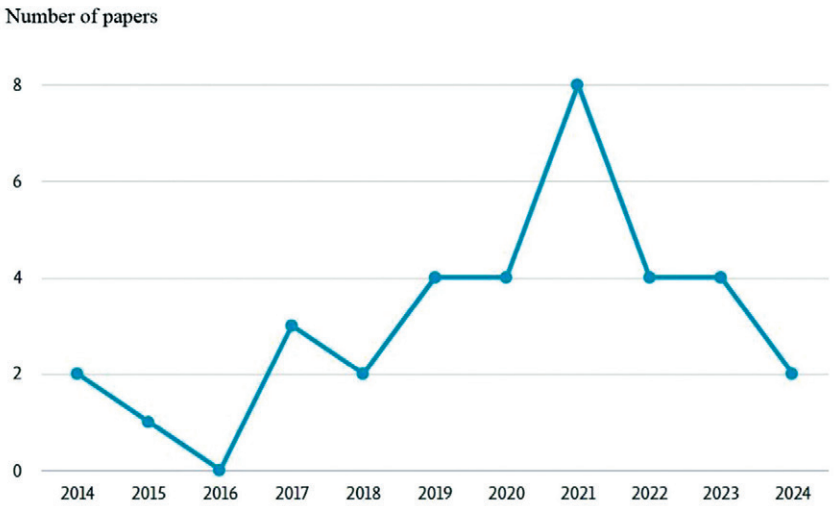


Figure 3. Statistics of requested documents by year

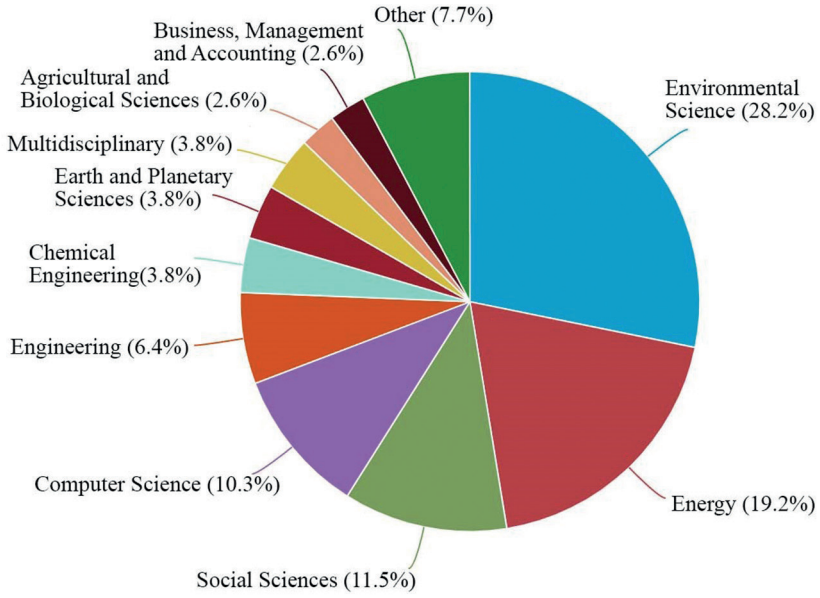


Figure 4. Statistics of requested documents by research topics

A detailed examination of the results of the studies indicates the following. Currently, Saudi Arabia generates almost 10-14 million tons of municipal waste per year with an average of 1.4 – 1.8 kg per capita per day, which is usually disposed of in landfills and open burning without material or energy recovery (Arshad et al., 2023; Rabeiy et al., 2023). The only recycling practice in Saudi Arabia is applied to metals and cardboard, with a percentage range of 10-15% of the total waste generated (Rabeiy et al., 2023).

Population growth, rural-urban migration and the predictable influx of tourists contribute to the growing challenges of solid waste generation, collection and disposal for planners. Saudi Arabia's projected population could reach 30 million in urban areas by 2025, contributing to increased waste generation rates expected to reach 1.7 kg/capita/day by 2025 (Rabeiy et al., 2023) and around 30 million tons per year by 2033 (Saeedi et al., 2023).

Current waste management practices in Saudi Arabian provinces show a lack of waste segregation at source. For example, in Jeddah, no policy for sorting and collecting municipal recyclable waste has been introduced at the city level. This was revealed through interviews, which also revealed that there are costs for mechanical sorting and hygiene at the landfill to recover recyclable materials of approximately 15-20% (Saeedi et al., 2023). Moreover, the current process of transporting municipal waste has a two-stage compaction process. Compaction of organic and wet waste with solid waste leads to damage to the raw materials, which significantly complicates waste segregation after unloading at the disposal sites. Therefore, segregation at the source can increase the amount of recyclable material (Saeedi et al., 2023).

4.1. Waste management and the natural environment

Although, it is globally recognized that the management of solid waste by placing it in landfills is an irrational, non-ecological and unsafe method, although cheap. Landfills pose a threat to all components of the environment (Morsy, 2022). It is necessary to take into account the natural conditions of the studied region such as temperature, relative humidity, precipitation and almost static wind speed, determined by the climate. Under certain meteorological conditions, a significant content of organic fragments in the waste mixture (approximately 40-50%) can provide a suitable environment for rapid anaerobic decomposition (Mallick, 2021), which corresponds to the waste situation in the provinces of Saudi Arabia. The potential for the formation of unwanted emissions into the atmosphere and the resulting leachate is accelerated, accompanied by the release of harmful substances into the environment. In addition, the contamination of soils and groundwater causes concern among the population and environmentalists.

For example, at Kaakia Landfill, located in Southwest Makkah (the meteorological conditions of this area are completely similar to Jeddah), researchers recorded an increase in the organic component of MSW, namely organics 48%, mixed plastic 25%, paper 19% (Morsy, 2022). Similar results were obtained in other studies (Aldhafeeri & Alhazmi, 2022; Osra et al., 2021).

A study (Midgley et al., 2021) found that anaerobic digestion, incineration and recycling were the most effective methods to reduce the total mass in a landfill by 73% over 30 years (compared to a classic landfill without any intervention). Midgley et al. (2021) showed that energy generated by incineration contributed a maximum of 2.3% to the annual energy production in Saudi Arabian provinces.

A study conducted in Saudi Arabia for three waste management scenarios using a landfill (Mallick, 2021) found that the highest environmental impact was caused by the disposal of 100% of collected MSW in a completely non-selective manner and disposal in an open landfill. This reasonably contributes to global warming, ozone formation (which is harmful to human health), fine particulate matter formation and soil acidification. At the same time, the scenario that includes the burial of part of the mixed waste in landfills with the possibility of gas and leachate extraction and incineration of the other part of the waste (approximately 80%) demonstrates a 55% reduction in greenhouse gas (GHG) emissions relative to the first scenario. This scenario assumes that 80% of MSW is treated as residual waste (WtE) and that dry recyclables and organic waste are treated separately, i.e. waste segregation is required. The third scenario, which assumes a higher share of waste for recycling and organic treatment instead of WtE (the main treatment in the second scenario), reduces GHG emissions by 58% compared to the baseline (simple landfill), which significantly improves the indicators for global warming and ozone formation. However, having better environmental indicators, the last two scenarios require more investment compared to the baseline (Mallick, 2021).

At the same time, numerous studies claim that the correct choice of landfill can reduce the burden on the environment. Among the criteria influencing the approach to waste disposal in the provinces of Saudi Arabia were the following: some faults in the study area – 14.28%, drainage network – 12.80%, city map (urban planning) – 11.43%, land use – 11.41%, roads as a criterion in the category of accessibility and infrastructure – 8.35% (Arshad et al., 2023).

4.2. Waste management and public attitudes

There are no obligations for waste segregation at source in Saudi Arabian provinces, in contrast to legal obligations for businesses to segregate and transport their recyclable waste (Saeedi et al., 2023). However, a household survey on waste segregation showed positive sentiments among respondents, with environmental factors and social benefits being the main drivers (Labib et al., 2021; Saeedi et al., 2023).

Research in the university environment has shown that students have lower awareness than teachers and staff. The knowledge and awareness of teachers are very important when developing programs and environmental education courses seminars related to waste management (Rabeiy et al., 2023). Most respondents (88%) are ready to implement waste segregation at home if a quality waste transportation service is provided or containers for separate fractions are available in the immediate vicinity (Labib et al., 2021; Saeedi et al., 2023).

Thus, the first step to move to a new level of solid waste management should be the segregation of solid waste at the source of formation. Depending on the total amount of solid waste already accumulated, on the volumes of individual fractions of solid waste collected separately, one should proceed to the choice of method.

4.3. Potential for MSW Management in Saudi Arabian Provinces

Waste recycling and waste-to-energy (WtE) from MSW have proven to be important in solving waste management problems as well as reducing greenhouse gas emissions from MSW management. This is because the key values of the circular economy are renewable energy generation and material value recovery. Saudi Arabia has set environmental targets in SV2030 that 2% of electricity should be generated by WtE (Aldhafeeri & Alhazmi, 2022).

Some waste management processes require a continuous, uninterrupted supply of waste, such as continuous combustion, and gasification. Using life cycle analysis (LCA) approaches, studies have found that waste generation and collection vary seasonally and for other reasons (Mosbah et al., 2022). This may have little effect in batch incinerators, but it certainly poses operational challenges in continuous incinerators, especially when supplies are insufficient. However, since the feedstock volume flow rate in gasification systems is much lower, the continuity or moisture content of the feedstock flow is not a significant issue. At the same time, batch kilns are not affected by the waste accumulation rate (Radwan et al., 2021). Continuous MSW feed has the least impact on composting (Labib et al., 2021).

The solid waste flow and components in Medina and Al-Ahsa were determined by random sampling to assess several key indicators: solid waste generation rate, energy content of MSW in Saudi Arabian provinces, and net electricity generation capacity. This is because the main energy plans of many countries around the world, including Saudi Arabia, are to reduce dependence on oil. However, Saudi Arabia is characterized by a high population growth of 3.4% per year and an increase in urbanization (people living in cities) of 80% per year. Table 1 provides data for determining the total energy per kg of waste, and Table 2 shows the annual data on waste generated. As shown in Figure 5, the total electricity generation from MSW is estimated by 2030, where the base (initial) year for the long-term forecast is 2010.

Table 1. Saudi Arabia's MSW energy contents

Indicator/Material	Cellulose	Polymer	Glass	Wood remains	Fabrics	Organic	Unsorted fractions
Waste Composition (%)	28.5	5.2	4.6	8.0	6.4	37.0	10.3
Energy potential of the material (kWh/kg)	4.39	9.05	0	4.73	5.20	1.55	3.36
Energy potential of the waste component (kWh/kg) LHV*	1.24	0.46	0	0.24	0.22	0.10	0.28
* LHV: lower heating value							

Total energy predicted for the mass combustion approach with recycling (kWh/kg) – 0.38
Total energy predicted for the complete mass combustion approach (kWh/kg) – 2.51

Table 2. Data on total waste for the years 2016, 2017, 2018, and 2020

S.No	Type of waste	Amount in tones			
		2016	2017	2018	2020
1	The amount of municipal solid waste incoming to the landfill	5,956,734	1,956,734	1,856,182	1,976,834
2	The amount of dams that were received in the landfill	4825006	2825006	2,373,391	2,915,321
3	The amount of tires that were received in the landfill	10,322	8322	7,987	8,386
4	The amount of plant waste contained in the landfill	723684	523684	498,741	528,665
5	The amount of waste received without being treated by the waste sorting unit*	37519	17519	16,170	17,787
6	The amount of waste treated on the belt of the screening unit	10,69396	969396	934,230	976,422
7	The amount of organic matter extracted and processed	792834	492834	467,115	497,975
8	The amount of materials destroyed by the paper incinerator	782	382	370.5	382.4
9	The amount of waste destroyed by burial	9532	1102	1,029	1,117
* Is the waste received and rejected by the waste sorting unit					

The primary source of data is published statistics in open scientific papers. In addition, the authors surveyed field interviews with professionals and officials in the Eastern Province involved in SWM. However, population growth is expected to continue at the historical rate of 3.4%, which is above the annual population growth rate of Saudi Arabia (Fig. 6).

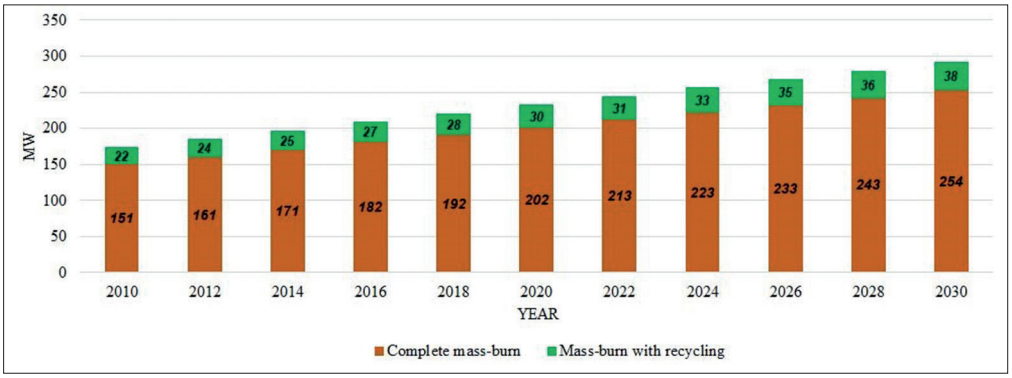


Figure 5. Net Power Generation Capacity Forecast for 2010–2030

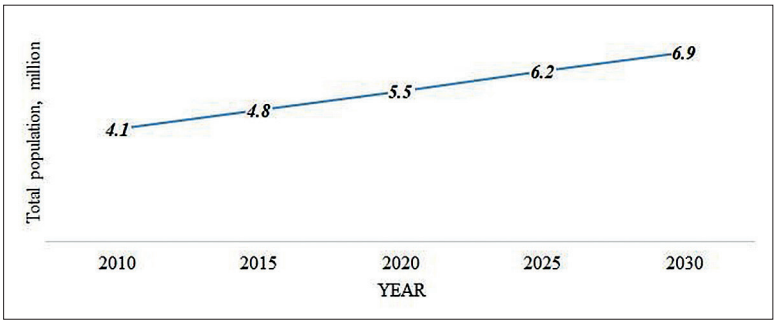


Figure 6. Population Growth Forecast in the Eastern Province of Saudi Arabia

The results of the forecast of solid waste generation from 2010 to 2030 for the Eastern Province are shown in Figure 7. According to the forecast, about 3545 thousand tons of waste will be generated by 2030, which requires a global approach to waste management to mitigate the long-term impact on the environment and health.

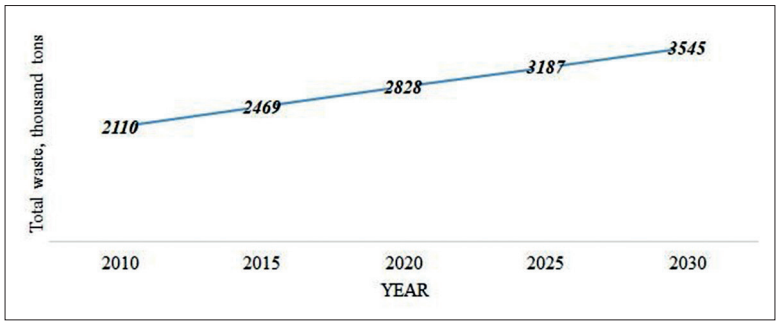


Figure 7. Projected Growth of MSW in the Eastern Province of Saudi Arabia

4.4. Physical and chemical indicators of waste in Saudi Arabian

4.4.1. Component composition

To better understand waste management in Saudi Arabia, using the Eastern Province as an example, waste must be categorized. Thus, the categorization of waste characteristics is mandatory. Although a significant proportion of municipal solid waste is made up of food or kitchen waste from households, non-hazardous biodegradable waste from gardens or parks, offices, catering outlets and establishments, or retail stores, the proportion of organic waste in MSW in Asian countries, including Saudi Arabia, is higher than in European countries (Vambol et al., 2023). At the same time, many tourist areas overlook the overall volume and nature of waste generated. For this reason, the generated MSW is collected in the study areas as mixed waste without any distinctive classification. Thus, there is a need for a waste management system in place that is efficient, cost-effective, and ecologically friendly. In addition, the waste component composition affects the choice of waste disposal method. The component composition is shown in Figure 8.

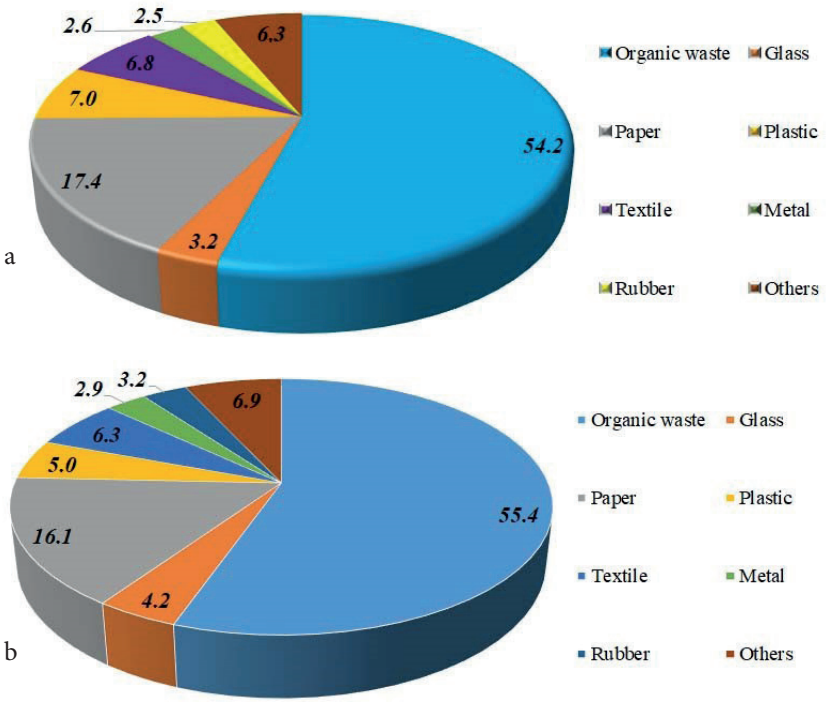


Figure 8. Component composition: a – in Jeddah; b – in Medina

It should be noted that the proportion of biodegradable waste is higher in summer, as evidenced by the difference in the seasonal physical composition of solid waste. This is due to the high temperature and frequent consumption of significant amounts of fruits and vegetables in the summer season. In addition, there is a significantly greater influx of tourists in the summer, which also makes an additional contribution to the total amount of waste generated.

4.4.2. Updates in waste management legislation

In order to improve the environmental situation, the Cabinet of Ministers approved new rules for the management of household waste in all cities and villages, which are aimed at creating an integrated waste management system. The system implies control by the Ministry of Urban and Rural Affairs over the implementation of operations and tasks for the management of solid waste. In addition, it is assumed that with the support of the Ministry of Urban and Rural Affairs, adequate and effective programs will be developed to educate people on how to handle waste properly.

4.5. Waste-to-energy opportunities

The current method of waste management in Saudi Arabia is to dispose of mixed waste in open dumps and to recycle some components. Garbage trucks with a crew of three people go out twice a day to residential and commercial areas to collect unsegregated waste. The prevalence of this waste management approach in the country is justified by the availability of waste storage space and the relatively low cost of this process. In the next few years, landfills will exhaust their capacity and will be overloaded, which will greatly contribute to environmental degradation. At present, scavengers in Saudi Arabia manually collect paper, metals, and materials, recycling less than 15% of collected MSW. While Saudi Arabia's domestic oil consumption is on the rise, making up over 25% of the country's output, there is a potential to manage waste utilizing WTE facilities in Saudi Arabia, according to world practice.

With the increase of waste, the load on infrastructure will increase, which will call into question the current practice of collecting and disposing of solid waste, especially in municipal services. It is necessary to change waste management tactics today before serious problems with environmental pollution and collapse in this area of activity appear.

4.6. Potential Waste-to-energy scenario

For the analysis, three Waste-to-energy scenarios were projected for the year 2012 to 2032: Mass Burn, Mass Burn-recycled and RDF with biomethanation. According to the results, the Mass Burn approach provides the possibility to obtain 61.3 and 180.0 MW, respectively, for Medina and Jeddah. Mass Burn's recycling power in the villages for Medina – 3.84 MW and for Jeddah – 11.25 MW. The RDF with biomethanation approach is capable of generating approximately 29.9 MW of Medina, 87.3 MW of Jeddah.

However, the results obtained are not final and cannot be improved. The municipality can further improve the efficiency of the MSW management system by selecting sustainable technology to achieve long-term goals. The basic principles of such improvement are presented in Figure 9.

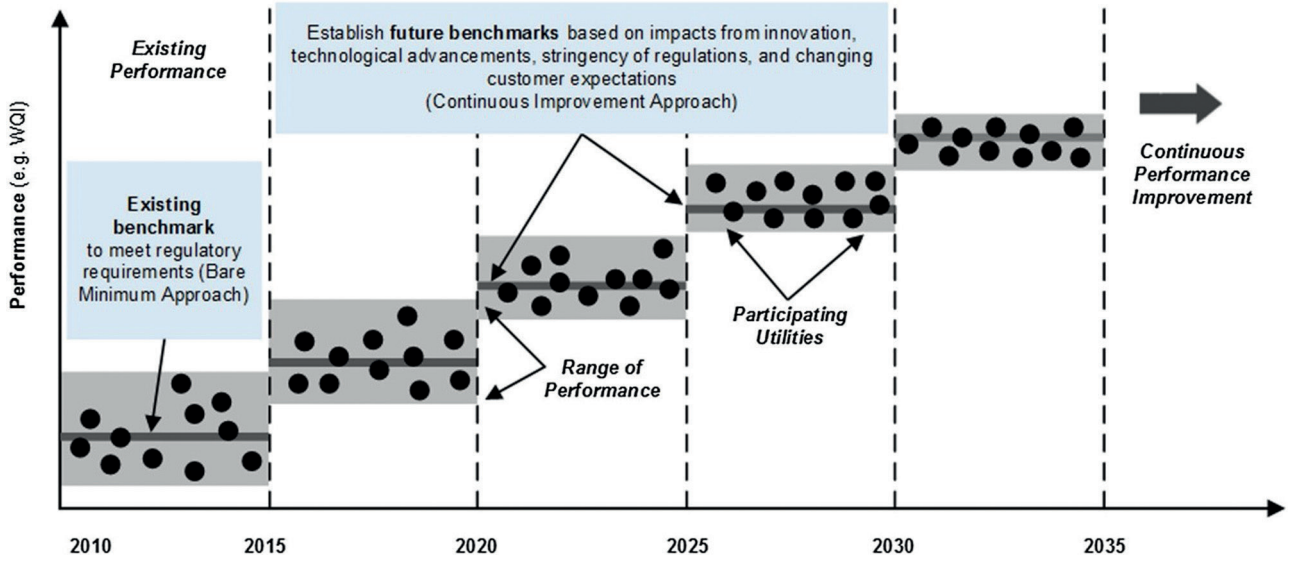
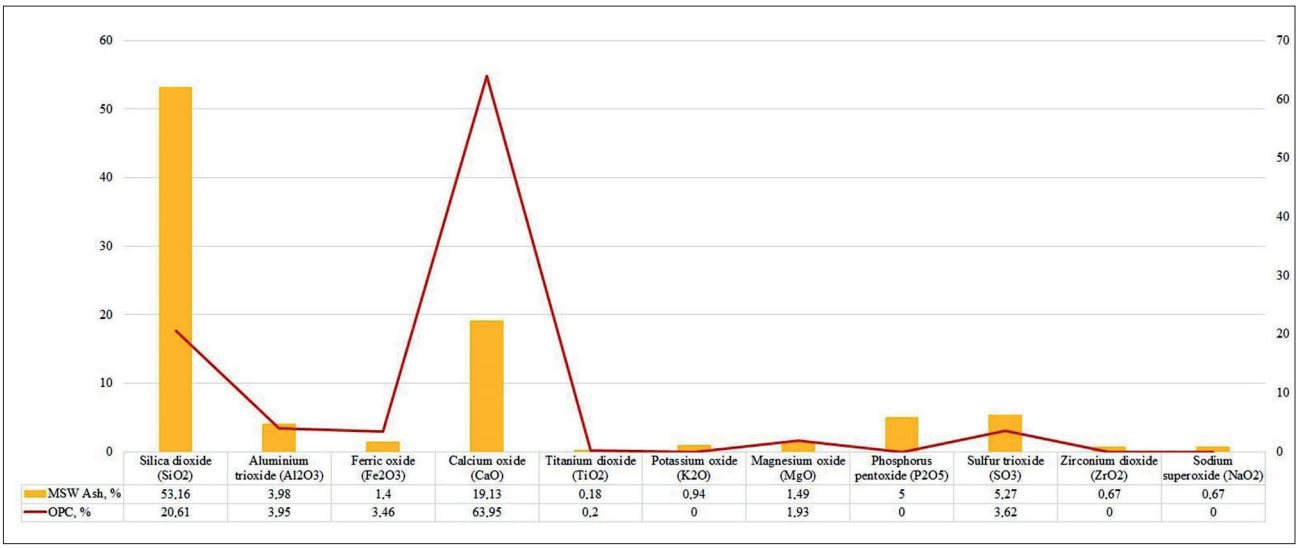


Figure 9. Continuous performance improvement concept for MSWM Systems (Bereskie et al., 2017)



	Silica dioxide (SiO2)	Aluminium trioxide (Al2O3)	Ferric oxide (Fe2O3)	Calcium oxide (CaO)	Titanium dioxide (TiO2)	Potassium oxide (K2O)	Magnesium oxide (MgO)	Phosphorus pentoxide (P2O5)	Sulfur trioxide (SO3)	Zirconium dioxide (ZrO2)	Sodium superoxide (NaO2)
MSW Ash, %	53,16	3,98	1,4	19,13	0,18	0,94	1,49	5	5,27	0,67	0,67
OPC, %	20,61	3,95	3,46	63,95	0,2	0	1,93	0	3,62	0	0

Figure 10. Chemical properties of MSW ash

4.7. Possibilities of removing solid waste ash after incineration

MSW incineration allows for a rapid reduction of waste by up to 70% by weight and 90% by volume and therefore reducing the load to landfills. The process of MSW incineration also allows for the recovery of energy. However, even in this process, a new waste appears – ash, which is more dangerous than incinerated waste. Many researchers are looking for a safe use of ash to avoid its burial and spread in the environment. Based on its chemical properties, it has been stated that MSW ash has good potential for use as a cementing material in concrete production. The typical composition of MSW ash is presented on Figure 10 for the region under study.

MSW ash is collected from various sources, and its chemical composition and its ability to impart pozzolanic properties comparable to ASTM C618 Class C are determined. The main indicators of the pozzolanic activity of the ash are Si, Al, and Fe. It is possible to increase the strength and durability of concrete by adding MSW ash if the total amount of SiO_3, Al_2O_3, and Fe_2O_3 surpasses 50%. According to its characteristics, there is a high concentration of calcium oxide in municipal solid waste ash, which can aid the hydration of cement paste in concrete. Furthermore, it meets the criteria for pozzolanic ash because it contains approximately 5.27 percent SO_3. A positive pozzolanic reaction can be guaranteed by mixing the ash. Different MSW ash have slightly different chemical compositions, besides, silica is a common ingredient. According to the specifications, Figure 10 shows a comparison of the chemical characteristics of MSW ash and ordinary portland cement (OPC).

5. Conclusion

The following constitutes an output that can be expressed in light of the findings:

1) Due to the high content of organic components in the total waste composition (more than 40%), energy production by anaerobic digestion is rational.

2) Existing landfills can be converted to remove biogas from the body of the landfill or waste from these landfills can be burned with energy recovery, which will reduce waste by 70% by weight and 90% by volume in a short time. The disadvantage in this case is the formation of ash.

3) In the case of waste incineration and the formation of a by-product such as ash, it can be used in concrete to avoid new burials in landfills.

4) The transport system for removing waste from neighbourhoods to disposal sites should be organized most efficiently to prevent an unsanitary situation and reduce the threat of the development and spread of diseases and viruses.

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References

Aldhafeeri Z.M. & Alhazmi H., 2022, Sustainability assessment of municipal solid waste in Riyadh, Saudi Arabia, in the framework of circular economy transition.

Sustainability 14(9), 5093. https://doi.org/10.3390/su14095093

Anestina A.I., Adetola A. & Odafe I.B., 2014, Performance assessment of solid waste management following private partnership operations in Lagos State, Nigeria. Journal of Waste Management 2014(1), 868072.

Arshad M., Hasan M.A., Al Mesfer M.K., Al Alwan B.A., Qureshi M.N. & Eldirderi M., 2023, Sustainable landfill sites selection using geospatial information and AHP-GDM approach: A case study of Abha-Khamis in Saudi Arabia. Heliyon 9(6), e16432.

Awasthi P., Chataut G. & Khatri R., 2023, Solid waste composition and its management: A case study of Kirtipur Municipality-10. Heliyon 9(11), e21360. https://doi.org/10.1016/j.heliyon.2023.e21360

Bereskie T., Haider H., Rodriguez M.J. & Sadiq R., 2017, Framework for continuous performance improvement in small drinking water systems, Sci. Total Environ 574: 1405–1414. https://doi.org/10.1016/j.scitotenv.2016.08.067.

Bhada-Tata P. & Hoornweg D., 2016, Solid Waste and Climate Change, [in:] State of the World. State of the World. Island Press, Washington, DC. https://doi.org/10.5822/978-1-61091-756-8_20

Cucchiella F., D'Adamo I., Gastaldi M. & Miliacca M., 2018, efficiency and allocation of emission allowances and energy consumption over more sustainable European economies. Journal of Cleaner Production 182: 805–817.

Goulart Coelho L.M., Lange L.C. & Coelho H.M., 2017, Multi-criteria decision making to support waste management: A critical review of current practices and methods. Waste Management & Research 35(1): 3–28.

Guerrini A., Romano G., Mancuso F. & Carosi L., 2016, Identifying the performance drivers of wastewater treatment plants through conditional order-m efficiency analysis. Utilities Policy 42: 20–31.

Hanoshenko O., Vambol V., Vambol S., Yeremenko S., Fialka M.I., Bodnar I. & Inozemtseva O., 2022, Medical waste generation, handling and crime statistics' analysis in this activity field: a case study of the Poltava region (Ukraine). Ecological Questions 33(3): 79–88. https://doi.org/10.12775/EQ.2022.026

Hoornweg D. & Bhada-Tata P., 2012, What a waste: a global review of solid waste management. Urban development series;knowledge papers no. 15. © World Bank, Washington, DC. http://hdl.handle.net/10986/17388

Hrynzovskyi A.M., Holovanova I.A., Omelchuk S.T., Kuzminska O.V., Hrynzovska A.A., Karlova O.O. & Kondratiuk V.Y., 2018, Public health and social supervision issues within public administration of ukrainian territories in the late 8th-early 9th centuries. Wiad Lek. 71(1 pt 2): 246–251.

Karlova O., Grinzovskyy A., Kuzminska O. & Karvatsky I., 2017, Hyperhomocysteinemia as a predictor of cardiovascular diseases in lead-exposed subjects. Georgian Medical News 271: 86–90.

Labib O.A., Manaf L., Sharaai A.H. & Zaid S.S.M., 2021, Understanding the effect of internal and external factors on households' willingness to sort waste in Dammam city, Saudi Arabia. Int J Environ Res Pub Health. 18(18), 9685.

Mallick J., 2021, Municipal solid waste landfill site selection based on fuzzy-AHP and geoinformation techniques in Asir Region Saudi Arabia. Sustainability 13(3), 1538.

Midgley W.J., Henshaw M.D.C. & Alshuhri S., 2021, A systems-engineering approach to nation-scale problems: Municipal solid waste management in Saudi Arabia. Systems Engineering 24(6): 480–496.

Morsy E.A., 2022, Geo-Environmental Evaluation of the Kaakia Landfill, Southwest Makkah, Saudi Arabia. Sustainability 15(1), 500.

Mosbah E.B., Alsanad M.A. & Sassine Y.N., 2022, Assessment of Environmental and Economic Impacts of Municipal Solid Wastes Management System: A Case Study. Journal of Ecological Engineering 23(1): 137–145.

Osra F., Morsy E.A. & Abd El-Rahim I.H., 2021, Guidance plans for solid waste management during COVID-19 in Makkah, Saudi Arabia. Arabian Journal of Geosciences 14: 1–13.

Pearson C., Littlewood E., Douglas P., Robertson S., Gant T.W. & Hansell A.L., 2015, Exposures and health outcomes in relation to bioaerosol emissions from composting facilities: a systematic review of occupational and community studies. Journal of Toxicology and Environmental Health, Part B, 18(1): 43–69.

Rabeiy R., Almutairi S., Birima A., Kassem L. & Nafady A., 2023, A Cross-Sectional Study of Knowledge, Practice, and Management of Solid Waste Segregation in Higher Educational Institutes: A Case Study in KSA. Sustainability 15(6), 5516.

Radwan N., Khan N.A. & Elmanfaloty R.A.G., 2021, Optimization of solid waste collection using RSM approach, and strategies delivering sustainable development goals (SDG's) in Jeddah, Saudi Arabia. Scientific Reports 11(1), 16612.

Saeedi K., Visvizi A., Alahmadi D. & Babour A., 2023, Smart cities and households' recyclable waste management: the case of Jeddah. Sustainability 15(8), 6776.

Salam M., Zheng L., Shi D., Huaili Z., Vambol V., Chia S.Y., … & Ullah E., 2023, Exploring Insect-based technology for waste management and livestock feeding in selected South and East Asian countries. Environmental Technology & Innovation 32, 103260.

Sequeiros B., 2012, Application of performance indicators in municipal waste services. Técnico Lisboa 12: 1–10.

Sharma N., Vambol V., Vambol S., 2024. Waste glass, [in:] Alternative Cementitious Materials for Self-Compacting Concrete. Woodhead Publishing Series in Civil and Structural Engineering, p. 119–133. https://doi.org/10.1016/B978-0-323-95139-5.00008-4

Themelis N.J., Kim Y.H. & Brady M.H., 2002, Energy recovery from New York City municipal solid wastes. Waste Management & Research 20(3): 223–233.

Vambol V., Kowalczyk-Juśko A., Vambol S., Khan N.A., Mazur A., Goroneskul M. & Kruzhilko O., 2023 Multi criteria analysis of municipal solid waste management and resource recovery in Poland compared to other EU countries. Scientific Reports 13(1), 22053.

Vambol V., Vambol S., Sawicka B., Krochmał-Marczak B., Ziarati P., Khan N.A., … & Salam M., 2024, Risks associated with waste accumulation and processing: existing experience, scientific approaches to assessment, examples, [in:] Advances in Energy from Waste Transformation Methods, Applications and Limitations Under Sustainability. Woodhead Publishing Advances in Pollution Research, p. 115–146.