International Journal of Scientific & Engineering Research Volume 10, Issue 5, May-2019
ISSN 2229-5518

The Pathway to Zero Waste: Case Study of Saudi Arabia's Solid Waste Management Techniques

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Abstract: Rising amounts of waste generation and poor waste management techniques are an increasing concern for the Kingdom of Saudi Arabia. With waste generations of around 15 million tons annually, Saudi Arabia's environment is being compromised due to the lack of effective Solid Waste Management (SWM) techniques. The purpose of this research is to understand the ongoing trends of waste generation, determine the best waste management techniques and provide methods to improve the foundation of SWM within the Kingdom. One aspect of SWM is the generation of energy called Waste-to-Energy (WTE). An analysis performed by the authors on the Municipal Solid Waste (MSW) generated in the Kingdom found out that the energy content of the waste is approximately 11,000 kJ/kg, which approximately adds up to a massive potential of 52,500 GWh/year in Saudi Arabia. According to Renewable Energy Project Development Office, Saudi Arabia eyes on generating about 3 GW of energy from wastes under Vision 2030 program. After analyzing the MSW generated in Dammam and examining the current and potential waste handling schemes of the Kingdom, an institutional framework for Integrated Solid Waste Management (ISWM) is designed by the authors.

Key words: Solid Waste Management, Saudi Arabia, Zero Waste, Waste-to-Energy

INTRODUCTION

Saudi Arabia generates approximately 15 million tons of solid waste per annum. Nearly half of this waste is generated in the three largest cities, Riyadh, Jeddah and Dammam [1]. Solid waste generation is expected to be around 22 million tons by the year 2030 [2]. The Municipal Solid Waste (MSW) throughout Saudi Arabia has high organic content of nearly 40% [3]. A breakdown of Saudi Arabia's MSW composition is given in the table below:

Table 1: MSW composition of KSA

Material	Waste Composition (%)
Paper	28.5
Plastic	5.2
Glass	4.6
Wood	8
Textiles	6.4
Organic	37
Others	10.3

Source: Ouda, et al. (2017)

Dammam is the largest city in the eastern province of Saudi Arabia with a population of around a million [4]. Out of all the cities in the Kingdom, Dammam hosts the highest per capita waste generation of nearly 3.31 kg per day [5]. Currently, majority of the MSW generated in Dammam ends up in dumpsites or landfills untreated. This untreated waste leads to several problems such as leachate, methane and odor emissions etc., due to poor sanitation [2]. However, these environmental and health issues can be countered with the help of waste management techniques, one of which is Integrated Solid Waste Management (ISWM).

Integrated Solid Waste Management can be defined as the strategic approach to sustainable management of solid wastes covering all sources and aspects such as generation, segregation, sorting, transfer, treatment, recovery and disposal in an integrated manner emphasizing on maximizing efficiency [6]. Solid Waste Management (SWM) works on the principle of 4 R's – Reduce, Reuse, Recycle and Recover. The principle of 4 R's or waste hierarchy is presented in Figure 1 below:

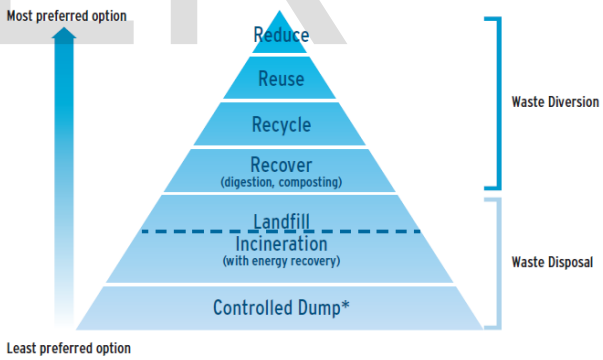

Figure 1: Waste Hierarchy
Source: Hoornweg & Bhada-Tata (2012)

One SWM technique is Waste-to-Energy (WTE) where energy is recovered from waste. The recovery is done by treating non-recyclable wastes to generate energy that can be included in the energy production of a country [7]. WTE has a promising future in the Kingdom of Saudi Arabia, thanks to Vision 2030's ambitious measures to reduce the Kingdom's dependency on oil and diversify its economy. King Abdullah City of Atomic and Renewable Energy (K.A.CARE) aims at generating nearly 70 GW of renewable energy by 2040, out of which 3 GW is to be generated through wastes [8].

The rules and regulations of waste handling and management in Saudi Arabia were laid down in 2001 in the General Environmental Regulations and Rules for Implementation by Kingdom of Saudi Arabia's Presidency of

Meteorology and Environment. Chapter Two Article Three provides the duties and obligations of the institutions to the environment. Appendix-4 provides waste control rules and procedures. Article IV(a) defines waste. Article V(b) provides the standards for waste generators. Appendix II of Appendix-4 provides 15 waste disposal regulations (D-15) and 13 recovery regulations (R-13). Appendix-6 of the same document lays down the violations and penalties for the institutions and individuals who fail to comply to the rules and regulations of the Presidency [9]. Sectioan 5.5 and 5.6 Section of the Royal Commission Environmental Regulations lays down the municipal waste collection and disposal regulations respectively. Section 5.6.7 of the Royal Commission Environmental Regulations states that, 'non-hazardous industrial waste and municipal waste shall be disposed off in a Class II (single lined) landfill site' and also lays down the characteristics of the landfill.

RESEARCH METHODOLOGY

The research carried out in this paper is primarily quantitative in nature. This paper investigates the situation of SWM and studies the MSW generated in D`ammam. For better understanding, waste is collected from five different locations and a proximate analysis is done. Based on the results of the proximate analysis, an estimate of energy content stored in Dammam's MSW is created. This paper further suggests measures to improve this technique and proposes an ISWM institutional framework for Saudi Arabia. This paper also provides its readers with a few ways and means that can be adopted in order to improve the future of SWM in the Kingdom of Saudi Arabia.

RATIONALE TO ADAPT ISWM: HIGH ENERGY POTENTIAL OF MSW

In order to complete the process of analyzing MSW of Dammam, 5 samples were selected. Out of these 5 samples, 2 were picked from residential areas, 2 from public places and 1 from industrial area respectively. After the collection, a proximate analysis was performed and density of the waste was measured. For the estimation of energy content, Table 2 was used and the results of the investigation are tabulated in Table 3 below:

Table 2: Average Energy Content of MSW

Typical Values for Inert Residue and Energy Content of Residential MSW

Component	Inert Residue[a], % Range	Energy Content, kJ/kg Range	Energy Content, Btu/lb Range
Organic			
Food wastes	2–8	3350–6700	1500–3000
Paper	4–8	11,200–18,000	5000–8000
Cardboard	3–6	13,400–16,800	6000–7500
Plastics	6–20	26,800–35,750	12,000–16,000
Textiles	2–4	14,500–17,900	6500–8000
Rubber	8–20	20,125–26,800	9000–12,000
Leather	8–20	14,500–19,000	6500–8500
Yard wastes	2–6	2225–17,900	1000–8000
Wood	0.6–2	16,770–19,000	7500–8500
Miscellaneous organics	—	—	—
Inorganic			
Glass	96–99+	110–225	50–100
Tin cans	96–99+	225–1100	100–500
Aluminum	90–99+	—	—
Other metal	94–99+	225–1120	100–500
Dirt, ashes, etc.	60–80+	2230–11,175	1000–5000
Municipal solid wastes		8950–13,400	4000–6000

Source: Tchobanoglous, et al. (1993)

Table 3: Proximate Analysis, Density and Energy Content of MSW in Dammam

Sample	Density (kJ/kg))	Moisture Content (%)	Volatile Matter (%)	Ash Content (%)	Carbon (%)	Energy Content (kJ/kg)
1	304.122	29.465	49.915	15.079	5.027	11935.982
2	315.662	33.065	48.311	14.177	4.651	11412.182
3	291.862	27.655	51.051	14.657	4.933	11705.712
4	308.522	24.994	50.436	21.047	5.073	12712.892
5	348.132	27.055	49.454	20.095	5.805	11469.862
Average	**313.66**	**28.387**	**49.83**	**17.01**	**5.09**	**11847.326**

HELPFUL HINTS

According to Anjum, et al. (2016), Dammam generates approximately 1,093,000 tons of solid waste per year. Based on this number, the potential energy content of MSW in Dammam adds up to a massive 3500 GWh/year. Assuming that the composition of waste is similar throughout the Kingdom, the potential energy content of Saudi Arabia's MSW is nearly 52,500 GWh/year. This number is equivalent to roughly 30 million barrels of oil. Such an enormous potential needs to be analyzed and further examined. As a proper SWM approach, recycling can be done through composting as well as anaerobic digestion. Anaerobic digestion can also recover energy as methane is a by product of this process. Energy can even be recovered by seperating the organic and inorganic components of waste and inducing the process of pelletization to yield refuse derived fuel (RDF). For disposal of wastes, authors suggest sanitary landfill, but

this is the least accepteable method of waste handling. All the mentioned techniques are briefly explained below:

Composting

Composting is a method of recycling waste defined as the biological process of decomposing organic waste materials such as food wastes, leaves, etc. into a useful humus substance with the help of micro-organisms like fungi and bacteria [10]. The different types of composting are aerobic composting, anaerobic composting and vermicomposting [11]. Vermicomposting is the healthiest form of composting as it reduces the need for mechanical operations and the yield is homogenous [12]. However, integrating traditional composting and vermicomposting enhances the overall process and improves the product qualities [13].

Anaerobic Digestion

Also known as biomethanation, anaerobic digestion is the process of breaking down organic matter by microorganisms in the absence of oxygen to produce digestate and biogas which mainly consists of methane and carbon dioxide [14]. This emitted carbon dioxide is called biogenic CO2 and is counted as carbon neutral, and its sequestration is cleaner in comparison to fossil carbon and contributes in carbon offset [15]. A step of anaerobic digestion is methanogenesis, which yields methane. Methane is a good fuel as it has a high calorific value of 55.6 MJ/kg [16]. Hence anaerobic digestion can also be used to recover energy from organic wastes in order to produce electricity.

Pelletization

The combustible and inorganic components of waste are pelletized after going through the processes of segregation, crushing and solidification [17]. These pellets can be used as fuel called refuse-derived fuel briquette (RDF). Energy recovery as RDF is a preferred option for utilizing plastic wastes when their potential recycling is not possible [18]. Generation of RDF is cheap, it has a high heating value (HHV) of around 10,000-15,000 kJ/kg and also has an efficiency of recovering 25% of energy [19]. The calorific value of biomass briquettes is nearly 4130 kcal kg-1 [20].

Sanitary Landfill

Sanitary landfill is a method of disposing waste on land without creating nuisance or hazards to public health and safety, by utilizing the principles of engineering to confine it to the smallest practical area, to reduce it to the smallest practical volume and to cover it with a layer of earth at the end of the operation [21]. There are three diffent types of landfills-mechanized, semi-mechanized and manual sanitary landfill [22].

BARRIERS TO SUCCESSFUL SOLID WASTE MANAGEMENT IMPLEMENTATION IN SAUDI ARABIA

There are several barriers and challenges that need to be acknowledged and adressed in order to implement ISWM in the Kingdom of Saudi Arabia and align it on the path to zero waste. To begin with, the government must encourage Public Private Partnerships (PPP) in order to assist the municipality with waste collection and transportation. Additionally, the most important factor affecting the proper execution of SWM is the lack of segregation of waste. Segregation is the key and the primary step for the success of SWM and there is no alternative to source segregation [23]. Waste recovery technologies are unable to work with unsegregated waste. Segregation can be facilitated by spreading awareness among the population of Saudi Arabia regarding SWM. Media and government play a vital role in spreading awareness. Awareness in the masses will result in active public participation. The government also needs to strictly implement the laws provided by the Presidency of Meteorology and Environment to facilitate this motion and to ensure the proper segregation, collection and transportation of waste is carried out by the public and the authorities. A few suggestions as to how these issues can be addressed and improved is provided below:

Public-Private Partnerships (PPP)

In most of the developing countries, waste is actively handled by both, the public and private sector. However, in Saudi Arabia, the private sector is secluded from this opportunity and the municipalities of the cities deal with MSW. Municipalities and city corporations fall under the category of public sector and they possess several limitations. For instance, this sector suffers from inadequate supervision, low productivity and unsatisfactory equipments. Private industries avoid indulging themselves in waste handling as it has no to low profit margins.

Outside the frame of the formal public sector exists a vibrant informal private sector. The term ‘informal’ sector is used to refer to the economic activities which have the following characteristics: non-permanence and casualness, outside the scope of existing company law or government regulations, carried on in small-scale by less capitalised establishments mostly relying on household labour [24]. Non-Governmental Organizations (NGOs) are a perfect example of PPP. Their motives are to achieve social goals rather than making profit. NGOs can hire waste pickers that provide door-to-door collection service for a fixed monthly fee per household. The governemnt or municipality can in return provide annual grants in order to promote financial resilience of the NGOs and continue to allow them offer improved, efficient and sustainable waste collection, handling and transportation. The establishment of micro-enterprises can also benefit the SWM market of the Kingdom. These enterprises can include recycling industries or service delivery industries. As these enterprises are profit oriented, they have better potential for better productivity.

Segregation of Waste

As mentioned before, segregation of waste or source separation is the key and the starting point of ISWM. Segregation of waste in the Kingdom of Saudi Arabia can be carried out in two ways. Waste pickers can collect from each house and segregate waste daily. This method is time consuming but efficient at the same time. The segregated waste can be transported accordingly to recylcing units, energy recovery stations or landfills.

The second method proposed by the authors is the installation of different colored bins for different kind of

wastes. The authors suggest four kinds of bins- green for organic and food wastes, white for plastic wastes, black for metal and glass wastes, red for paper, cartons and textile wastes. Every household should segregate waste themselves and dispose off according to the property of the waste. This method is easier to implement, is cost effective and is less time consuming. However, it is less efficient and requires constant monitoring by the PPP or the municipality to ensure whether the wastes are disposed in the correct way.

Spreading Awareness

Public participation is vital for the success of SWM. This participation is not possible without spreading awareness and making the people understand the benefits and hazards or different waste disposal techniques. Media and education are the most important aspects in spreading awareness amongst the masses. Children must be taught about the preservation and protection of the environment from a young age and motivated to work for the welfare of the society through government initiated environmental campaigns. Advertisement boards alongside the roads can also be used to spread awareness. Ads on social networking websites regarding SWM can also be used as they will be seen by the masses. The more the awareness, the better the SWM techniques can be implemented in the Kingdom.

Governmental Policies and Strategies

The government needs to actively participate in the implementation and advancement of SWM in order to make it a success. They should monitor the public and the private sector industries and ensure they follow the General Environmental Regulations and Rules for Implementation provided by the Kingdom's Presidency of Meteorology and Environment. They must make necessary amendments to the document and execute it strictly. The government must also conduct an annual waste management survey and build a comprehensive, transparent database for the population to witness. This database should include the amount of waste generated and the percentage of it being recycled, recovered or disposed. The data can be further divided into provinces, cities and even localities for broader understanding. Such a database will be beneficial for the government or municipality to develop strategies, plans and policies for the future.

Institutional Framework for ISWM in Saudi Arabia

Based on the ideas presented in this paper, a framework has been designed for ISWM in the Kingdom of Saudi Arabia by the authors:

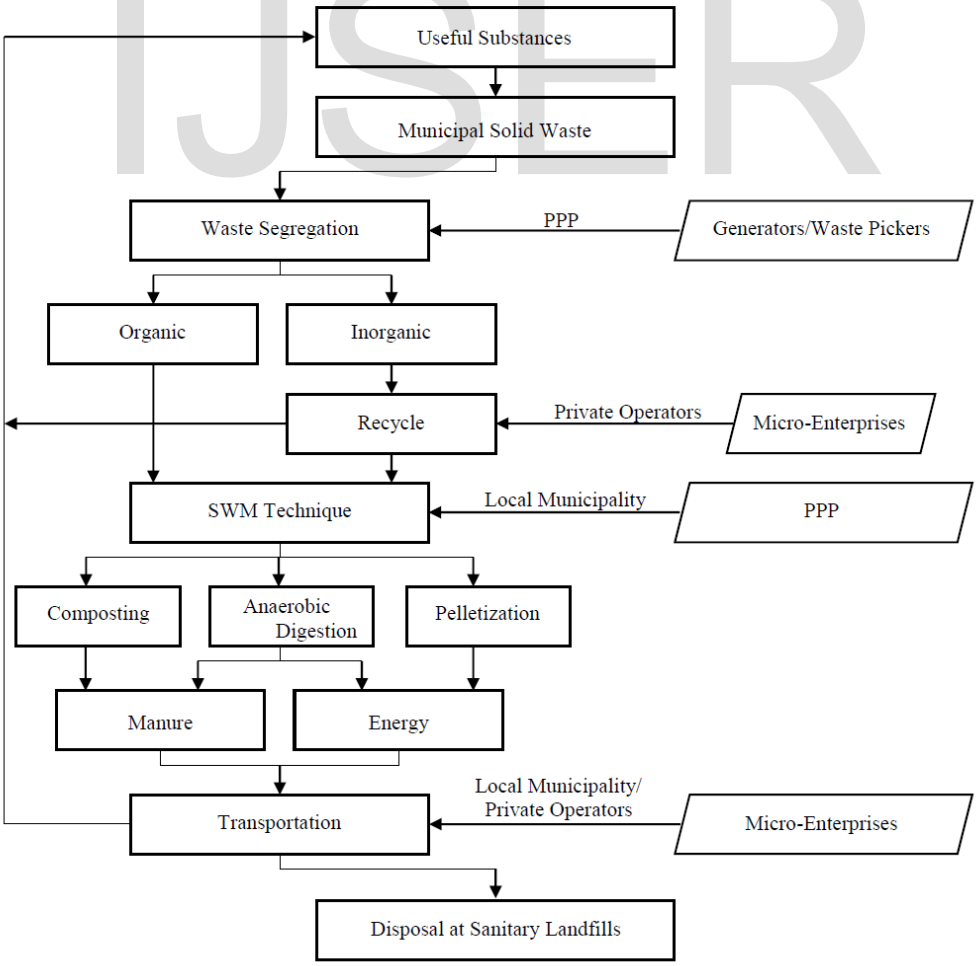

Figure 2: Flowchart of the Institutional Framework for ISWM

Conclusion

The SWM sector has been neglected in the Kingdom of Saudi Arabia for a long time. Currently, majority of the Kingdom's population is unaware of the hazards of waste disposal and the benefits of proper waste management. However, a lot is changing in Saudi Arabia since the initiation of Vision 2030. The Renewable Energy Project Development Office demands an energy generation of 3 GW from wastes by the year 2030. This capacity of generation is difficult to achieve without the implementation of improved SWM techniques in the Kingdom. Improving the waste management system requires spreading awareness amongst the people of the Kingdom as they are the most important role players in this system. Segregation and source separation of waste is the first step in ISWM scheme. Involving the people through NGOs and PPPs is another factor that can improve SWM. The government must also improve their framework and legislation regarding the environment and waste management. The government also plays a crucial role in educating its citizens and involving them in this sector. They must be motivated such that their primary motive is to reduce waste generation, just like waste hierarchy presented in Figure 1. As quoted by Albert Einstein, "a clever person solves a problem. A wise person avoids it".

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