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Research article

Estimating the Energy Recovery Potential from Municipal Solid Waste in Ha'il Region (Kingdom of Saudi Arabia)

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Keywords: Waste-to-energy (WTE), Energy recovery (ER), Municipal solid waste (MSW), Solid waste management (SWM), Energy Recovery Potential (ERP), Kingdom of Saudi Arabia (KSA)

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In the Kingdom of Saudi Arabia (KSA), the need of an agile solid waste management (SWM) system is vital to control safely the rapid growth of its municipal solid waste (MSW) with minimal environment toll. Further, the domestic energy production in KSA is thriving and putting a tremendous pressure on its reserves of fossil oil. Waste-to-energy (WTE) plants provides an excellent opportunity, even if MSW mitigation and energy production are usually considered separately. Energy recovery (ER) from waste is not a new field of study; however, its implementation remains a challenge in KSA. Although there is abundance of useful waste in the urban markets, practices aiming at WTE conversion are still negligible. In the KSA, so-called green markets are abundant with renewable energy potential, yet the practical implementation of this potential is missing. This work aims to present the worldwide SWM methods, the classification and the characteristics of solid waste in KSA especially in Ha'il region. In addition, the present research deals with the evaluation of waste generation in Ha'il region for the ER purpose and depicts that WTE is not only environmentally friendly but also financially rewarding. Data were collected regarding solid waste in Ha'il region and the calculations of ER potential from solid waste were conducted. The obtained results show that ER from solid waste can save energy consumption in Ha'il region; the saving factor was estimated to be 18%.

I. INTRODUCTION

Kingdom of Saudi Arabia (KSA) has been witnessing rapid industrialization, high population growth rate, and fasturbanization that have resulted in increased levels of pollution and waste. Solid waste management (SWM) is becoming a big challenge for the government and local bodies. With a population of around 29 million, KSA generates more than 15 million tons of solid waste per year. The per capita waste generation is estimated at 1.5 to 1.8 kg per person per day. More than 75 percent of the population is concentrated in urban areas, which make it necessary for the government to initiate measures to improve recycling and SWM scenario in the country. Solid waste generation in the three largest cities (Riyadh, Jeddah and Dammam) exceeds 6 million tons per annum, which indicates the enormity of the problem faced by civic bodies.[1–3]

In KSA, the garbage is collected from individual or community bins and disposed in landfills or dumpsites. KSA's SWM system is characterized by a lack of waste disposal facilities. Most of the landfills are expected to reach their capacities within the next 10 years. Although they are getting increased attention, recycling and energy recovery (ER)remain at an early stage. The recycling rate, mostly manual and labor intensive, ranges from 10% to 15%; this is mainly due to the presence of informal sector that extracts paper, metals, and plastics from municipal waste.[4,5]

Composting is gaining increased interest in KSA due to the high organic content (around 40%) of municipal solid waste (MSW). Efforts are also underway to deploy waste-to-energy (WTE) technologies, and all activities are coordinated and financed by the government.[5–8]

The government is aware of the critical demand for SWM solutions, and is investing heavily in solving this problem; the 2011 national budget allocated SR 29 billion for the municipal services sector, which includes water drainage and waste disposal. It is making concerted efforts to improve recycling and waste disposal activities.

However, more efforts stay required to improve SWM scenario in the country. A methodical introduction of modern SWM techniques like material recovery facilities, WTE systems, and recycling infrastructure can significantly im-

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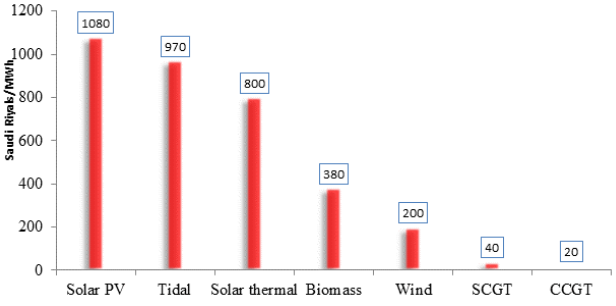

Figure 1. Comparison of renewable energy costs in KSA.

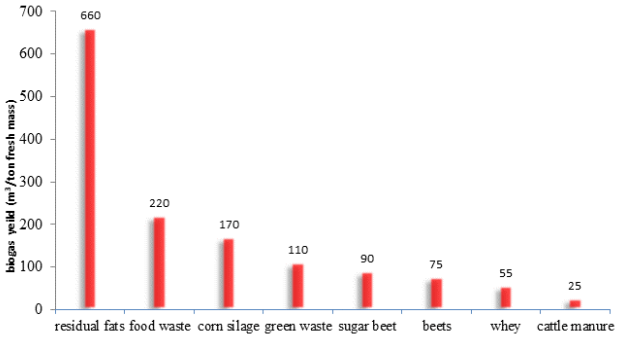

Figure 2. Biogas production from various substances.

prove SWM scenario and can generate good business opportunities.

Strong legislations, financial support, public awareness, modern technologies and stakeholders' participation are crucial in transforming KSA into a 'green' country. Therefore, a strong political commitment and unflinching public support aremandatory for implementing a sustainable SWM strategy in the country.[9,10]

II. STATUS OF THE SOLID WASTE MANAGEMENT (SWM)

The KSA is the largest country in the Arabian Peninsula. KSA's population is 27 million, including 8.4 million foreign residents, and its capital is Riyadh City. KSA's geography is diverse, with forests, grasslands, mountain ranges and deserts. Ḥa'il Province is one of the 13 provinces of the KSA. It is the eighth-largest province by area at 103,887 km^2 and the ninth-largest by population, with the population in 2020 being 750,147. The province accounts for roughly 2% of the population of the country.

In the KSA, the huge amount of waste is mainly generated in the form of MSW, industrial organic waste, and sewage. It has been estimated that the total biomass energy potential in the KSA is 3.0 million tones; it stands fourth in the Arab world after Morocco, Egypt and Sudan. The solid waste generation is increasing rapidly; it is much higher comparatively with some industrialized and emerging Arab countries. This could be due to tourism to the Islam's holiest places in the kingdom, rapid urbanization, and population density. Indeed, KSA's per capita generation is 1.75 kg of waste per day, compared to other countries in the region that have less than one.[9–11]

The diversion of generated organic waste into biogas and bio-fertilizer will ensure that it is treated in such a way that it becomes a useful product instead of a harmful one to the environment and can add to the revenues of the kingdom in the form of clean energy (Figure 1 and Figure 2).

The recovery of energy from MSW offers a few additional benefits as follows[12–14]:

- The total quantity of waste may be reduced by nearly 60% to over 90%, depending on the waste composition and the adopted technology.
- Reduce of the demand for land, which is already scarce in cities, for landfilling.
- Reduce of the cost of transportation of waste to far-away landfill sites.
- Reduction in the environmental pollution.

The WTE technologies are able to convert the energy content of different types of waste into various forms of valuable energy. Power can be produced and distributed through local and national grid systems. Heat can be generated and utilized for specific thermodynamic processes. As of today, the most common developed technology is in the form of Combined Heat and Power plants, which treat MSW and possibly a combination of industrial, clinical and hazardous waste, depending on the system settings through an incineration process.[14,15] Figure 3 represents summary of methods used for ER from solid waste.

III. CLASSIFICATION AND CHARACTERIZATION OF SOLID WASTE

In general, the decomposable materials in refuse are isolated from glass, metal, and other inorganic items through sorting and separating operations. These are carried out mechanically, using differences in such physical characteristics of the refuse as size, density, and magnetic properties. Ha'il region has many types of solid waste. The main types of solid waste in Ha'il region include the following:

A. HOUSEHOLD WASTE

Household waste can be defined as solid waste comprising garbage and rubbish (bottles, cans, clothing, compost, disposables, food packaging, food scraps, newspapers and magazines, and yard trimmings) that originate from private homes or apartments. It may also contain household hazardous waste. The statistics obtained from Ha'il municipality show that the value of household wastes in Ha'il City is 300.000 kg every month, but all the wastes are burnt every day.[9–12] The approximate classification of MSW in KSA is represented in Figure 4.

B. INDUSTRIAL SOLID WASTE

Industrial waste is produced by industrial activity, which includes any material that is rendered useless during a manufacturing process such as that of factories, industries, mills,

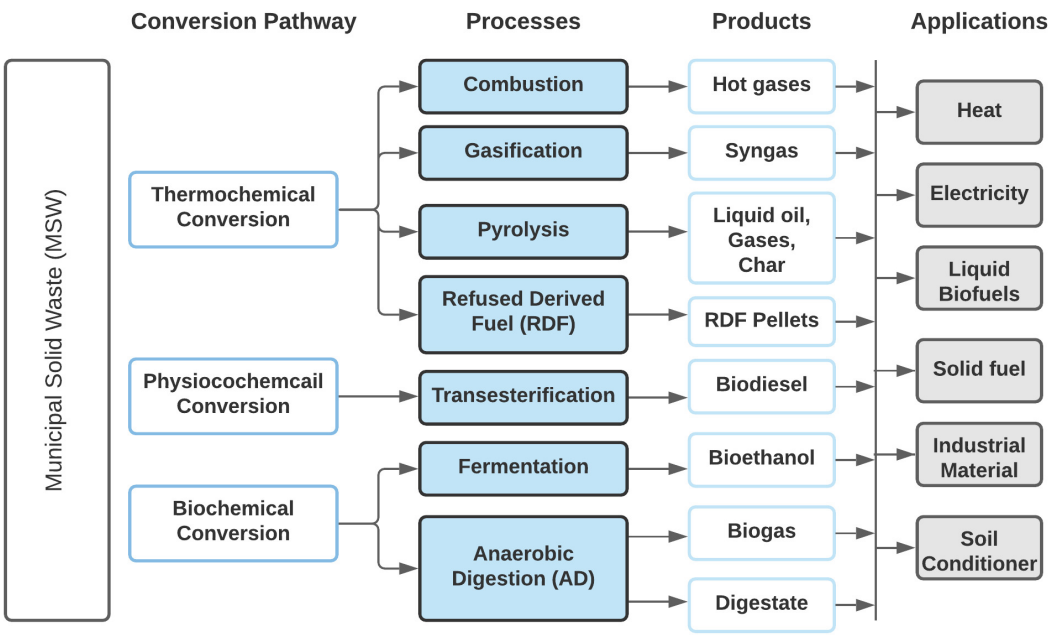

Figure 3. Waste-to-energy (WTE) technologies based on their conversion process.

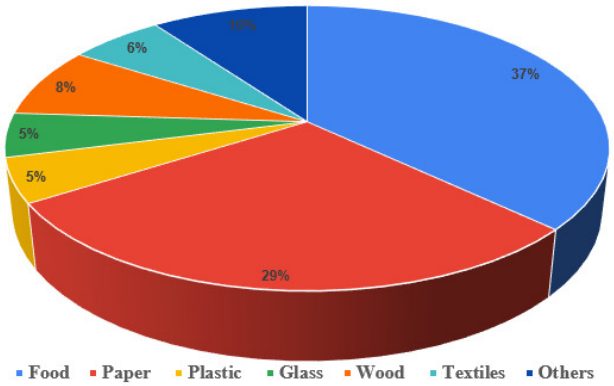

Figure 4. Composition of the Municipal Solid Waste (MSW) in KSA.[3,4]

and mining operations. Some examples of industrial wastes are chemical solvents, paints, sandpaper, paper products, industrial by-products, metals, and radioactive wastes. Industrial solid waste may include waste resulting from the following manufacturing processes: electric power generation, fertilizer/agricultural chemicals, food and related products/by-products, inorganic chemicals, iron and steel manufacturing, leather and leather products, nonferrous metals manufacturing/foundries, organic chemicals, plastics and resins manufacturing, pulp and paper industry, rubber and transportation equipment, and water treatment. According to the statistic of 2016, the solid industrial wastes in Ajafar Company is 810 tone/year.[12,13]

C. FARM ANIMAL SOLID WASTE

Farm animal waste comes from livestock, poultry, and dairy production and it can also be the waste by-product from inland fish farm aquaculture. It can contain organic matter, disease-causing organisms, bacteria, and nitrates, which can contaminate drinking water and cause human illnesses. During this work, many farms in Ha'il City have been visited in order to gather statistics about the animal wealth in Ha'il and the number of animals in the farms of Ha'il City. The total number of sheep is (3089281), the total number of camels is (189060), the total number of cows is (11368), and the number of chickens is (30539). The statistics about the animal's wastes in the farms, show that the total number of animals waste for sheep, cows, camels, and chickens is (307325.179 tons/year).[14–16]

D. AGRICULTURE SOLID WASTE

Agricultural waste must have been produced on a farm, it can be both natural and artificial waste. A large quantity of animal waste, generated by concentrated animal feeding operations and disposal of the waste, has been a major problem. The statistics about the wastes of the agriculture and farms in Ha'il, show that the approximate total waste of agricultural activity in Ha'il region was estimated to be 25000 tone/year.[16,17]

IV. ENERGY RECOVERY POTENTIAL (ERP) FROM SOLID WASTE

Based on the literature survey of various methods of ER from solid waste in the World, and taking into account the classification of solid waste in Ha'il region, The incineration

Table I. Municipal Solid Waste (MSW) energy content in the KSA.

Material	Waste composition (%)	Energy (btu/lb)	LHV of waste (kWhr/kg)	LHV of material (kWhr/kg)
Paper	28.5	15820	4.39	1.21
Plastic	5.2	32570	9.05	0.46
Glass	4.6	0	0	0
Wood	8	16983	4.73	0.24
Textiles	6.4	18844	5.2	0.22
Organic	37	5583	1.55	0.1
Others	10.3	12097	3.36	0.28
Total energy for mass burn with recycling scenario (kWhr/kg)				0.3772
Total energy content of mass burn scenario (kWhr/kg)				2.5121

Table II. types and rates of solid produced waste in Ha'il region.

	Type of Solid	Amount of solid waste (tone/year)	Amount of solid waste (tone/day)
1	Municipal	**300000**	**821.92**
	• Paper	**50000**	**136.98**
	• Food	**100000**	**273.97**
	• Plastic	**75000**	**205.47**
	• wood	**75000**	**205.47**
2	Agriculture	**25000**	**68.49**
3	Animal	**307325**	**841.98**
4	Industrial	**810**	**2.22**

process is selected as a prospective method of ER from solid waste in Ha'il region.

A. ENERGY RECOVERY (ER) BY INCINERATION FOR ELECTRICITY PRODUCTION

The Energy Recovery Potential (ERP) (GWhr/day), Power Generation Potential (in MW) and Net Power Generation Potential (in MW) are evaluated by the following equations.[7–11]

$$ERP\left(\frac{GWhr}{day}\right) = \frac{Dry\ waste\left(\frac{tones}{day}\right)}{1000} \times LHV\ of\ waste\left(\frac{kWhr}{kg}\right) \quad (1)$$

$$Power\ Generation\ Potential\ (MW) = \frac{(Dry\ waste\left(\frac{kg}{days}\right) \times LHV\ of\ waste\left(\frac{kW}{kg}\right))}{1000} \quad (2)$$

$$Net\ Power\ Generartion\ Potential\ (MW) = \eta \times Power\ Generation\ Potential \quad (3)$$

where:η is the efficiency of the process taken 25% and 18% for incineration and refused derived fuel, respectively.

In order to apply these equations, heat values of different solid waste are to be used in addition to the rate of solid waste production in Ha'il region. Table I and Table II illustrate the heat values and the data regarding the types and rates of solid waste produced in Ha'il region.

B. ENERGY RECOVERY POTENTIAL (ERP) CALCULATION

The calculation the ER from solid waste in Ha'il is performed using the equations from 1 to 3[7–11]:

$$ERP\left(\frac{GWhr}{day}\right) = \frac{Dry\ waste\left(\frac{tones}{day}\right)}{1000} \times LHV\ of\ waste\left(\frac{kWhr}{kg}\right)$$

For MSW:

1. *Paper*

$$ERP\left(\frac{GWhr}{day}\right) = \frac{136.98\left(\frac{tones}{day}\right)}{1000} \times 4.39\ LHV\left(\frac{kWhr}{kg}\right) = 0.601(\frac{GW \cdot hr}{day})$$

2. *Plasic*

$$ERP\left(\frac{GWhr}{day}\right) = \frac{205.47\left(\frac{tones}{day}\right)}{1000} \times 9.09\ LHV\left(\frac{kWhr}{kg}\right) = 1.87\frac{GW \cdot hr}{day})$$

3. *Food*

Table III. Results of Energy Recovery Potential (ERP)

Type of waste	Amount of solid waste (ton/day)	ERP (GWhr/ day)
Municipal	821.92	3.86
Agricultural	68.49	0.94
Animal	841.99	1.30
Industrial	2.22	0.01
Total	842879.43	5.26

$$ERP\left(\frac{GWhr}{day}\right) = \frac{273.97\left(\frac{tones}{day}\right)}{1000} \times 1.55\ LHV\left(\frac{kWhr}{kg}\right) = 0.42\ (\frac{GW\cdot hr}{day})$$

4. *Wood*

$$ERP\left(\frac{GWhr}{day}\right) = \frac{205.47\left(\frac{tones}{day}\right)}{1000} \times 4.73\ LHV\left(\frac{kWhr}{kg}\right) = 0.971\ (\frac{GW\cdot hr}{day})$$

For Agricultural:

$$ERP\left(\frac{GWhr}{day}\right) = \frac{68.49\left(\frac{tones}{day}\right)}{1000} \times 1.55\ LHV\left(\frac{kWhr}{kg}\right) = 0.094(\frac{GW\cdot hr}{day})$$

For Animal Waste

$$ERP\left(\frac{GWhr}{day}\right) = \frac{841.9868\left(\frac{tones}{day}\right)}{1000} \times 1.55\ LHV\left(\frac{kWhr}{kg}\right) = 1.30(\frac{GW\cdot hr}{day})$$

For industrial:

$$ERP\left(\frac{GWhr}{day}\right) = \frac{2.219\left(\frac{tones}{day}\right)}{1000} \times 0.36\ LHV\left(\frac{kWhr}{kg}\right) = 0.0075(\frac{GW\cdot hr}{day})$$

The results of our calculation of ER from different types of solid waste in Ha'il region by incineration methods are summarized in Table III.

V. ENERGY SAVING

The electricity consumption in KSA per capita was considered equal to:

$$E_{con.(Hail)/capita} = 55917 \times 10^6\ W\ /\ 28 \times 10^6 = 1.997\ kW/capita$$

The consumption of electricity in Ha'il region, assuming that the total population in Ha'il region equal to 600000, is:

$$E_{con.(Ha'il)} = 1.997\left(\frac{kW}{capita}\right) \times 600000\ (capita) = 1.1982\ GW$$

Percentage of saving energy in Ha'il region by converting solid WTE:

$$E_s = 100\times \left(\frac{Electricity\ from\ solid\ waste\ in\ Ha'il\ area}{Consumption\ of\ electricity\ in\ Ha'il\ area}\right) \quad (4)$$

$$E_s(\%) = \left(\frac{ERP}{E_{con.(Ha'il)}}\right) \times 100$$

$$E_s = \left(\frac{\frac{5.26}{24}GW}{1.1982\ GW}\right) \times 100 = 18.4\%$$

VI. CONCLUSION

Municipal solid waste (MSW) management has been given serious attention by the authorities of KSA. This study focuses on MSW that predominantly contains food, paper, and plastic waste. However, improper handling of MSW causes several environmental and human health issues. Therefore, it is necessary to review the current practices and future opportunities that have been adopted for solid waste collection, handling, and disposal. Considering the current scenario, this study proposed a reversal approach for MSW management. This study considered that MSW generated in KSA has great potential to be converted into wealth. The main conclusions and recommendations regarding future research are:

- The abundant production of MSW increases the demand for landfills, which occupy huge areas of land and create environmental problems.
- Solid waste is a problem facing modern societies and needs to be solved.
- Data were collected regarding to solid waste in Ha'il region.
- Calculations of ERP from solid wastes in Ha'il region were conducted and results were obtained in this work.
- ER from solid waste can save energy consumption in Ha'il region. The saving factor was estimated to be 18%.

Hence, a reversal approach has been proposed for the minimization of MSW at the source. This approach could reduce the cost of segregation and transport. Besides that, this study suggests the following points:

- Complete Life Cycle Assessment for MSW in (KSA and especially Ha'il) are basically needed.
- Further investigations are recommended to compare among the different scenarios based on financial, social, technical and environmental criteria.
- The socio-economic studies shall consider WTE production cost, recycling value, land saving, job creation, and human capacity building opportunities.

- Technical studies shall be focused on determining the optimum WTE technology to be implemented in Ha'il region and in the KSA in general.

The diversion of solid waste into biogas and bio-fertilizer will ensure that it is treated in such a way that it becomes a useful product instead of harmful one. Furthermore, as the policy makers and planners in renewable energy sector have intended for KSA to be "country of sustainable energy" as well, hence they are needed to give special attention toward the largest KSA's green market and should invest more to implement this plan.

NOMENCLATURE AND UNITS

WTE: Waste-to-energy
ER: Energy recovery
MSW: Municipal solid waste
SWM: Solid waste management
ERP: Energy Recovery Potential (GWhr/day)
KSA: Kingdom of Saudi Arabia
η: The efficiency of the process (%)
LHV: Lower Heating Values (kWhr/kg)
E_s: Saving energy (%)
E_{con}: Electricity consumption

DISCLOSURE STATEMENT

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Dr. Noureddine Elboughdiri is an associate professor and currently the head of the Chemical Engineering Department, College of Engineering, Ha'il University(KSA). He received his B.Sc., Master, and Ph. D. degree in the field of Chemical Engineering from the National School of Engineers Gabes, University of Gabes, Tunisia. He joined the Central Laboratory for Analysis and Testing LCAE (Tunisia) in 2004 and SGS Group (Tunisia) in 2008 and held different teaching and administrative positions including optimization methods, statistical analysis, academic accreditation (NCAAA/ABET) and industrial accreditation (ISO 17025/ISO 9001) to provide reliable solutions to many of the contemporary problems facing the chemical industries.

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