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Waste to Energy: A Case Study of Madinah City

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Abstract

The concept of energy from waste is getting popular nowadays across the globe, as being capable of producing multi fuels and value-added products from different fractions of municipal solid waste (MSW). The energy recovery technologies under this concept are anaerobic digestion (AD), pyrolysis, transesterification, refuse derived fuel (RDF) and incineration. This concept is very relevant to implementation in countries like Saudi Arabia, who wants to cut their dependence on oil. Moreover, the waste to energy becomes the imperative need of the time because of new governmental policy 'Vision 2030' that firmly said to produce renewable energy from indigenous sources of waste, wind and solar and due to given situations of Hajj and Umrah with massive amounts of waste generation in a short period. This study focused on two waste to energy technologies, AD and pyrolysis for food (40% of MSW) and plastic (20% of MSW) waste streams respectively. The energy potential of 1409.63 and 5619.80 TJ can be produced if all of the food and plastic waste of the Madinah city are processed through AD and pyrolysis respectively. This is equivalent to 15.64 and 58.81 MW from biogas and pyrolytic oil respectively or total 74.45 MW of continuous electricity supply in Madinah city throughout the whole year. It has been estimated that the development of AD and pyrolysis technologies will also benefit the economy with net savings of around US $63.51 and US $53.45 million respectively, totaling to an annual benefit of US $116.96 million. Therefore, in Saudi Arabia and particularly in Holiest cities of Makkah and Madinah the benefits of waste to energy are several, including the development of renewable-energy, solving MSW problems, new businesses, and job creation and improving environmental and public health.

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1. Introduction

The growth trends of human population, urbanization and municipal waste generation (MSW) are increasing significantly worldwide [1]. This creates serious economic and environmental challenges, especially in developing countries [2]. The Kingdom of Saudi Arabia (KSA)'s population has been increasing at an average rate of 3.4% over last few years and is currently around 30 million. Moreover, millions of Muslims visit KSA from all over the world every year to perform Pilgrimage (Hajj) and Umrah [3-5]. The Hajj and Ramadhan periods, due to limited time and space conditions of these religious rituals, make special scenarios and require highly advanced and sophisticated plans and developments. It has been reported that around 15 million tons of MSW per year is produced in KSA, giving an average of 1.4 kg per capita per day. This amount has been estimated to increase up to 30 million tons by 2033 using the growth rates of current population and urbanization [1,3]. Apart from the waste generated by the local population, extra waste is generated due to millions of Hajj and Umrah visitors every year the Madinah city. The highest waste generation takes place in the closing ten days of the month of fasting (Ramadan) [6]. Currently, there is very limited formal recycling in KSA, and most of the MSW generated is disposed of in landfills or dumpsites without the recovery of energy and other value-added materials [7-9]. This can result in serious environmental issues including air, water, and soil pollution along with public health issues [10-12].

KSA has recently launched Vision 2030 with an ambition to diversify and strengthen the country's economy by a determination to become a global investment powerhouse [13]. Moreover, the Vision highlights the plan to reduce all types of waste and produce renewable energy from its indigenous sources such as the wind, solar, geothermal and waste [14]. The policy also emphasized on the development of an integrated solid waste management (ISWM) system to optimize the financial and environmental values of waste through recovery, reuse, and recycling [15-19]. This study was focused on generating fuel and energy from waste in line with Vision 2030. The potential of converting two largest MSW waste streams of food (40%) and plastic (20%) into fuels and energy through anaerobic digestion (AD) and pyrolysis technologies were studied. The amounts of biogas and pyrolytic oil from AD and pyrolysis respectively were estimated together with the potential of electricity generation from biogas and pyrolytic oil. Furthermore, the economic benefits of both technologies in terms of savings from landfill diversion and electricity production were estimated. The impact of Vision 2030 on MSW generation and its proposed solutions have also been discussed.

2. Methodology

2.1 MSW generation in Madinah city

The total MSW generated in Madinah city was estimated based on waste generated by the local population, by Hajj visitors and Umrah visitors in 2016. The Madinah population was estimated to be around 1.513 million in 2016 and 1.4 Kg/capita/day was used to calculate the total waste amounts. Around 1.8 million Hajj visitors were present during 2016 Hajj and 2.2 Kg/visitor/day was used together with each visitor staying on an average of 7 days in Madinah. Similarly, about 6 million Umrah visitors came to KSA throughout the 2016 year. It was assumed that each Umrah visitor stayed in Madinah for an average of 7 days and produced 2.05 Kg/visitor/day.

2.2 Fuel and energy generation and economic benefits estimations

The current study focused on conversion of two large waste streams, food (40%) and plastic (20%), into fuel and energy through AD and pyrolysis technologies respectively. The AD process converts the food waste into biogas with a typical value of 180.6 m^3 of biogas per 1 ton of food waste. The energy potential of biogas used was 22 MJ/m^3 or 6.1 KWh/m^3. The pyrolysis process converts the plastic waste into liquid oil, char, and gases. An average yield of 0.8 Kg of pyrolytic oil can be produced from 1 Kg of mixed plastic waste and average energy potential of pyrolytic oil was used as 39.6 MJ/Kg or 11 KWh/Kg [7]. The economic benefits were calculated based on savings from landfill diversion and electricity generation potential from both biogas and pyrolytic liquid oil. Landfill cost of US $152.6/ton and electricity value of US $0.085 /kWh were used in the calculations [4,16]. The waste collection, plant operational cost, and maintenance of 20% and 40% were deducted from the gross savings of both AD and pyrolysis technologies respectively. All the savings are presented in net savings that can be generated on an annual basis.

3. Results and Discussion

3.1 MSW generated in Madinah city in 2016

The amounts of MSW in Madinah city was estimated based on MSW generated by local population and by Hajj and Umrah visitors. The total amount of MSW, using 1.4 Kg/capita/day, by the local population was estimated to be around 773.14 thousand tons for the year 2016. Similarly, total amounts of MSW of around 27.72 and 86.10 thousand tons were generated in 2016, using 2.2 Kg/visitor/day and 2.05 Kg/visitor/day, by Hajj and Umrah visitors respectively. This equals to about 886.96 thousand tons of total MSW generated in Madinah city in 2016 [1-3,6]. The MSW amounts are estimated averaged values, and more detailed amounts and characterization of MSW in KSA is yet not well established in scientific literature. The two largest waste streams of food (40%) and plastic waste (20%) equal to about 354.79 and 177.39 thousand tons respectively.

3.2 Conversion of food waste into fuel and energy by AD

Figure 1 shows the flow diagram of waste to energy concept and its benefits. Both AD and pyrolysis technologies produce fuel, in the form of biogas and pyrolysis oil respectively, that can be used to produce heat, electricity, and use as transportation fuel after further cleaning and treatment. The diversion of both largest waste streams from landfill not only provide huge financial benefits but also saves land, help to reduce environmental pollution and improve public health. The AD process can convert the food waste into biogas which is an important fuel that can be used to generate electricity. It has been estimated that around 64.07 million m^3 of biogas can be produced if all the food waste of 354.79 thousand tons is treated in AD process. The biogas energy potential of 22 MJ/m^3 gives the total energy generation potential of 1409.63 TJ or 391,565 MWh per year. The efficiency of electricity generation plant from biogas was assumed to be 35%. This means the plant can produce and deliver a total of 15.64 MW of continuous electricity supply in Madinah city throughout the whole year.

3.3 Conversion of plastic waste into fuel and energy by pyrolysis

The pyrolysis process can convert the plastic waste into pyrolytic oil that can be used as a fuel to generate electricity. It has been estimated that around 141.91 million Kg of pyrolytic oil can be produced if pyrolysis process treats all the plastic waste of 177.39 thousand tons. The pyrolytic oil energy potential of 39.6 MJ/Kg gives the total energy generation potential of 5619.80 TJ or 1,561,054 MWh per year. The efficiency of electricity generation plant from pyrolytic oil was assumed to be 33%. This means the plant can produce and deliver a total of 58.81 MW of continuous electricity supply in Madinah city throughout the whole year. So overall, both the AD and pyrolysis technologies, can generate a total of 74.45 MW of continuous electricity supply in Madinah city throughout the whole year. The total energy potential of 5619.80 TJ from pyrolytic oil is much higher than the total energy potential of 1409.63 TJ from biogas, even though the plastic waste stream is half (20%) of food waste (40%) stream. This is because the energy potential of pyrolytic oil is around 39.6 MJ/Kg, which is much higher than the energy potential of biogas of 22 MJ/m^3.

3.4 Economic benefits of waste to energy in Madinah city

The economic benefits of treating both food and plastic waste streams by AD and pyrolysis respectively are shown in figure 2. The savings were calculated based on savings from landfill diversion and electricity generation potential from both biogas and pyrolytic liquid oil. Landfill cost of US $152.6/ton and electricity value of US $0.085 /kWh were used in the calculations [4,16]. It can be seen in figure 2 that net savings of US $54.15 and US $9.36 (total US

$63.51) million can be generated from landfill diversion and electricity production respectively if AD technology treats food waste stream. Similarly, net savings of US $27.08 and US $26.38 (total US $53.45) million can be generated from landfill diversion and electricity production respectively if pyrolysis technology treats the plastic waste stream. This means there is a potential of generating total net savings of US $116.96 million per year by treating food and plastic waste streams through AD and pyrolysis respectively.

The current study highlighted the possibilities of diverting only two large waste streams, food (40%) and plastic (20%), into fuel and energy through AD and pyrolysis technologies respectively. Apart from the economic and environmental benefits stated above, there are other benefits that could be achieved through waste to energy concept in KSA including creation of jobs, reducing the country's dependency on crude oil, diversifying the economy from mainly oil based into circular economy, creating more public awareness and health improvement, saving millions of riyals by avoiding the health issues due to poor environment and so on. The authors have proposed various other solutions to waste issues in KSA and other developing countries including generation of energy from various sources and other value-added products, utilizing indigenous resources like natural zeolites as well as developing novel catalysts [17,20-23].

3.5 Impact of Vision 2030 on pilgrims and waste generation

Vision 2030 has been launched recently by KSA government, which highlights the key strategies to boost the country's economy as well as setting targets to improving all the major infrastructure, education, environment and public health sectors. The need and importance of an advanced integrated waste management system are also documented. KSA also wants to cut on its dependence on fossil fuels, and therefore special emphasis will be put on producing renewable energy from indigenous sources such as waste, the wind and solar. On the other hand, the total number of Hajj and Umrah pilgrims will be increased significantly from around 8 million up to 30 million by 2030.

Figure 1. Flow diagram for waste to energy concept and its benefits

This would also significantly increase the savings from fuel and energy produced by increased MSW. All these policies and targets favor our proposal of converting up to 60% of MSW, the two main streams of food (40%) and plastic (20%), into fuel and energy by AD and pyrolysis technologies respectively. Despite all the government support, favored policies and benefits of the proposed solution, many scenarios must be considered carefully before taking the decision. Increasing the number of Hajj and Umrah pilgrims from around 8 million per year to 30 million per year by up to 2030 will increase the total MSW generated by visitors by 4 times. The Hajj and Ramadhan periods would create special scenarios, given the massive amounts of waste generation in a short period of time and limited space. Other considerations including visitors' health and safety, transportation, food, accommodation and other necessities would also require highly advanced and sophisticated plans and developments.

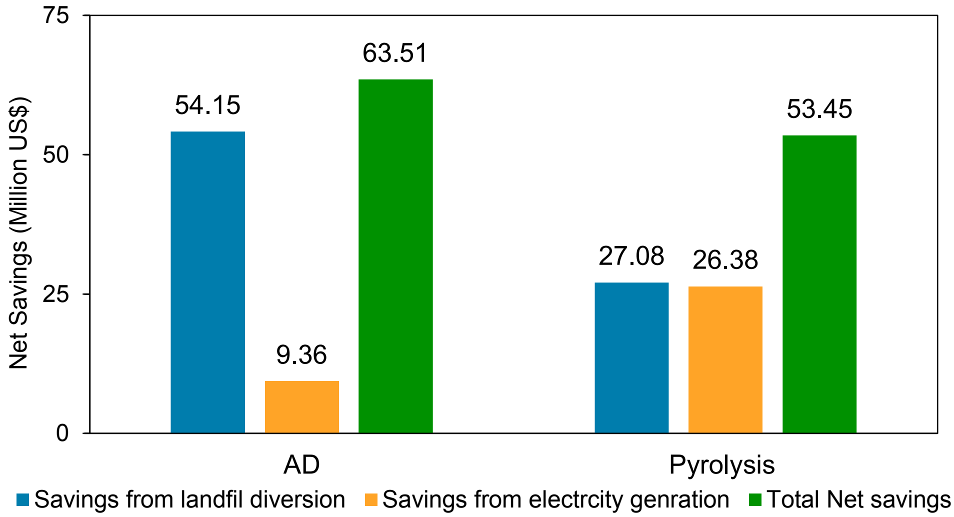

Figure 2. Economic benefits of adopting AD and pyrolysis technologies for treatment of food and plastic waste streams in Madinah city

3.6 Practical implications of this study

There are very few studies reported on MSW generation and its impact on the environment and human health in KSA. The solution proposed in this study, to divert two main waste streams of MSW, food, and plastic, need further detailed studies including the technical, economic and environmental assessments. Moreover, other waste streams also need to be diverted from landfill to recover materials and energy through appropriate technologies. The impact of huge increase in the number of Hajj and Umrah pilgrims, according to Vision 2030, also need to be carefully assessed in more detail. It would be useful and important to conduct detailed LCA studies of any proposed solutions to treat the waste in KSA to help the policy makers to take the right decision. Overall, there is a huge scope of work and improvements to develop advanced ISWM in order to not only improve the environment and public health but also to boost the economy.

4. Conclusions

The case of MSW generated in Madinah city in 2016 by the local population and millions of Hajj and Umrah pilgrims has been studied. It has been estimated that total 886.96 thousand tons of MSW were produced in Madinah city in 2016. The two largest waste streams of food (40%) and plastic (20%) waste accounted for 354.79 and 177.39 thousand tons respectively. It has been proposed that the food and plastic waste streams can be converted into fuel and energy through AD and pyrolysis technologies respectively. It was estimated that total energy potential of 1409.63 and 5619.80 TJ could be produced if all of the food and plastic waste of the Madinah city are processed through AD and pyrolysis respectively. This is equivalent to 15.64 and 58.81 MW from biogas and pyrolytic oil respectively or total 74.45 MW of continuous electricity supply in Madinah city throughout the whole year. Furthermore, It has been estimated that the development of AD and pyrolysis technologies will also benefit the economy with net savings of around US $63.51 and US $53.45 million respectively, totaling to an annual benefit of US $116.96 million.

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