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Developing waste biorefinery in Makkah: A way forward to convert urban waste into renewable energy

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HIGHLIGHTS

- Waste biorefinery is proposed to convert waste in Makkah into renewable energy.
- Total revenue of 758 million SAR can be achieved from waste biorefinery.
- 1.95 million barrels of oil and 11.2 million MCF of natural gas can be saved.
- Reduction in global warming potential of 1.15 million Mt.CO_2 eq. can be achieved.

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ABSTRACT

The city of Makkah in the Kingdom of Saudi Arabia (KSA) hosts millions of Muslim worshippers every year. As a consequence, the municipal solid waste (MSW) quantities become enormous. City landfills receive about 2.4 thousand tons of MSW every day, whilst during the months of fasting (Ramadan) and Pilgrimage (Hajj), these quantities become 3.1 and 4.6 thousand tons per day respectively. Currently, there is no waste-based biorefinery or waste-to-energy (WTE) facility existing in KSA to treat different fractions of MSW as a source of renewable energy production and a solution to landfill waste problems. Therefore, the waste-based biorefinery, if developed in Makkah city, including WTE technologies such as anaerobic digestion (AD), transesterification, pyrolysis and refuse derived fuel (RDF) can be able to treat around 87.8% of the total MSW. The remaining 12.2% of MSW fraction can be recycled. The waste-based biorefinery, along with the recycling approach, can generate savings of about 87.6 million Saudi Arabian Riyal (SAR) from carbon credits. Similarly, a total net revenue of 758 million SAR can be generated from landfill diversion (530.4 million SAR) and electricity generation (288.5 million SAR). Moreover, 1.95 million barrels of oil and 11.2 million MCF of natural gas can be saved with a cost savings of 485.5 million SAR. Collectively, the waste-based biorefinery and recycling can reduce the global warming potential (GWP) of 1.15 million Mt.CO_2 eq.

1. Introduction

Muslim Pilgrimage to the Kingdom of Saudi Arabia (KSA) is one of the oldest and largest religious gatherings in the world [1]. Millions of Muslims from all over the world gather every year in KSA to perform worship at Al-Haram (Holy Mosques in Makkah and Medinah) and Al-Masha'ir (Mina, Arafat and Muzdalifah). The area of Al-Haram mosque in Makkah, including indoor and outdoor prayer space, is around 356,800 square meters. More than 2 million Muslims can worship at a time, especially during the Ramadan (9th month of the Islamic lunar calendar) and Hajj (12th month of the Islamic lunar calendar) [2]. The number of pilgrims visiting KSA has been significantly increased over the past few decades, with an annual rate of 1.15% from 1993–2014 (Fig. 1) due to expansion in the Holy Mosques, improved

Abbreviations: AD, anaerobic digestion; CH_4, methane; GHG, greenhouse gas; HHV, high heating value; IPPC, Intergovernmental Panel on Climate Change; KSA, Kingdom of Saudi Arabia; LCA, life cycle assessment; MPW, municipal plastic waste; MSW, municipal solid waste; OFMSW, organic fraction of municipal solid waste; RDF, refuse derived fuel; SAR, Saudi Arabian Riyal; VAP, value-added product; WTE, waste-to-energy.

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transportation and accommodation, increased security, and reduced overall cost and time [1]. In 2015, more than two million pilgrims from around 183 countries arrived in KSA to perform Hajj [4].

The waste collection and disposal is a challenging task for the authorities during Hajj and Ramadan seasons due to substantial increase in waste generation in a relatively short period of time; in addition to a composition of waste having high food and plastic waste fractions [2]. Most of this waste is disposed to the landfill sites [5], which are not equipped with leachate and landfill gas collection systems [2,6]. This results in soil and water contamination, along with the release of large amounts of greenhouse gas (GHG) emissions [7]. Therefore, to cope with the increasing amounts of waste generated by local population and the pilgrims in Makkah city, there is a need for a sustainable approach toward waste management. The new approach should effectively integrate a number of waste-to-energy (WTE) technologies and waste recycling within a waste-based biorefinery [8]. Moreover, the Government is seeking sustainable solutions for waste disposal, including its treatment and energy recovery as a viable source to bridge the ever increasing energy demand–supply gap of the country [7]. Makkah has the potential to be the leading city in KSA with regard to the development of waste-based biorefinery given the fact that city authorities are in continuous efforts to make the Hajj, a 'Green Hajj' every year with minimal pollution and maximum waste recycling [1].

A waste-based biorefinery in Makkah will generate enormous economic and environmental benefits from carbon credit, landfill diversion, renewable electricity generation and GHG emission savings along with managing the waste produced by local population and pilgrims [6,7]. However, in order to build such a plant, it requires a strong commitment from all stakeholders, including government, public, policy and decision-makers and business investors based on a detailed assessment study [2]. In this regard, the current study will make a foundation by selecting the most suitable WTE technologies under a waste-based biorefinery concept in accordance with Makkah city's waste categories and WTE's technical, economic and environmental values [8].

This paper aims to assess the value of waste-based biorefinery and recycling as a sustainable solution to landfill waste problems and renewable electricity production for Makkah city. Four different WTE technologies for waste-based biorefinery; anaerobic digestion (AD), pyrolysis, transesterification, and refuse derived fuel (RDF) have been selected, based on their economic, environmental and technological advantages and local waste categories. Furthermore, the energy-saving benefits for recyclable materials such as glass, metal, aluminum and card board are highlighted for Makkah.

2. Review of waste generation in Makkah city

The Makkah landfills received 2.4 thousand tons of municipal solid waste (MSW) during the normal days in 2014, while these quantities became 3.1 and 4.6 thousand tons per day during the Ramadan and Hajj periods respectively [8]. The waste generation peak occurred during 8–13 Zulhijjah (the time of Pilgrimage) and the last ten days of Ramadan [2]. The total estimated waste generation in Makkah during 2014 was about 970 thousand tons, including waste generated by the local population (880 thousand tons), and Hajj (70 thousand tons) and Ramadan (20 thousand tons) pilgrims [8]. The MSW of Makkah showed that the food (50.6%) and plastic (17.4%) wastes were the largest waste streams (Fig. 2).

During 2014s Hajj, more than 2.5 million animals were sold for slaughtering [9]. Similarly, around 2.1 million plastic drinking water cups were used every day during the 2014s Ramadan. Around 5 thousand tons of food was wasted in Makkah province in the first three days of 2014s Ramadan [10]. The Hajj and Ramadan periods add a significant amount of food and plastic wastes due to serving of food in disposable plates. In Al-Masha'ir, most of the generated waste is from Mina (Table 1), where pilgrims stay most of their time. There is an annual wastage of 35–40% of cooked rice, which is equivalent to 3 million tons rice per year with loss of 1.6 billion Saudi Arabian Riyal (SAR) [11].

The MSW with a high fraction of organic contents, especially the food waste (50.6%) with high moisture content (38.4%), carbohydrates (25.6%) and proteins (17.3%) (Table 2) makes it a very suitable feedstock for WTE technologies. Moreover, the animal slaughtering also produces animal-related waste in huge quantities each year, especially during the Hajj period. The waste originating from animal slaughtering is around 12% per body weight for sheep and goats, while it is about 38% per body weight for cattle [13]. The waste fractions consist of inedible body parts such as feathers, blood vessels, ligaments, integuments and offal material along with blood, rumen, intestine and waste fats [14]. There is very little information available on the actual amounts of slaughtering waste produced during the annual Hajj periods in Makkah.

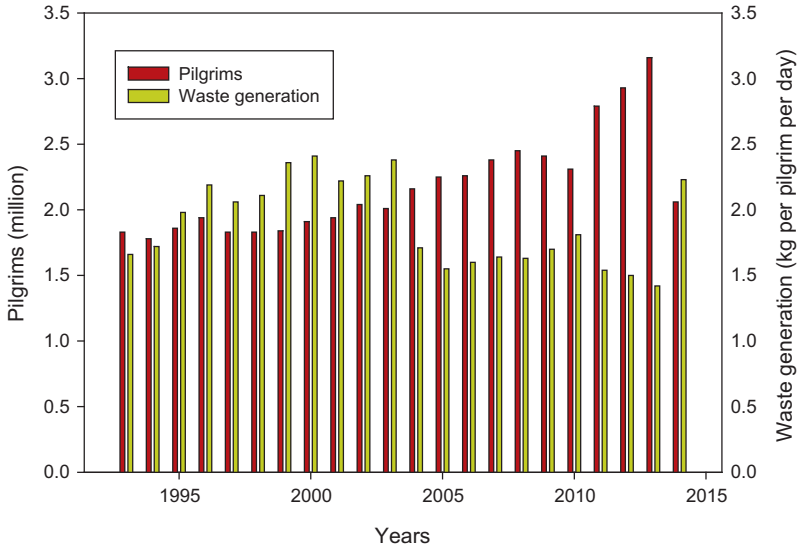

Fig. 1. The number of pilgrims and waste generation per pilgrim per day, from 1993 to 2014 [2,3].

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