MUNICIPAL SOLID WASTE AND CIRCULAR ECONOMIES: A CASE STUDY OF MADINAH CITY

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SUMMARY: The world is facing many challenges including economic imbalances, food, water, and energy shortages together with increasing environmental pollution and health risks. The nations, especially developing countries, have to shift from the linear economy (taking, making, consuming and throwing away) towards a circular economy (sharing, leasing, reusing, repairing, refurbishing and recycling). In Kingdom of Saudi Arabia (KSA), the municipal solid waste (MSW) is mostly disposed in open landfills or dump sites, without the recovery of value-added materials and energy, potentially causing several environmental and public health issues. The KSA government has recently launched a new policy of Vision 2030 to safeguard the local environment through increased MSW recycling, employing sustainable waste-to-energy (WTE) technologies and developing renewable energy sources. This paper aims to examine the sustainable management of MSW through WTE and waste recycling as a solution to current waste disposal problems and a source of revenue, jobs, and environmental benefits in developing countries, especially in the holiest city of Madinah.

1. INTRODUCTION

The sustainable management of municipal solid waste (MSW) is a continuing problem in most of the developing countries (Nizami et al., 2017a). The waste disposal environmental and economic issues along with public health concerns are forcing the governments to find alternative sustainable management options instead of open dumping or landfilling of MSW (Nizami et al., 2016). Developing countries produce a significant amount of biomass, chemicals, and recyclable materials that, if MSW is wisely managed, can be converted into various value-added products and renewable energy (Figure 1).

In the Kingdom of Saudi Arabia (KSA), most of the collected MSW is disposed to open or non-sanitary landfill sites that are causing greenhouse gas (GHG) emissions, and leachate production and soil contamination. In order to overcome these problems and to create economic opportunities, jobs, and environmental benefits, the waste-to-energy (WTE) and waste to recycling facilities are recommended as a way forward. The KSA new policy of Vision 2030 (Vision2030, 2017) is supporting the maximum diversion of MSW from landfills to material recovery facilities (MRF) with the production of renewable energy and recycling and value-added products (Anjum et al., 2016).

In KSA, the solid waste research group at the Center of Excellence in Environmental Studies (CEES) of King Abdulaziz University, Jeddah has investigated the possibilities and potential of WTE, waste biorefineries, waste recycling and waste composting utilizing domestic sources of...
MSW in order to produce energy, power, heat, chemicals, and value-added products. For example, Miandad et al. (2016a,b; 2017) and Rehan et al. (2016; 2017), have examined the catalytic pyrolysis of various plastic wastes produced in KSA and pyrolysis process conditions for pyrolysis liquid oil and char. Similarly, Waqas et al. (2017a,b) have examined the food waste of KSA for producing nutrient-rich compost as an organic fertilizer through the continuous thermophilic temperature reactor and agricultural waste-biochar. Nizami et al. (2015a,b; 2016; 2017a-c) and Khan et al., (2017) have examined the potential of developing WTE technologies and waste biorefinery in KSA along with exploring natural minerals like natural zeolite for optimizing the WTE technologies and converting local domestic and industrial waste into power through microbial electrolysis cell (MEC) technology respectively.

Nizami et al. (2017b,c), Anjum et al. (2016) and Khan and Kaneesamkandi (2013) have recommended anaerobic digestion (AD) and pyrolysis as promising WTE technologies of KSA. As the country produces an enormous amount of organics and plastic waste that could be effectively treated through these technologies to value-added products such as biogas and liquid oils. In addition, they also proposed technologies for the up-gradation of the suggested technologies such as biogas purification by separating \( \text{CO}_2 \) and regeneration of \( \text{CO}_2 \) for various applications as well as the conversion of methane (\( \text{CH}_4 \)) to liquid fuel (methanol) with a wide range of applications. Similarly, the pyrolysis technology and quality of liquid oil could be highly improved through the addition of various catalysts during the process, including natural zeolites. Nevertheless, along with liquid oil, the obtained char as a result of pyrolysis of plastic waste could be efficiently used as an adsorbent for wastewater treatment. The adsorbent potential of char could also be enhanced by changing its physiochemical characteristics through various technologies such as acid activation, thermal activation, and doping. Hence the significant potential of these technologies could make waste management practices highly effective and eco-friendly in KSA (Anjum et al., 2016).

![Figure 1. A model of WTE in developing countries](image-url)

This paper aims to examine the potential of WTE and waste recycling in developing countries, especially in the holiest city of Madinah in KSA as a solution to current waste disposal problems and a significant source of revenue, jobs, and environmental benefits.
2. WASTE BIOREFINERIES AND CIRCULAR ECONOMIES IN DEVELOPING COUNTRIES

It is becoming evident that a shift from a linear economy towards a circular economy is important, especially in developing countries considering their budget deficits, waste disposal issues, and environmental concerns. Therefore the futuristic WTE or waste biorefinery model must consist of targets and vision to help switching from the consumption of fossil fuels to renewable or “green” resources (Figure 2). It will also to mitigate GHG emissions and their detrimental impacts on the climate. Moreover, it will create tremendous job opportunities both in industrial and academic sectors, particularly in the sectors of food, agriculture, pharma and logistics, chemical and healthcare (Amulya et al., 2016; Clark and Deswarte, 2015). A biorefinery is a new concept, similar to petroleum refinery to produce multiple products from multiple or single crude feedstock at one platform (Figure 3).

Nizami et al. (2017c) have recently examined the potential of waste biorefineries facilities to produce energy, fuel, heat, and other value-added products in the developing countries in order to overcome waste disposal problems and generate renewable energy. They reported that there are various biorefinery technologies such as anaerobic digestion (AD), fermentation, pyrolysis, gasification, refuse derived fuel (RDF), and incineration that can convert a variety of waste like agricultural and forestry waste, food waste, industrial waste, animal waste and even wastewater to a wide range of energy and value-added products. Agricultural waste is a rich source of organics such cellulose can be successfully converted to biogas, bioethanol, and biohydrogen. Likewise, the forestry waste which is a rich source of lignocellulosic materials, including cellulose (40–47%), lignin (16–31%), hemicellulose (25–35%), and various extractives (2–8%) that could produce about 1030 quadrillion BTU energy per year. Moreover, paper and pulp industrial sludge also contained up to 75% carbohydrate that could also be a promising source of cellulose-derived fuels and value-added materials. Additionally, they also revived the conversion of plastic waste to liquid fuel oil through pyrolysis and energy production from
treat wastewater (Nizami et al., 2017c). The MEC technology provides the promising opportunity of hydrogen (H₂) production along with treating wastewater. The environmental and life cycle assessment (LCA) studies showed that compared to other energy generation technologies, the proposed WTE technologies or waste biorefineries would have less environmental impacts in term of GHG emissions and water pollution (Nizami et al., 2017c).

Figure 3. Comparison of salient features between biorefinery and petroleum refinery (Ismail and Nizami, 2016)

3. A CASE STUDY OF SUSTAINABLE WASTE MANAGEMENT IN MADINAH CITY

In KSA, millions of Muslims gather every year to perform religious rituals and visit the two holiest mosques in Makkah and Madinah cities. As a result of pilgrims, tremendous amounts of MSW are generated. The municipal authorities manage the collection, transportation, and disposal of MSW very efficiently. However, there are no WTE and MRF facilities in Makkah and Madinah cities to recover energy or value-added products from MSW (Nizami et al., 2015a).

Rehan et al. (2017) examined the economic, technical and environmental aspects of two WTE technologies, AD, and pyrolysis for sustainable treatment of food (50.6% of MSW) and plastic (17.4% of MSW) waste streams respectively in one of the holiest cities of Madinah. The food waste can be converted into biogas (gaseous fuel) and plastic waste into oil (liquid fuel), char, and gasses through AD and pyrolysis respectively. They have estimated that biogas from AD and liquid oil from pyrolysis carry total energy potential of 1783 and 4889 TJ respectively. This can produce continuous electricity supply of around 20 and 52 MW from biogas and pyrolytic oil respectively or total 72 MW in Madinah city throughout the whole year. Furthermore, the development of AD and pyrolysis technologies will also benefit the economy with net savings of around 302 and 196 million SR respectively through landfill diversion and electricity generation, totaling to an annual benefit of around 498 million SR.

Nizami et al. (2017b) overviewed the waste production in KSA with a special focus on one of the holiest city Madinah along with the feasibility of various waste recycling schemes for energy recovery and environmental benefits. They reported that annually about 887 thousand tons of MSW are produced that are disposed to landfill with a partial recycling of ~10-20% of the total
MSW. They have estimated that from only the recyclable materials such as glass (2.90%), metals (1.90%), aluminum (0.81%) and paper and cardboard (18.60%) about 10,009 TJ of energy could be conserved per year. The energy conservation potential of the individual recyclable material is 142 TJ (glass), 1,081 TJ (metals), 2,418 TJ (aluminum), and 6,368 TJ (paper and cardboard). Moreover, the revenue savings based on landfill diversion and carbon credits are estimated to be about US $32.78 and US $5.92 million respectively. Whereas, the direct net revenue added to the KSA’s economy from the recycling these materials will be US $49.01 million per annum. Moreover, it has also been estimated that through recycling about 254,600 Mt.CO$_2$ eq. of global warming potential (GWP) and 10,200 tons of CH$_4$ emissions can be saved that could be a positive step towards environmental and public health protection of the Madinah city (Nizami et al., 2017a).

4. CONCLUSIONS

The benefits of developing WTE technologies in KSA are several, including the development of renewable-energy and other value-added products, sustainable MSW management, new businesses and job creation and minimizing environmental and public health problems. However, there exist some technological and economical challenges during implementing of each waste biorefinery. Hence the detailed social, financial, and technical approach is highly required during the decision to select the types of waste biorefineries in developing countries.

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