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An assessment of the potential contribution from waste-to-energy facilities to electricity demand in Saudi Arabia

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ABSTRACT

The Kingdom of Saudi Arabia (KSA) is the largest crude oil producer in the world and possesses the largest oil reserves. The crude oil revenue has resulted in a massive socio-economic development over the last four decades. This situation has resulted in rapid growth of the country's electricity demand and municipal solid waste (MSW) generation. The KSA is proposing an impressive plan towards renewable energy utilization that includes waste-to-energy (WTE) facilities. This research assesses the potential contribution of WTE facilities to total Saudi peak power demand up to the year 2032 based on two scenarios: Mass Burn and Mass Burn with recycling for the entire country and for six major cities in the KSA. The analysis shows a potential to produce about 2073 Megawatts (MW) based on a Mass Burn scenario and about 166 MW based on Mass Burn with recycling scenario. These values amount to about 1.73% and 0.14% of the projected 2032 peak electricity demand of 120 Gigawatt. The forecasted results of each city from the two scenarios can be used to design future WTE facilities in the main cities of Saudi Arabia. Further investigations are recommended to evaluate the two scenarios based on financial, social, technical, and environmental criteria.

1. Introduction

The Kingdom of Saudi Arabia (KSA) is located in the Middle East and lies between 16° 22′ and 32° 14′ North Latitudes and 34° 29′ and 55° 40′ East Longitudes. The KSA is the world's largest crude oil producer and possesses the largest oil reserves. The revenues generated from oil have contributed to large scale socio-economic development over the last four decades. This development has come with a substantial increase in population and a rapid increase in the standards of living for the majority of the population. Internal immigration from rural to urban areas and the influx of expatriate workers has dramatically increased the urban population. The population of the kingdom has grown at an annual average rate of 3.4% over the last 35 years. Overall, the total population has dramatically increased from 7 million in 1975 to about 27 million in 2010 [4]. This situation has resulted in rapid growth of the country's electricity demand and municipal solid waste (MSW) generation [1–3]. This demographic explosion was also coupled with an increase in the urbanization level, with the urban population rising from about 50% of the total population in 1970 to about 80% in 2000 [4]. There are six major cities in the KSA with a population of one million or more: Riyadh, the capital, with 5.2 million, Jeddah with 3.4 million, the Dammam area with 2.0 million, Makka with 1.7 million, Madinah with 1.2 million, Al-Hassa with 1.1 million, and Al-Taif with 1.0 million [4].

1.1. Electricity demand

The electricity demand grew on average at a rate of 5.8% between 2006 and 2010 [5]. The current electricity peak demand is about 55 Gigawatt (GW). The peak electrical demand is projected to reach 120 GW by the year 2032 as shown in Fig. 1 [6]. The current demand is typically met through conventional heavy oil, diesel, and gas power plants spread across the country [6]. Towards diversifying the sources of electricity and ensuring the sustainability of power generation, the government initiated the King Abdullah City of Atomic and Renewable Energy (KACARE) in 2010 [7]. The vision of the KSA government and KACARE for the future power resources in Saudi Arabia is to maximize utilization of science, research, and industries related to atomic and renewable energy for peaceful purposes in a way that leads to raising the standards of living and the quality of life in the KSA [7]. In this direction, the KSA is proposing an impressive plan regarding renewable energy utilization on the planet that includes WTE facilities. The two decade plan includes a hybrid feed-in-tariff program and production of up to 54 GW from nuclear and renewable energy sources. The first round of bidding slated for 2013 includes

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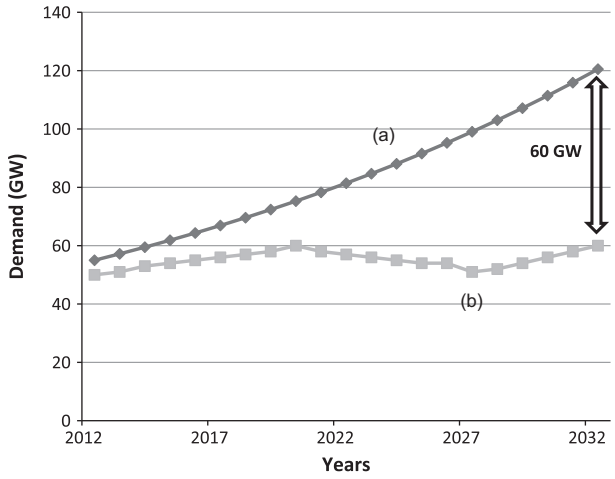

Fig. 1. Gap between (a) peak demand and (b) existing and planned capacity [6].

200 Megawatt (MW) of Geothermal and WTE facilities [8]. However, research is needed to forecast the potential energy production from renewable resources, including the WTE system.

1.2. Municipal solid waste management

Municipal solid waste (MSW) should be considered as a valuable source for recycled materials and energy. The benefits from MSW are immense and are unquestionable for countries like Saudi Arabia and the other Gulf oil states as they may help in saving the primary source of energy in this part of the world—oil. Currently, municipalities are governing MSW management in the KSA [3]. The extent of MSW practices in the KSA is simple: collect and get rid of it by dumping it in open landfill sites. In addition, the low cost of landfills makes a large MSW recycling program implementation unachievable for the time being [2]. The only large scale recycling system that currently exists is the trash sorters labor collection of metals and cardboards from garbage containers [2]. Few initiatives for MSW recycling are in place in the Eastern Province of the KSA. These initiatives are small scale and their contributions are not documented. The KSA currently generates about 14 million tons of MSW per year with an average of 1.4 kg/capita/day [2,9]. The landfill requirement is about 2.8 million m^2/year [2]. The MSW wastes of the KSA include 37% organic materials, 28.5% paper, 5.2% plastics, 8.3% mineral, 4.6% glass, 8% wood, 6.4% textile, and 2% others [9]. The above average MSW production rate is the result of the lack of community-wide programs to enhance environmental awareness, and to encourage reduction of MSW generation, and to promote recycling. US EPA considered WTE technology as a renewable source of electricity with less environmental impacts than almost any other sources [11]. WTE reduces the amount of MSW deposited at landfill sites; typically about 90% volume reduction and 80% mass reduction [18]. Incineration also minimizes leachate and methane formation and odor emissions. Methane is 21 times more detrimental than carbon dioxide from the global warming perspective [17]. Many of landfills in KSA are mature landfills in that substantial amount of volume has already been used by municipal waste deposits. With additional dumping, the amount of undesirable by-products such as leachate, municipal waste sludge, renegade methane and odor emissions and all health hazards associated with these will keep increasing. The KSA does not have any WTE facility in place. The huge annual quantity of MSW and its high energy contents show the significant potential for WTE facilities in the Kingdom.

Table 1
Energy content of different types of wastes [10].

Type of waste	Energy content (Btu/lb)
Mixed paper	6800
Mixed food waste	2400
Mixed green yard waste	2700
Mixed plastic	14,000
Rubber	11,200
Leather	8000
Textiles	8100
Demolition softwood	7300
Waste hardwood	6500
Coal	12,300
Fuel, oil	18,300
Natural gas	23,700

2. Objective and methodology

This research aims to assess the potential contribution of waste-to-energy facilities to total Saudi peak power demand up to the year 2032. The potential contribution will be assessed by conducting quantitative analysis of potential WTE electricity production in the KSA. The analysis will consider two scenarios for WTE development: Mass Burn and Mass Burn with recycling. The Mass Burn scenario implies full utilization of MSW for WTE production. Mass Burn with recycling assumes removal of all potentially recyclable materials from the waste stream and utilizing the remaining MSW for WTE production. The total Saudi MSW electricity generation quantity and for the major six cities up to year 2032 will be forecasted. The year 2010 was chosen as the starting year for forecasting. The MSW production rate was assumed to be 1.4 kg/capita/day. MSW contents were considered as per AFED 2008, mentioned in Section 1.2. The caloric energy content of the various types of waste are listed in Table 1 [10]. These measures were used to calculate the total energy content per kilogram of Saudi municipal waste. There are a number of developed and emerging technologies that are able to produce energy from waste. The most widely used and proven WTE is the process of producing energy in the form of heat and/or electricity from waste sources via combustion [11–14]. The research literature has documented a combustion efficiency of 25% to 30% for operated WTE facilities in different places across the globe [15–17]. A combustion efficiency of 25% will be assumed in calculating the WTE for Saudi Arabia.

3. Results and discussion

The population is expected to continue growing on the same pattern (3.4% per year) given the cultural norms determining Saudi reproductive behavior and the social and economic characteristics of the country. There are six major urban areas in the KSA. About 62% of the Saudi population lives in these six areas. The forecast KSA population up to the year 2032 is presented in Fig. 2. In 2032 the population of the KSA will be almost twice that of the 2010 figure of about 27 million. This will also result in doubling the generated MSW quantity. The yearly generated MSW for the whole country and for the six main cities are presented in Fig. 3. The 2012 MSW quantity is about 13.8 million tons and this is estimated to reach about 26.9 million tons by 2032. This is a huge (quantify) amount of MSW and should be managed wisely. Managing the MSW with the current practices in Saudi (landfilling) will result in huge environmental and financially negative consequences. Undoubtedly, WTE is an alternative solution and recycling will help as well.