A Sustainable Energy Production from MSW in Oman

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Abstract:

The adverse impact of the energy production from fossil fuels is now well recognized globally; therefore, the move towards renewable and sustainable energy has become an integral part to achieve United Nations Sustainable Development Goals. This article presents a comparative study considering a waste to energy plant to produce electricity in Oman. A research strategy that includes both qualitative and quantitative research methods were adopted to evaluate the MSW generation and emissions, electricity consumption and emissions, public participation in waste segregation, and to estimate the reduction in emission considering a 5,000 tonnes/day waste to energy plant in Oman. The results show that a current emission from fossil fuels to meet the electricity requirement of 70,633.37 Million kWh/year is 161.781 Million tonnes CO_2e/year. Similarly, the emissions from MSW which currently stood at 2.159 million tonnes/year is 3,424,247 tonnes CO_2e /year. A 5,000 tonne per day waste to energy plant will not only produce 2.93 Million kWh daily but will also enable an annual reduction of 2455.31 Million Kg CO_2e. Such an initiative will help Oman to improve its sustainability performance in energy, climate change, waste reduction, and economic growth and will pave the road to achieve the relevant SDGs by 2030.

Keywords: Renewable Energy, Sustainability, Waste management & disposal.

1. Introduction:

Energy is an integral part of today's modern life but the way most the energy is produced around the world creates several environmental and sustainability issues. Environmental sustainability is the core issue that needs to be addressed for development to focus on human well-being and yet stay within the limitations of the planet’s capacity. Gulf Cooperation Council (GCC) member countries (Saudi Arabia, Oman, United Arab Emirates, Kuwait, and Qatar) are considered as a major consumer of the natural resources which results in a larger amount of emissions (Umar and Wamuziri, 2016; Umar and Egbu, 2018). Similarly, the annual solid waste generation in the GCC region has exceeded 150 million tonnes. This waste generation is more than some of the countries such as Brazil, Indonesia, Russia, and Mexico which are known as some of the top waste generating countries (Statista, 2020). GCC countries featuring among the world’s top ten per capita waste generators (Zafar, 2018, Umar et al., 2020-a).

This article considers the MSW in Oman to produce electricity. This is not only important to produce electricity from the MSW but also to reduce GHG emissions from MSW. One of the common methods that is already adopted by many countries is to use MSW in a plant to produce energy. This type of plant is commonly known as waste to energy plants. The aim of this research is therefore to explore the opportunities to use MSW for electricity production in Oman. Such opportunities cannot be understood well without knowing the composition of the MSW, public participation, and cooperation in activities related to recycling. This research, therefore, incorporates both quantitative and qualitative approaches, commonly known as mixed method was adopted to accomplish the aims and objectives set for the research.

2. Research Methodology:

Considering the scope of the research and different methods employed in different stages of the research, the methodology section is further divided into different sections.

2.1. Method Used for MSW Composition and Public Awareness:

Both the qualitative and quantitative research strategies were employed to obtain the aims and objectives set for this research. Since the quantity and the composition of the MSW are important to know energy content and emissions, therefore, the samples of MSW were collected from different households. As a rule of thumb, a minimum number of samples is 10 if the sample size is 100 kg or larger (Dahlén and Lagerkvist, 2008). Thus, as a research strategy, to know the composition of the MSW in Oman, a total of 238 samples collected from 25 residential houses (175 samples), 4 restaurants (28 samples), 3 shopping markets (21 samples), and 2 hotels (14 samples) as shown in table 1. The houses were selected in a way so that the reliability could be achieved. Thus, the houses with the family member of 2, 3, 4, 5, and 6 were considered for data collection. Samples of waste were collected from each house on a 24-hour basis. The same approach was adopted to collect the samples from restaurants (4 numbers), shopping markets (3 numbers), and hotels (2 numbers). The samples were collected on each day of the week. The samples were deposed in the municipality collection point after recording the required data. Every morning the samples were collected, segregated, and measured. The data collection was completed in two months, from 27 June 2019 to 26 August 2019. The segregation method adopted was according to the criteria followed in the 3R projects implemented by Japan International Cooperation Agency (JICA) in Hanoi (Taniguchi and Yoshida, 2011; JICA, 2012; Otoma et al., 2013).

Table 1: MSW Samples Collection Approach

Additionally, the residents' willingness and participation in recycling activities were captures through an interview conducted at the time of sample collection. A total of 34 interviews, 25 from residential houses, 4 from restaurants, 3 from shopping markets, and 2 from hotels were conducted. The sample used to know the residents' willingness and participation was considered appropriate as there is evidence in the existing literature that similar studies were conducted with much smaller samples. For instance, Umar (2020-b) while developing an integrated approach to promote sustainability in university campuses used a sample to 20 respondents. Although the questionnaire used for this purpose was prepared in English, due to the diversity of the respondents, the interview process was deemed fit to the respondents. Overall, 45% of the residents in Oman are expatriates and the majority of them belong to some Asian countries (Umar, 2018). The participants in the data collection were therefore interviewed in the local language so that there could be no communication barriers.

2.2. Method Used to Estimate the Emissions from MSW:

The Intergovernmental Panel on Climate Change (IPCC) 2006 model is used to calculate GHG emissions from landfills (IPCC, 2006). Equation 1 is used to calculate the CH_4 emission from landfills. For the environmental performance of waste to energy approach, different parameters such as emissions per tonnes, reduction in landfills, and energy production and social indicators such as employment were considered. For instance, equation 2 was used to determine the emissions from crude oil when used in electricity production. In the comparison of emissions from both scenarios, landfilling and waste to energy approach, the emissions produced from the transportation of waste were ignored. The emissions from the transportation of the MSW to the disposal point is normally calculated based on the distance between collection and disposal points. Briefly, the GHG emission factor which accounts for MSW hauling can be 19.1 g CO_2e/tonne/km (DEFRA, 2011).

CH_4 = [($MSW_{(Land\ Fill)}$×MCF×DOC×DOC_f×F×(16/12)-R)×(1-OX)] …………Equation 1

Where,

CH_4 = Methane Emission in Gg/year (1 Gg = 10^9 g; 1 Gg = 1,000 tonne; Gg = giga gram)

$MSW_{(Land\ Fill)}$ = total amount of MSW in the landfill in wet weight basis (Gg/year)

MCF = CH_4 correction factor – (value used in the calculation = 0.6)

DOC = the fraction of degradable organic carbon in MSW (Gg C/Gg MSW) – (value used in the calculation = 0.2455)

DOC_f = the fraction of DOC that can decompose (fraction) – (value used in the calculation = 0.77)

F = the fraction of CH_4 in generated landfill gas – value used in the calculation = 0.5)

R = the recovered CH4 (Gg/year), 16/12 is the molecular weight ratio CH_4/C – value used in the calculation = 0)

OX = the oxidation factor – value used in the calculation = 0)

$E = A\ x\ B\ x\ C\ x\ D$ ………………………..Equation 2 (EPA, 2017; Umar and Egbu, 2018).

Where,

E = CO_2e *emission per barrel (tonnes)*

A = The average heat content of the crude oil (= 5.80 mmbtu per barrel; mmbtu = one million British Thermal Units).

B = The average carbon coefficient of crude oil (=20.31 kg carbon per mmbtu)

C = The fraction oxidized (= 100%, (IPCC, 2006))

D = The ratio of the molecular weight of carbon dioxide to the carbon (= 44 kg CO_2e */12 kg C)*

2.3. Method Used for Estimating Energy from MSW:

The electricity content and emissions from the MSW is well established in the existing literature. Different keywords such as “electricity content in MSW”, “energy production from MSW”, “waste to energy plant” and emissions from energy to waste” were used in main search engines. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines were adhered to during the review process (Moher et al., 2009; Umar, 2020-a, Umar, 2020-c). Different results associated with the electricity content and emissions from waste to energy plants were obtained from the systematic review. For instance, in the United States, there 68 waste to energy power plants that produce about 14 billion kilowatt-hours (kWh) of electricity using 26.76 tonnes of combustible MSW (EIA, 2019). In other words, the energy or electricity content per tonnes of MSW in the United States is approximately 586 kWh. The waste to energy plant installed in Qatar which has a capacity of 2,300 tonnes per day produces 50 Mega Volt Amp (MVA) which is equal to 40,000 kWh per day (Keppel Seghers, 2020). Likewise, the statistics issued by Waste Management World indicates that electricity production from MSW can be up to 875 kWh per tonne of MSW processed in a waste to energy plant (WMW, 2015). The calculation presented in this paper, considers a value of 586 kWh per MSW used in a waste to energy plant keeping in mind that this value is from the United States which uses the same types of waste to plant as proposed in this research.

The total waste which is burned for energy recovery in the United States currently stood at 12.70% of the total waste. Apart from producing energy, the burning of waste can reduce the volume of waste by 90%. A recent waste to energy plant constructed in Ethiopia uses the same approach of burning waste to produce electricity. The collected waste is kept for five days to allow the moisture to seep out and then burning the waste at 1,000^{o}C to turn it to heat energy to run the steam turbine (Abebe, 2018). The latest and modern waste to energy plant can reduce the emissions (CO_2e) ranging from 100 ~ 350 kg CO_2e per tonne of the MSW used (Rogoff and Screve, 2019). An average emission reduction value of 225 kg CO_2e per tonne of MSW can be used to measure such reduction in emission, however, the Environmental Protection Agency (EPA) of the United States reveals that the burning of one tonne MSW in a waste to energy plant results in 1 tonne of less CO_2e when compared to the common practice of landfilling (EPA, 2019). The potential reduction in emissions between landfilling and waste to energy plants investigated by Wang et al. (2017) in China noted that such reduction can be more than 1,000 Kg CO_2e per tonne of MSW. The study conducted by Obermoser et al. (2009) to establish a reliable CO_2e value from waste to energy plant noted that CO_2e emission can be in the rage of 30 to 67 kg CO_2e per Giga Joule which can be translated into 0.175 Kg CO_2e per kWh.

3. Results and Analysis:

Considering different aspects of the results and analysis, this section is divided into different sub-sections. The first subsection describes the results and analysis of the MSW composition and the public participation in the MSW segregation.

3.1. MSW Composition and Public Willingness:

As noted in section 3, a total of 175 samples were collected from the residential houses. These samples were used to determine the MSW generation per capita. The results show that the mean weight of the MSW samples was 1.3 $\pm$ 0.28 kg/ per capita. Currently, as of May 2020, the total Oman population stands at 4,613,726, which can be translated into total of 5,998 tonnes MSW generation per day in Oman (NCSI, 2020; Umar, 2020-b). The whole samples collected from the residential houses, restaurants, shopping markets, and hotels were used to determine the MSW composition in Oman. This composition is reported in figure 1. Overall, the composition of the MSW represents a good percentage of waste that can be combustible and suitable to be used in a waste to energy plant to produce electricity.

During the MSW sample collection process, the inhabitants were asked about their cooperation and participation in the waste segregation activities. The willingness of the residents was considered important as this may be helpful to transfer only the MSW that is suitable to be used in the waste to energy plant. A total of 34, consisting of 67.64% male and 32.35% female, face to face interviews were conducted during this stage. All the participants appraised the idea of using MSW for electricity generation. A large number of the interviewees (70.58%) agreed that they are willing to participate in the segregation of the MSW at their doorsteps. The remaining participants did not answer as no but they were somehow not sure how they can do such segregation. Overall, the majority of the respondents (79.94%) noted that they required some sort of training and tools to do such tasks in their homes.

Figure 1: Composition of MSW in Oman

3.2. Emissions from MSW:

To calculate the emissions from MSW using equation 1, DOC for different waste materials was obtained from the IPCC and the Atmospheric Brown Clouds Emission Inventory Manual (ABC EIM). Based on these two documents, the DOC paper = 0.25, DOC food = 0.4, DOC textile = 0.25, and the DOC rubber = 0.39 were considered. The average DOC value was calculated based on the above values and waste fraction as shown in figure 1. The final DOC value used in the calculation, therefore, stands at 0.2455. The total MSW waste considered in this calculation was equal to 2,159,219 tonnes per year or 2159 Gg per year. This MSW produces a total of 163,060 Gg/year CH_4 which is equal to 3,424,247 tonnes/year CO_2e equivalent. This can be translated into the emissions produced by one tonne of MSW, which can be equal to 1.58 tonne per year CO_2e per tonne of MSW.

3.3. Electricity Production and Emissions:

In terms of electricity production, Oman is using both oil and gas to meet its electricity requirement. The current consumption of electricity per capita in Oman is 15,309.4 KWh per year that can be translated into total energy consumption by multiplying this figure with the total population of Oman (15,309.4 x 4,613,726), which gives a total consumption of 70,633.37 Million kWh per year. To calculate the emissions from electricity production through oil and gas, 70% of the electricity production is considered to be from oil, and 30% is considered to be from natural gas. These percentages were taken from the study conducted by the Authority of Electricity Regulation in Oman (AER, 2008). Similar percentages for electricity production in Oman were also reported by British Petroleum PLC and International Energy Agency (BP PLC, 2018; IEA, 2011). The EIA guidelines were used to establish the emissions both from oil and gas when used for electricity production. As per these guidelines, to produce 29.31 Kwh (1 million British thermal units (btu)) from oil, a total of 73.16 kg

(161.30 pounds) of CO_2e is produced. Similarly, if the same amount of electricity is produced from gas, then the total emissions will be equal to 53.07 kg (117.0 pounds). The emissions from electricity production in Oman considering both oil and gas are therefore calculated as under:

Emissions from oil:

Electricity produced from oil = total electricity consumption x percentage produced from oil = 70,633.37 Million kWh x 70% = 49,443.35 Million kWh per year.

Emissions for 29.31 Kwh from oil = 73.16 kg CO_2e

Emission for 49,443.35 Million kWh = $\frac{49{,}443.35\ x\ 73.16}{29.31}$ = 1.234x10^{11} kg = ***123.414 Million tonnes*** **CO_2e** ***per year.***

Emission from gas:

Electricity produced from oil = total electricity consumption x percentage produced from oil = 70,633.37 Million kWh x 30% = 21,190.01 Million kWh per year.

Emissions for 29.31 Kwh from gas = 53.07 kg CO_2e

Emission for 21,190.01 Million kWh = $\frac{21{,}190.01\ \ x\ 53.07}{29.31}$ = 3.836x10^{10} kg = ***38.367 Million tonnes*** **CO_2e** ***per year.***

Total Emission from Electricity Production in Oman = 123.414 + 38.367 =161.781 Million tonnes **CO_2e** ***per year.***

Overall, the emission from MSW and electricity production in Oman therefore equal to 161.781 Million tonnes CO_2e per year.

3.4. Energy Production from MSW:

The composition of MSW presented in figure 1 shows that more than 50% of the MSW can be classified as combustible materials suitable for use in waste to energy plants. This indicates that a total of 1,079,610 tonnes per year (~3,000 tonnes per day) of MSW can be used in waste to energy plants. The United States Energy Information Administration statistics indicate that 85% of the MSW can be burned in a waste to energy plant to produce electricity. In some cases, the segregations of the waste are also not required as some of the latest plants known as the mass-burn waste-to-energy plant can process all the waste together. As shown in figure 2, such plants have the capacity to segregates the waste such as metals, and ash. The plant can also segregate the food waste and other organic waste that can be used in landfilling or for composting. Likewise, Roethel and Breslin (1995) noted that the separated ash can also be used as aggregates in construction works, provided that there are no heavy metals that cannot be suitable for the use in construction. In this case the ash will need to be disposed in a special landfill which can result into excessive cost. The ash generated from the combustion process can be 25% of the original weight of the MSW (Michael, 2014). The emission of CO_2, CO, SO_2, NOx, N2O, HCl, NH_3 and HF is common from waste to energy plant. In addition, ferrous metal, bottom ash, fly ash, waste such as air pollution residue and landfill leachate are produced. Similarly, particulate matter, such as PM10 and PM2.5, are also released from such plants (Kabir and Khan, 2020). While a waste to energy plant may release less emissions compared to a coal-fired power plant, public health risk still exists due to the release of smoke, dust, noise from the plant, and traffic congestion all of which affects both the mental and physical health of local communities (Roberts and Chen, 2006).

The waste to energy plants can also be classified based on their daily capacity. After reviewing the total waste to energy plants manufactured and installed by Deltaway Energy, these plants have a capacity from 68 tonnes per day to 4,900 tonnes per day (Deltaway Energy, 2020). To ensure a realistic estimate for the waste to energy plant, the MSW produced in different governorates were considered. As noted in table 2, Muscat governorate, which is also the capital of Oman, is on the top of the waste production having a waste production capacity of 1,905 tonnes per day. If Muscat, North AlBatinah, Al-Dakhiliya, South AlBatinah, South AlSharqiya, North AlShariqiya, and Al-Dhahirah governorates which are somehow close to each other (as shown in figure 3) are considered then the total production of waste will be equal to 5,000 tonnes per day. Of course, this is 2017 data, and the population of these governorates will increase, the MSW production in these governorates will also increase. For instance, based on World Bank statistics, Oman's population increased at a rate of 3.4% per year (WDI, 2020). Based on this indicator, the 2020 waste production in different governorates can be calculated using equation 3.

$MSW_{(future)} = MSW_{(Current)} \times (1+i)^n$ …………………equation 3

Where;

$MSW_{(future)}$ = the MSW generation in future (for instance in 2020) for Muscat governorate

$MSW_{(Current)}$ = the MSW generation in future (for instance in 2017) for Muscat governorate

i = Annual growth rate (decimal) – in this case, it can be 0.034

n = Number of years projected into future – in this case, it will be 3 years

Based on the above parameters and using equation, the Muscat governorate MSW production in 2020 will be 757,996 tonnes per year, which was 685,654 tonnes per year in 2017.

Figure 2: A Typical Waste to Energy Plant

Table 2: Waste Generation in Different Governorates of Oman (Be'ah, 2017)

Figure 3: Oman Map Showing Different Governorates

As noted in section 2, one tonne of MSW in the United States has the potential to produce 586 kWh, thus 5,000 tonnes daily capacity waste to energy plant will be able to produce 2.93 Million kWh daily. This will help to reduce the volume of the waste that directly goes to landfills and produce emissions. Considering different parameter, the reduction of emissions through waste to energy plant is calculated below:

A) CO_2e Emissions from 2.93 Million kWh per day when produced by oil considering Emissions for 1 Kwh from oil = 2.5 kg CO_2e = 2.93 x 2.5 = **7.325 Million Kg CO_2e = <u>26.37 Million Kg CO_2 per year</u>**

B) Emission from 2.93 Million kWh per day when produced by waste to energy plant considering 0.175 Kg CO_2e per kWh (Obermoser et al., 2009).

= 2.93 x 0.175 = 0.**512 Million Kg CO_2e per day** = **<u>184.59 Million Kg CO_2e per year.</u>**

C) Reduction of waste emissions from landfilling, considering a reduction of 1 tonne per tonne of MSW.

Emissions per tonnes of MSW when disposed in landfilling = 1.58 tonne per year CO_2e per tonne of MSW

Reduction in emissions per tonnes = 1.58 – 1.0 = 0.58 tonne CO_2e per year

Emissions from 5,000 tonnes per year = 5,000 x 0.58 = **2,900 tonnes CO_2e per year** = **2.9 Million Kg CO_2 per year.**

Total reduction in Emissions = A – B + C = 2637 – 184.59 + 2.90 = 2455.31 Million Kg CO_2e per year.

Apart from the environmental performance of waste to energy plants, initial cost, operational cost, and return on investment are the key factors that the government or the investors considered in their decision. The initial cost of a waste to energy plant can be established considering its daily waste capacity. The Waste to Energy Research and Technology Council (WTERTC) has established the initial cost of a waste to energy plant at a rate of US $200,000 per daily tonne of capacity. As the plant considered in the research has a capacity of 5,000 tonnes per day, thus the initial cost of the plant can be estimated at US$ 1,000 Million (WTERTC, 2020). While the initial cost is established on the most recent trend available on the WTERTC website, it is still possible that the actual cost may vary at a rate of ±15% considering the demographic and other local factors. Therefore, it is suggested that estimated cost may vary. A 1,000 tonnes daily capacity of the plant would require a total of 60 personnel, thus at this rate, a 5,000 tonnes daily capacity plant would be able to generate employment for 300 workers. The operating costs of waste to energy plants in China are calculated at approximately US $30 per tonnes (Xin-gang et al., 2016). A general worker wages in Oman rage from US $ 390 to US $ 520. Thus, total wages of the workers per month can, therefore, be estimated at US $136,500 per month [= 300 x 390+540)/2] or US $ 4,550 per day. Depending on the life span of the plant, the operation cost can be up to 85% of the plants' total costs. If the plant has an estimated life of 40 years, then the cost of supply and construction can be 14% and the management and feasibility cost can be up to 1% of the total costs of the plant (UNEP, 2019). The research conducted by Carneiro and Gomes (2019) established a levelized cost of electricity production from waste to energy plant at US$ 76 per MWh. The electricity production cost from waste to energy plant is still higher that the solar and fossil fuels which currently stand at $30/MWh $75/MWh respectively (EIA, 2020). The profit margin of a waste to energy plant can be up to 25% while the return on investment can be up to 18%. Since fossil fuels are quite subsidize, thus practically, 18% return on investment is not going to happen if the only thing from the plant is to sell the energy. The investment in the plant would therefore be only attractive when the government would provide other incentive on investment. The research in other countries shows that the payback period of a waste to energy plant is normally 13 years with an internal rate of return up to 11% (Xin-gang et al., 2016). The research conducted by Kaplan et al. (2009) in the United States estimated the average cost of electricity production from MSW at a rate of four cents per kWh with average revenue of US $25 per tonnes of MSW used in a waste to energy plant.

The next section provides a discussion and conclusion of the research.

4. Discussion and Conclusion:

Considering the discussion and conclusion arising from this research, this section in further divided into three sub-sections. Each sub-section covers a specific agenda of the discussion and conclusion. All the sub-sections are underlined below.

4.1. Electricity Production from MSW in Oman:

The samples of the MSW collected from different entities including residential houses, shopping markets, hotels, and restaurants indicate a good volume (~50%) of combustible waste that can be used in a waste to energy plant. More than 70% of the interviewees confirmed that they are willing to segregate their MSW. The results further show that the current MSW generation in Oman stands at 1.3 $\pm$ 0.28 kg/ per capita. This value and the current population of Oman are used to determine the total daily MSW generation in Oman. Since landfilling is used to dispose the total waste in Oman, the IPCC and ABC EIM guidelines were used to estimate the emissions from the total MSW. These calculations indicate the emission of 3,424,247 tonnes CO_2e /year or 1.58 tonne CO_2e per year per tonne of MSW. Currently, Oman is producing 70% of electricity from oil and 30% from natural gas. The emissions from current electricity consumption (~70,633.37 Million kWh per year) is estimated at 161.781 Million tonnes CO_2e per year. If the emissions from the MSW are also added to this emission, then the total emission from electricity consumption and MSW generation in Oman will be equal to 165.205 Million tonnes CO_2e per year. Considering the current energy consumption, MSW generation, and emissions from these variables, waste to energy plant that has a capacity of 5,000 tonnes per day is proposed to use the waste from Muscat, North AlBatinah, Al-Dakhiliya, South AlBatinah, South AlSharqiya, North AlShariqiya, and Al-Dhahirah governorates. Apart from producing 2.93 Million kWh daily, this plant will be able to significantly reduce the emissions from the MSW and electricity production in Oman. The reduction in emission from this waste to energy plant is estimated at 2455.31 Million Kg CO_2e per year (Table 3). This plant will be able to provide jobs for at least 300 personnel. The literature review suggests that the initial costs of such a plant with a capacity of 5,000 tonnes per day can be equal to the

US $ 1,000 Million. The operating costs can be up to the US $30 per tonnes of waste used in the plant.

Table 3: Saving in Emissions Through Waste to Energy Plant

4.2. Limitations of the Research:

Although, a proper research method was adopted in this study to collect the required data, there are a few assumptions made in this study, which make the research exploratory in nature. To proceed for a waste to energy plant, a larger sample size at the feasibility stage will be required to investigate the composition of the MSW. Proper risk assessment that should include the recycling capabilities, the cost of energy production from other renewable resources and logistic issues will required to be conducted. The sample collected in this research show that organic contents (food and other green waste) are quite high, which will require the treatment and thus will reduce the overall energy production per tonne. The capacity of the plant will also be required to establish on the future MSW generation, allowing room for other form of recycling. Similarly, the collection of MSW at the plant will results some emissions from the vehicles that will transport the waste. Such emissions are required to be considered in future studies. Such transportation will also result into additional cost. Currently, the progress of Oman towards several UN SDGs is not satisfactory. Such an initiative of waste to energy plants will help Oman to improve its performance in a number of areas including energy, climate change, waste management, and economic growth.

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