

## Research Article

# Analysis of 3E (Energy-Economical-Environmental) for Biogas Production from Landfill: A Case Study

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Nowadays, generating energy is discussed as a paramount option in waste management, because the share of energy from waste is increasing annually. The ever-increasing need for energy and limitations of using fossil resources, and also the increase in environmental pollution from consuming these resources have made the use of renewable energies of especial importance. In this research, we first studied renewable energies, followed by technologies related to the biogas system. Biogas systems have been referred to by landfill and discussed comprehensively in this scheme for utilization. For this purpose, the input source of this system is considered as the volume of garbage in the city of Germe as the study area. In the next step, the amount of garbage produced in this city was extracted and the Landfill software was used for methane production potential assessment from this system and the Homer software was used for economic analysis and reliability evaluation. The most important results are payback period, which is about 10 years, and the amount of electricity produced per year, which is 11658.265 MWh.

## 1. Introduction

Waste incineration is a process by which garbage or brown coal (sewage sludge) is ignited in the vicinity of the heat and produces materials such as ash and exhausted gases from the chimney as combustion products. During this process, most of the metals and metal compounds in the waste remain unchanged and can be extracted from the resulting ash. The most important advantages of the waste incineration method are the large reduction in the volume and weight of waste and sewage sludge without the need for a long time or a large area of operation, the elimination of most hazardous waste and consequently reduction of environmental degradation, and the possibility of energy recovery as electricity or heat from the heat released during combustion of these materials as well as the possibility of recycling metals (both

ferrous and nonferrous metals) from combustion products [1, 2]. The minimum thermal value for waste generation is estimated at 7,000 kJ/kg. Today, the global waste incineration capacity for waste disposal, along with the generation of energy and recycling of metals from municipal solid waste, is about 130 million tons a year, with around 600 large waste-to-energy incineration plants in the world, which are often in the first world countries. The burning of solid municipal waste and sewage sludge is a controlled process in which solid waste is burnt and turned into ash, and the remaining is converted into safe or low risky gases [3–5]. In European countries due to strict environmental regulations, there are special filters in the exhaust outlet so that the harmful gas is filtered and added to the ash. In this method, the amount of waste is reduced by up to 90%. Waste incineration is one of the ways to dispose of solid municipal waste. This method is

especially applicable in cities with a problem of land shortage. In addition to reducing volume, these devices can also be used to reduce or eliminate toxic substances. In general, materials such as municipal waste, organic chemicals, radiological materials, biological materials, fire-retardants, explosives, and sewage sludge from the wastewater treatment plants can be burned in waste incinerators. The benefits of burning waste can include reducing the volume of the plant, reducing the volume of waste, reducing the volume of the waste garbage, removing hazardous waste, reducing costs, eliminating the risk of contamination of surface water, reducing the odour, reducing greenhouse gas emissions, reducing the amount of air pollutants, and destruction of the habitat of vile animals. Among these technologies, there is also a kind of technology called biochemical in which the waste materials are buried and gases such as methane and ethyl alcohol derived from biodegradation are collected by buried pipes in the ground and are used for fuel use at the plant. Gases such as methane can also be obtained in another way called anaerobic digestion [6, 7].

Biogas is also one of the biomass products. The process of decomposing biomass resources is by bacteria in the absence of air, in which methane and secondary products with moderate thermal value (biogas) are produced. The most prominent example of this process is in landfill. In the past few years, digestion tanks have been significantly noticed. The anaerobic digestion takes place at a relatively wide temperature range of 10–60 Celsius. All materials used to produce biogas in the process of anaerobic digestion should be made up of organic materials that essentially contain proteins, lipids, and carbohydrates. This organic matter is decomposed by a group of bacteria in the absence of oxygen, and the digestion efficiency is also affected by digestibility, pH, carbon to nitrogen rate, time remaining, and the presence of toxic substances for bacteria.

The primary sources for the production of biogas are livestock feces, plant remains, food waste and corrosive organic materials, organic waste, sewage, and agricultural waste products. All these methods are somehow biogas [8, 9]. Biomass resources contain organic compounds with coarse chain molecules that break down molecules into simpler molecules during digestive processes (buried in the ground, in special tanks or abandoned in nature). The ultimate outcome of this flammable gas process is called biogas. Biogas is also called methane [10, 11]. Some studies in the field of biogas are mentioned.

Urbancl et al [12] presented the evaluation of heat production using municipal biomass coincineration within a thermal power plant. Santos [13] presented an energy recovery from municipal solid waste materials for boilers of incineration plants. Lee et al. [14] presented an energetic and economic feasibility analysis of utilizing waste heat from incineration facility and power plant for large-scale horticulture facilities. Petridis et al. [15] studied a DEA/Goal programming model for the performance of incineration plants. In the UK, Di Gianfilippo et al. [16] presented LCA of management strategies for RDF incineration and gasification bottom ash based on experimental leaching data. Costa et al. [17] presented CFD modelling of a RDF incineration

plant. Toniolo et al. [18] assessed the “design paradox” with life cycle assessment, which is a case study of a municipal solid waste incineration plant. Walser and Gottschalk [19] presented stochastic fate analysis of engineered nanoparticles in incineration plants. Solheimslid et al. [20] presented calculation of first-law and second-law-efficiency of a Norwegian combined heat and power facility driven by municipal waste incineration, which was a case study. Li et al. [21] presented government responses to environmental conflicts in urban China, which was the case of the Panyu waste incineration power plant in Guangzhou. Huang et al. [22] presented public acceptance of waste incineration power plants in China, with comparative case studies. Wang et al. [23] presented characteristics and trends of research on waste-to-energy incineration, with a bibliometric analysis, 1999–2015. Tang et al. [24] presented energy analysis and environmental impacts of a MSW oxyfuel incineration power plant in China. Košnář et al. [25] presented investigation of polycyclic aromatic hydrocarbon content in fly ash and bottom ash of biomass incineration plants in relation to the operating temperature and unburned carbon content.

Given that 45 mg of waste is produced daily in urban areas of Germe, the dumping of this waste requires large areas away from food and water resources, and on the other hand, landfill is one of the most outdated and harmful ways to the environment. One of the drawbacks to this is the leachate produced from the waste that can easily penetrate to agricultural land and underground water resources. These leachate, due to the uncertain mix of different chemicals, have unknown properties and sometimes very toxic compounds.

The waste incineration plants, in addition to the very low cost of consuming fuel, contribute to the conservation of the environment. The enlargement and power output of these power plants and the prediction of the cost of constructing and operating these power plants requires precise economic assessment. This economic assessment will be carried out in the city of Germe based on the amount of waste produced and its growth rate.

In this research, contrary to the research studies conducted and mentioned above, first, the potential of municipal waste is measured and then for the realization of the present research, the estimation of urban waste is performed for a period of 20 years and then to objectify the present project, economic and energy analysis with the approach of supplying part of the electrical energy required by the building sector of the study area has been performed and then environmental analysis has been done to complete the research.

## 2. Materials and Methods

The waste incineration plants are one of the most polluting waste disposal methods, but if not designed properly, they will not have a good performance and will have environmental negative impacts. Due to the fact that the fuel consumed by the incinerator does not have a stable composition, Germe’s waste has been tested for its physical and

chemical properties and its thermal value has been determined. Following technical, economic, and environmental studies of various waste incineration technologies, the appropriate technology is selected according to the characteristics of the waste and other effect parameters and the design of the waste incineration plant is based on the above information and environmental criteria. Generating power capacity and selecting the type of generator of these plants are designed according to each region and according to the type and volume of waste. Germe is a city in and the capital of Germe County, Ardabil Province, Iran. Germe is one of the old cities of Ardabil province of Iran and the center of Germe County and a part of Mughan plain. The county's area is almost 1725 square kilometers (latitude: 39.02139, longitude: 48.08000).

*2.1. Sources of Waste Produced in Germe.* The sources of waste products in the city of Germe have been investigated, and the obtained information is summarized in Table 1.

*2.2. Estimating the Electrical Energy Potential of Germe Biomass Sources.* Today, energy extraction technologies (electrical and thermal) from biomass resources have become widespread, and these resources are the second largest source of nonfossil energy supply in the world. The prerequisite for energy extraction from these resources is the availability of appropriate information on the potential of resources and the amount of energy that can be extracted from them. In this project, we try to estimate the amount of energy extracted from biomass resources in the city of Germe based on the documentary information.

### *2.3. Biomass Resources Studied in Germe*

*2.3.1. Solid Waste (Garbage).* An important part of biomass resources is municipal solid waste. With high corrosive materials, these materials are capable of generating a large amount of greenhouse gases through biochemical interactions [26, 27]. Municipal solid waste includes solid materials from commercial, office, home, and in-town industries. In Iran, the corrosive rate of these materials is generally more than 60%, and its moisture content is higher than 65%. In order to estimate the amount of energy that can be extracted from Germe's waste, there is a need for accurate information on the amount and composition of the produced waste, so that the amount of recoverable energy can be estimated by analysing information based on energy extraction technologies from urban dry waste.

In order to calculate the potential of urban waste, it should be theoretically noted that, each volume of biomass resources has its own energy potential, but it may not be economically feasible to extract this amount of energy. Therefore, in order to estimate the potential of solid wastes generated in Germe, it is more efficient and economical to consider waste collection (if possible) that will result in lower energy costs of electrical energy [28].

*2.4. Determination of the Thermal Value of Garbage Waste.* Regarding the governing relationships, the analysis of Germe's garbage is carried out and the results of the analysis are presented in Table 2.

*2.5. Analysis of Germe Waste.* One of the notable negative characteristics in Germe waste is high humidity which is about 60%, and it reduces its thermal value. The average thermal value of Germe waste is 7.907 Mj/kg. According to the recommendation of the World Bank, in connection with the low minimum thermal value required for the construction of a waste incineration plant (7 Mj/kg), it can be concluded that the thermal value of the waste garbage is at a minimum and should be achieved by dehumidifying to the desired thermal value. Also, with the expansion of waste sorting and dividing waste into dry and wet, it can also significantly increase the thermal value.

As shown in Table 3, reducing the moisture content of the waste can increase the thermal value and therefore the amount of electrical energy produced. The landfill waste input for Germe from 2014 to 2016 is given in Table 4

*2.6. Estimation of Input Landfill Waste.* Assuming that there is no limitation in Germe landfill in 2014 and considering the 20-year plan for using it, the amount of landfill waste input from 2014 to 2033 is estimated considering population growth, waste per capita per person, waste amount in previous years (according to extracts from the Department of Municipal Affairs and Provincial Governor Councils), and according to the physical analysis and the percentage of waste generated in the production of methane in the landfill area using the EViews software and the following equation.

$$Y = C1 + C2X. \quad (1)$$

where  $Y$  is the landfill waste input and  $X$  is the year of landfill waste input.

The EViews software uses the constants  $C1$  and  $C2$  to establish a linear relationship between the variables  $X$  and  $Y$ .

Software considers the  $C1$  and  $C2$  constants as factors such as population growth rates and other factors that influence this. The EViews software and waste estimation equation are shown in Figure 1. Figure 2 shows the result of estimating the amount of waste generated in EViews software analysis.

*2.7. Analysing the Produced Gasses from Wastes after Being Buried by Landfill Method Using LandGEM.* One of the most important methods for disposal of waste in the world, including in the city of Germe, is the method of disposal of solid waste by sanitary landfill. At landfills, as a result of biodegradation of organic matter in the waste, a variety of gases are produced, most of which are methane and carbon dioxide. These gases are polluting the environment due to the greenhouse effect. Therefore, careful studies are needed in order to know more about how these gases are released from landfills and their effects in order to create useful strategies for their proper control and management.

TABLE 1: The sources of waste products in the city of Germei [https://pasmand.ardabilcity.ir].

Source	Various produced waste	Waste-producing regions
Domestic	Food waste or dry waste and scraped equipment	House or apartment
Commercial	Food waste, dry waste, packaging materials, fruit and vegetable waste	Shops, markets, restaurants, hotels, repair shops, fruit and vegetable fields
Industrial	Waste material, dry wastes, special waste materials and sometimes hazardous waste	Small industries within the city limits
Open areas	Dry waste, dirt, special waste	Public places and parks
Health and therapy	Food waste, dry waste, especially hospital waste and hazardous	Hospitals, pharmacies and medical centers
Government offices	Waste materials and dry wastes, paper	Government buildings of universities, ministries and organizations
Construction activities	Construction waste and special waste	Repair, deconstruction and construction

TABLE 2: percentage of weighted arithmetic mean of waste components and thermal value per kilogram of garbage in Germei [https://pasmand.ardabilcity.ir].

The amount of energy of germei municipal waste components based on wet weight							
	Waste components	Weighted arithmetic mean	Moisture percentage	Dry heat energy unit btu/lb<	Dry heat energy unit Kj/Kg	Moisture rate	Total energyKj/Kg
1	Food waste	59.27	65.83	2000	4652.7	1589.83	942.29
2	Paper	11.15	21.17	7200	16749.72	13203.81	1472.22
3	Plastic	16.22	25.09	14000	33568.91	24397.37	3957.22
4	Rubber	0.65	9.52	10000	23263.51	21048.82	136.82
5	Textiles	5.93	19.57	7500	17447.63	14033.13	832.16
6	Leather	0.38	7.02	7500	17447.63	16222.81	61.65
7	Wood	2.85	30.11	8000	18610.8	13007.09	370.7
8	Glass	1.05	1.94	60	139.58	136.87	1.44
9	Ferrous metals	0.36	10.98	300	697.91	621.28	2.24
10	Non-Ferrous metals	0.1	8.76	0	0	0	0
11	Stone and ash	2.04	8.43	3000	6979.05	6390.72	130.37
	Sum	100					7907.11
The amount of thermal energy per kilogram of garbage in a wet state							7907.11

TABLE 3: Thermal value of waste for waste incineration in terms of waste moisture content.

Weighted percentage of waste moisture	60%	30%	0%
Thermal value Mj/kg	7.9	11.375	16.25

TABLE 4: Landfill waste input for Germei from 2014 to 2016.

Year	Weight (1000 kg)
2014	9360
2015	9720
2016	10800

2.7.1. *Input Information of Germei Landfill.* The methane production potential has been obtained according to the standards that the software was designed for, so the calculated low value for urban waste is 170 grams per m<sup>3</sup>/mg. In methane generation rate (k), factors such as humidity of the environment are of particular importance, since waste with a mean moisture content of about 60% is considered as a city with semihumid waste. The value of 0.05/y is obtained for k. In this software, the production of four major pollutants of methane, carbon dioxide, total gas, and organic compounds

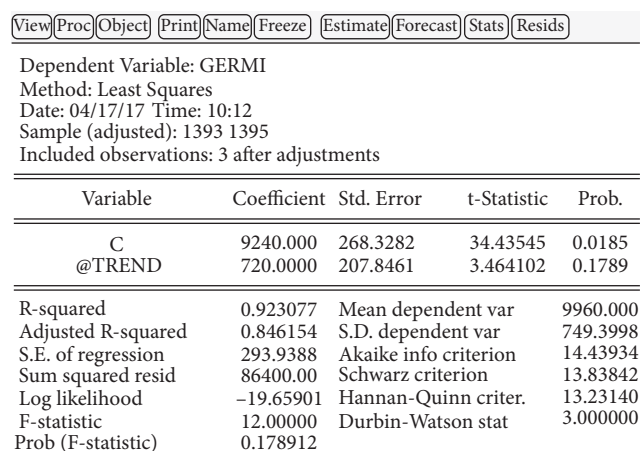


FIGURE 1: EViews software and waste estimation equation.

without methane will be calculated and expressed in terms of charts and tables.

Landfill's other information, such as the landfill open year, landfill closure year, capacity, and weight of existing and estimated waste, is included in the LandGEM software.

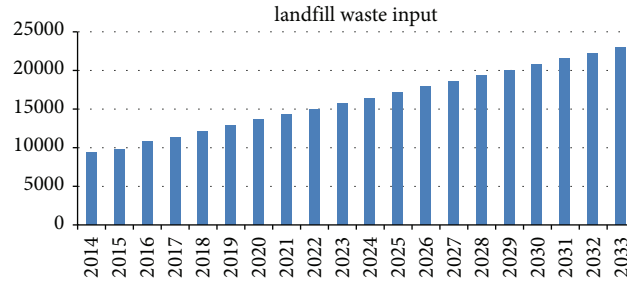


FIGURE 2: The result of estimating the amount of waste generated in EVIEWS software analysis as a graph.

TABLE 5: Total quantities of gas and methane gas in the landfill outlet.

Year	Total landfill gas			Methane		
	(mg/year)	(m <sup>3</sup> /year)	(av ft <sup>3</sup> /min)	(mg/year)	(m <sup>3</sup> /year)	(av ft <sup>3</sup> /min)
2014	0	0	0	0	0	0
2015	176/6	141500	9/504	47/18	70730	4/752
2016	351/5	281400	18/91	93/88	140700	9/455
2017	538/2	430900	28/95	143/7	215500	14/48
2018	727/1	582200	39/12	194/2	291100	19/56
2019	920/3	737000	49/52	245/8	368500	24/76
2020	1118	895100	60/14	298/6	447500	30/07
2021	1319	1056000	70/97	352/4	528200	35/49
2022	1524	1221000	82/01	407/2	610300	41/01
2023	1733	1388000	93/24	462/9	693900	46/62
2024	1945	1558000	10/47	519/6	778800	52/33
2025	2161	1730000	11/62	577/1	865100	58/12
2026	2379	1905000	12/80	635/5	952500	64/00
2027	2601	2082000	13/99	694/6	1041000	69/96
2028	2825	2262000	15/20	754/5	1131000	75/99
2029	3052	2444000	16/42	815/1	1222000	82/09
2030	3281	2627000	17/65	876/4	1314000	88/26
2031	3513	2813000	18/90	938/3	1406000	94/50
2032	3747	3000000	20/16	1000/1	1500000	10/08
2033	3983	3189000	21/43	1006/4	1595000	107/1

### 3. Results

**3.1. Results of LandGEM Software Analysis.** The results obtained by analysing the software for the gases from landfill are shown in Table 5 and Figures 3 and 4.

After estimating the extraction of methane and other gases from landfill over the course of the 20 years studied by using the LandGEM software, the obtained information analyzed through technical, economic, and environmental aspect using the Homer software.

According to the average electric power generation during the studied period which is 8502157.9 kWh, the estimated power plant is 1 MW. It means that, based on the potential of urban waste of Germe, this waste is capable for building a power plant with a capacity of 1 MW.

**3.2. Economic Analysis of a Landfill with Capacity of 1 MW.** Among renewable energies, biomass energy, especially gas extraction technology from landfill sites, is one of the most

economical methods of generating electricity. To analyze the economics of landfill with capacity of 1 MW, simulation was carried out to estimate investment costs using the Homer software. The landfill simulation with capacity of 1 MW is shown in Figure 5.

According to the results of simulation of this process, the investment cost will be 1544400256\$ and the variable cost will be 5446428.57\$. Each unit of electrical energy produced by this system will cost about 14.3\$. The result of 1 MW landfill simulation by Homer is shown in Figures 6 and 7.

According to the simulation, the electric power produced by this plant will be 11658.265 MWh/year, equivalent to 1.3 MW.

**3.3. Environmental Analysis.** In energy extraction from landfill gas, reliable technologies are used for landfill gas trapping. Environmental analysis of the biomass power plant using the Homer software is shown in Table 6.

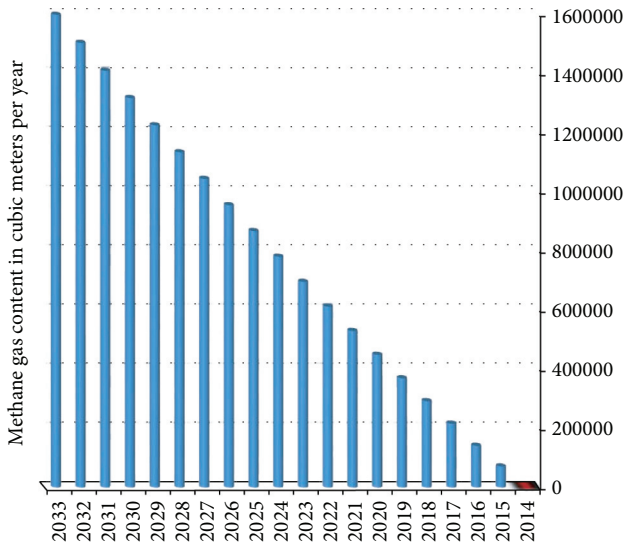


FIGURE 3: Methane gas content in cubic meters per year.

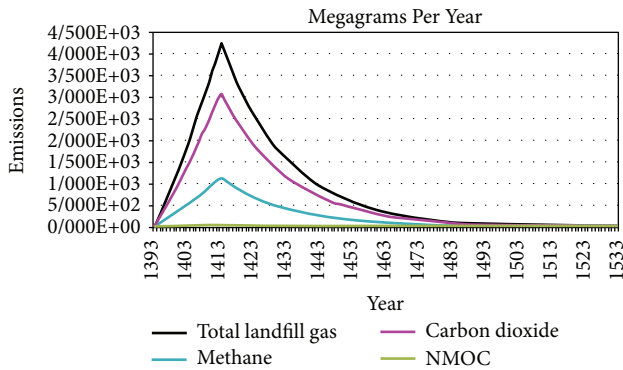


FIGURE 4: Methane emission curve in mg per year.

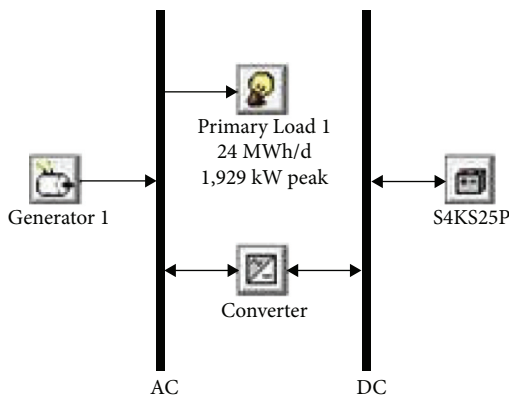


FIGURE 5: The landfill simulation with capacity of 1 MW.

According to the results of the Homer software, the environmental analysis shows that with setting up of this plant, the emission of carbon dioxide can be reduced by 7433850 kg/year and carbon monoxide gas by 25052 kg/year and other toxic gases to a specified extent.

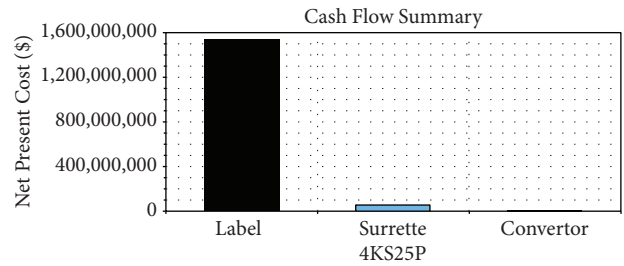
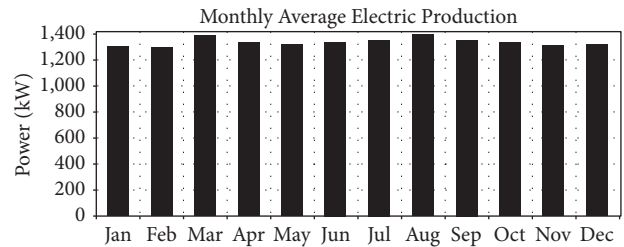


FIGURE 6: The result of 1 MW landfill simulation by Homer.



— Generator 1

FIGURE 7: The result of 1 MW landfill simulation by Homer.

TABLE 6: Environmental analysis of the biomass power plant.

Pollutant	Emissions (kg/yr)
CO <sub>2</sub>	7433.85
CO	25052
NO <sub>x</sub>	223542
SO <sub>2</sub>	19635
Unburned hydrocarbons	2775
Particulate matter	1889

### 4. Conclusions

Increasing population, increasing energy consumption, pollution of fossil fuels, environmental pollution, and declining resource resources have prompted researchers to research alternative fuels. Alternative fuels that do not have the mentioned problems can be sources such as solar, wind, biomass, geothermal, and hydropower, among which biomass resources seems to be a good option due to its presence in all areas. Biomass energy is available in all places where there is population, and the larger the population, the higher the amount of this resource, so it is suitable for cities with high population. With this method, in addition to producing energy and supplying part of the energy required by the area, pollution caused by this type of source can also be prevented. In order to supply the required electrical energy of the study area from biomass energy, first, the amount of biomass production estimated for 20 years has been done using the LandGEM and EViews software and then, the Homer software has been used for economic, environmental, and energy analysis. From the results of this research, it can be said that

- (1) Nonreliance on fossil fuels due to their high and rising costs and the expiration of their content
- (2) Diversification of energy sources in order to ensure its security
- (3) Reduce fuel consumption, export, storage, or production of more value-added oil derivatives
- (4) Reducing greenhouse gas emissions and eliminating environmental pollutants

## Data Availability

The data used to support the findings of this study are included within the article.

## Conflicts of Interest

The authors declare that there are no conflicts of interest.

## Acknowledgments

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