Progress in Engineering Application and Technology Vol. 3 No. 2 (2022) 945-955

PEAT

Homepage: http://publisher.uthm.edu.my/periodicals/index.php/peat
e-ISSN : 2773-5303

Biofuel in Yemen; an alternative energy resource toward sustainability

Fozy Binhweel[1,2], Murad Bahadi[3], Godswill Sambo[1], Md. Sohrab Hossain[1], Mardiana Idayu Ahmad[1*]

[1] Environmental Technology Division, School of Industrial Technology, Universiti Sains Malaysia, 11800 Penang, MALAYSIA

[2] Faculty of Environmental Science and Marine Biology, Hadhramout University, Hahdramout, YEMEN

[3] Faculty of Education, Hadhramout University, Hadhramout, YEMEN

*Corresponding Author Designation

DOI: https://doi.org/10.30880/peat.2022.03.02.094
Received 27 January 2022; Accepted 20 July 2022; Available online 10 December 2022

Abstract : Yemen, as one of the third world countries, heavily depends on fossil fuel as a primary resource of energy. Despite being an oil exporter, the country, with around 30 million population, lacks the accessible energy for a long time. Outbreak of the armed conflict in 2015 made matters worse. Hindering oil industry, falling oil imports to 1 %, and losing 90 % of the Yemeni people for the public power supplies are among the manifestations. Besides the energy scarcity, Yemen is in the list of the top three countries generating biomass wastes in the Middle East and North Africa Region (MENA). Around 3.8 million tons of wastes are generated annually, mostly agricultural residues and organic wastes. People used the discarded biomass to utilize their own energy needs in a primitive method like fuelwood and charcoal. The bright side is that these amounts of discarded biomass can open horizons to biofuel industry. Biofuel is a promising and sustainable energy resource to meet the energy demands in Yemen. The biofuel products, which include biodiesel, biogas, and bio-oil, are suitable substitute for the conventional petroleum fuel without any modifications in the engines, storing, and transporting gadgets. Even though, modest initiatives and projects were launched to exploit the discarded biomass for biofuel production in Yemen, this paper intends to overview the energy status in Yemen and review the studies regarding biofuel productions on both lab and industrial scales to meet the country's energy demand, considering the economic and environmental impacts.

Keywords: Biofuel, Biodiesel, Biogas, Bio-oil, Biomass, Renewable Energy, Yemen

**Corresponding author: mardianaidayu@usm.my*

1. Introduction

Republic of Yemen is considered one of the oil producing and exporting countries. According to the statistics of the Yemeni ministry of oil and minerals, the highest production of oil was 438,501 bbl/day in 2001. As a result of extensive extraction, the oil production depleted to about 142,264 bbl/d in 2015 [1]. Most of the Yemeni extracted oil was exported overseas as a crude oil instead of covering the local needs. The paradox is that Yemeni energy industry covers only 30 % of the energy needs while 70 % of the energy consumed in Yemen is imported from outside sources [2]. Unfortunately, the armed conflict in 2015 crippled the oil industry. Since then, Yemen experiences energy crisis. As a developing country, Yemen is mostly depending on the fossil fuel as an energy resource, namely diesel, gasoline, Liquified Natural Gas (LNG), heavy oil and kerosine. Devastating internal and external disorders disrupted the energy supplies. According to the United Nations (UN) estimations, about 90% of the Yemeni population lost the electrical power supplies completely [3]. Consequently, the oil exporting country is classified as one of the poorest countries in the energy resources.

Putting aside the environmental impact, lacking the energy resources led to complicated economic, social, and health issues. Water supplies were disrupted significantly because of the shortage in diesel fuel to operate the water pumps since Yemen depends on groundwater as a source of freshwater. Furthermore, the agricultural sector was impacted negatively due to the limitations of energy resources required to water the crops. Most of the industrial and commercial activities, which account for 28% of the energy consumption in Yemen, were halted due to the inadequacy of power supplies [4]. Also, transportation vehicles became either unavailable in cases of fuel inexistence or unaffordable when the fuel is available at higher prices. Consequently, thousands of people who work in the transportation sector lost their jobs, students cannot move to their schools and universities, workers find difficulties to reach their work premises, Municipal Solid Wastes (MSW) were accumulated in the streets because the garbage trucks ran out of the diesel fuel, and function disruptions in the governmental centers [5]. The negative impacts on the economic, social, and environmental aspects increases rapidly as the armed conflict becomes worse.

Yemeni people tended to manage their energy needs using alternative resources of energy outside the governmental framework. Electrical diesel-generators are used to generate electricity for houses either by householders or private electricity vendors. This approach is used just in case the diesel fuel is available, which is limited cases because of supplies disruptions. The other choice is the photovoltaic solar panels that provide simple solution for lighting houses and switching on the electrical devices that do not need high current intensity. Although these resilient solutions exist, they cannot fill the expanding gap of energy resources.

Biofuel is a promising approach to contribute covering parts of the energy demands in Yemen. Biofuel commonly refers to biodiesel, bio-oil, and biogas synthesized from organic feedstocks whether plants, animal fats, leftover wastes, or sludge. It is mostly used to heat houses, power electricity stations, and operate transportation vehicles [6]. Biofuel has the advantages of being eco-friendly fuel, synthesized from organic materials, biodegradable, less toxic emission, applicable as a substitute for current engines without modifications, and affordable in case of accessible raw materials [7]. So, biofuel is considered as a real competition to the fossil fuel as it contributes to covering the people's needs of energy.

Since Yemen is blessed with a wide range of the natural and agricultural green cover, tremendous amounts of biomass are reported every year as vegetative wastes. Additionally, sorted wastes include animals' barns wastes, food industry wastes, organic municipal wastes, and sewage sludge can be a potential rich source of biomass to synthesize different kinds of biofuel [8]. Based on literature, there were attempts to produce biodiesel and biogas on both lab and industrial scales [5], [9]–[11]. Zabara & Ahmad [12], concluded that there is a high potentiality for a blooming biofuel industry in Yemen because of the high abundance of the biomass. However, Al-Shetwi et al. [3], reported that producing

biofuel in Yemen is limited by technology and investment. Intensive investigations are required to establish a solid biofuel industry in Yemen. Hence, this paper aims to give an overview about the energy status in Yemen and to review the previous studies regarding synthesizing biofuel as an alternative and potential approach to meet the expanding energy demand.

2. Energy outlines in Yemen

2.1 Fuel resources & consumption

Yemen mostly depends on the fossil fuel as a main resource of energy. The most common oil products are gasoline, diesel, heavy oil, LNG, and kerosine. According to a statistics before the armed conflict in 2015 made by the Oxford institute for energy studies, the annual consumption of oil products in Yemen was 2.6 barrels / capita [13]. **Figure 1** shows distribution of the fuel consumption on different sectors. Transportation sector, which uses gasoline and diesel fuel, is responsible for 40% of the fuel consumption in Yemen [14]. It was reported that 45 million liters of diesel fuel was consumed annually in the transportation sector, agricultural, and household activities. Kerosine is heavily used in the rural area as a resource of energy for cooking and lighting. For the heavy oil, it is exclusively used for power stations and the giant pump stations. Compared to the liquid fuels, LNG is considered the cheapest fuel in Yemen. Based on the statistics of the energy consumption, about 78 % of the Yemeni people used LNG for cooking, lighting homes, heating spaces, and generating power [13].

Fuel supplies were disrupted currently. The documents from the Yemeni ministry of oil and minerals refer to a decline estimated by 96.2 % in the oil production compared with the highest production point before the armed conflict [1]. In 2016, UN statistics reported that the fuel imports in Yemen declined by 1 % of the monthly needs [15]. This fuel scarcity led to transportation disruptions, hindering the industrial and commercial activities, decreasing the agricultural production, electricity blockade, and other devastating economic and social impacts.

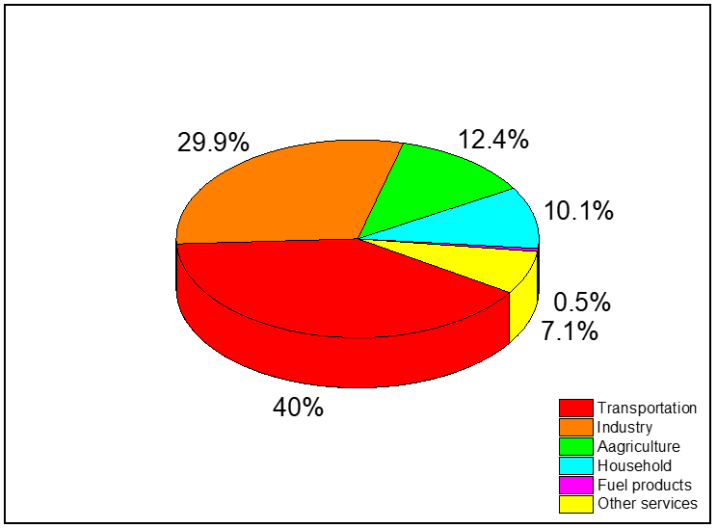

Figure 1. Distribution of fuel consumption on different sectors in Yemen before the armed conflict in 2015 [14]

2.2 Electricity generation & distribution

Yemen is considered as one of the poorest countries in the electrification [13]. Only 40 % of 30 million people dwelling in Yemen have access to the public electrical grid. Most of them are in urban areas. The total demand of electrical power was 2,650 MW. However, the public electrical grid covered only 52.8 % of the power demand [3]. **Figure 2** shows the distribution of the electrical power consumption on the different sectors. According to the UN reports, about 90 % of the Yemeni people

lost the power supplies after 2015 [3]. Resilience initiatives were triggered to provide electrical current represented in diesel-powered generators and private electrical vendors. However, fuel supplies disruption hinders the efforts [16].

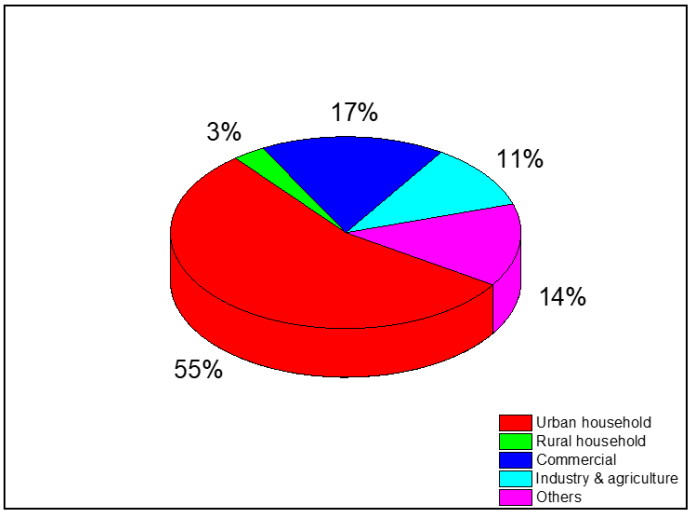

Figure 2. Distribution of the electrical power consumption on the different sectors in Yemen before the armed conflict in 2015 [3], [4]

3. Biomass generation

Yemen is one of the three countries in the Middle East and North Africa (MENA) that produce the major quantities of the biomass. Most of the biomass comes from the agricultural wastes, wastewater sludge, industrial wastes, and MSW. 3.8 million tons with 3 % annual growth was the total production of the MSW in Yemen [12]. **Figure 3** shows the distribution of the MSW composition. As one of the third world countries, Yemen still disposes these MSW in the landfills prepared for this purpose. In addition, most of the agriculture residues and MSW find their ways to the water bodies by means of natural runoff or intended dumping. Beside the negative environmental impacts resulted from such approaches, the biomass is wasted rather than being lucrative. Multiple approaches are applied using biomass wastes to produce worthy products. For example, fertilizers, construction bricks and cement, bioplastic, extracting specific chemicals, and biofuels are among profitable applications [17], [18]. Since this review is interested in the biofuel production in Yemen, the discussion is limited in utilizing biofuel from the biomass generated in Yemen.

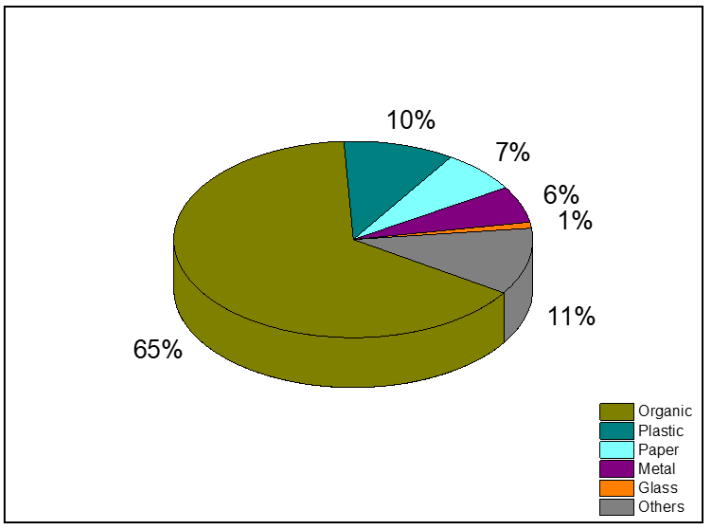

Figure 3. Distribution of MSW composition in Yemen [3], [12]

4. Biofuel production in Yemen

4.1 Primitive utilization of biomass energy

In response to compensate the energy gap, most of the Yemeni people relied on the biomass to provide their daily needs of energy. Primitive applications were implemented to utilize the biomass energy needed for household purposes. The most known forms of biomass used by the householders are fuelwoods, crop and animal wastes, and processed charcoals. The most intensively used biomass is fuelwood. It was reported that about 74% of the Yemeni households used fuelwoods for the purposes of cooking, heating, and lighting. They get their fuelwoods' supplies either by collecting fuelwoods themselves or from the fuelwood vendors. The averaged collected amounts of fuelwoods were estimated as 98.6 kg / household / month. The agricultural and animals' wastes are collected by local people. They mix these wastes with the fuelwoods and charcoals to increase the intensity of the energy produced for cooking and heating. In most cases, the agricultural and animals' residues are used in the rural areas where the raw materials are available nearby. Charcoals are mostly processed and treated by the suppliers. The consumers usually buy their needs of the charcoals, which are mostly used for cooking, directly from the local vendors. Such traditional methods offered affordable energy resources for the Yemenis, particularly for the low-income rates. **Table 1** gives details about the primitive utilization of the traditional biomass forms [12], [13].

Table 1. Primitive utilization of biomass energy in Yemen [12], [13]

Biomass form	purpose	Supply	Usage (% households)
Fuelwoods	- Cooking. - Heating. - Lighting.	- Residential collectors. - Fuelwood vendors.	74 %
Crop and animal wastes	- Cooking. - Heating.	- Residential collectors.	23 %
Charcoals	- Cooking. - Heating.	- Charcoal vendors.	18 %

4.2 Modern techniques of biofuel production

Modern conversion techniques are used to utilize biofuel from the biomass efficiently. Biofuel synthesis includes biogas (methane and syngas), biodiesel, and bio-oil. Beside the synthesis, the direct combustion of biomass is one of the most practical and widely used technique result in very hot steam to generate power [12]. **Table 2** elaborates the different technologies for the biofuel production.

Table 2. Modern techniques for biofuel production

Technique	Process type	Preferable biomass	Biofuel product	Reference
Transesterification	Chemical	- Vegetative oils - Animal fats - Sludge	Biodiesel	[19], [20]
Pyrolysis	Thermochemical	- Agricultural wastes - MSW	Bio-oil	[21]
Gasification	- Thermochemical - Biochemical	- Agricultural wastes - Mixed wastes	- Methanol - Ethanol - Dimethyl ether - Synthetic natural gas - Hydrogen	[22]
Direct combustion	Thermal	- MSW - Agricultural wastes	Hot steam	[23]

Despite of blooming raw biomass in Yemen, biofuel industry is still limited because of lacking investments, equipped premises, and expertise personnel. However, there were some attempts for biofuel synthesis in both lab and industrial scales. Those attempts are explored in the following subsections.

4.2.1 Biodiesel

Biodiesel is chemically known as fatty acids methyl or ethyl esters [20]. Hence, it is a promising fuel for the energy industry in Yemen which can contribute to meet the high demand of energy resources. According to Bhuiya et al. [24], about 70 to 95 % of biodiesel production costs are related to the feedstock. Yemen has affordable green feedstock for biodiesel production. In addition to what have been reported before about the agricultural residue and organic wastes, Yemen has a variety of natural and man-made green cover all around the country which can be a potential oil source for the biodiesel industry [10]. The Small and Micro Enterprise Promotion Service (SMEPS), non-government organization promoting the development projects, established two industrial projects for the biodiesel production from waste cooking oil. The initial studies showed promising results. The synthesized biodiesel is worthy if the production line reaches 2000 L/day with a pricing policy 0.62 USD for each letter. If the production line falls below, the industrial production of waste cooking oil-based biodiesel would not be worthy. The advantage of biodiesel production is the capability of the fuel to be a substitute for the diesel without any modifications in the engines which will meet the people's needs.

A few studies were conducted to produce biodiesel fuel in Yemen. Baggash & Abdulrahman [10], used jatropha curcas as a feedstock to produce biodiesel. Based on their study, jatropha curcas is a good potential source for the fatty acids required for the biodiesel production in Yemen since these plants have the advantage of fast growth, high oil productivity, and suitability for the Yemeni environment. The oil was extracted from jatropha curcas by a traditional method to be further subjected to the base-catalyzed transesterification reaction with alcohol methanol. The conversion percentage was 80 % as biodiesel which was characterized based on the cloud point (- 10 °C) and the flash point (167 °C). The study came up to confirm the possibility of the biodiesel production from jatropha curcas on the industrial scale to cover some of the energy needs. In contrast, Mohammed et al. [9], used the frying oil instead of extracting oil from the vegetative feedstock. According to their study, Yemen consumes 113,182.64 tons / year of cooking oils. Around 1,799 liters of waste cooking oil are collected on a daily basis from Taiz state, where the study samples had been collected from. The best yield of biodiesel was 96%. It was obtained based on the optimized values 25 % wt methanol, 0.78 % wt NaOH catalyst, and 70 °C for the reaction temperature. The characterizations of the obtained biodiesel are revealed in **Table 3**. The output of the study is that waste frying oil is a lucrative source for the industrial production of

Table 3. Summary of the studies conducted for biodiesel production in Yemen

Items	Al-attab et al. [5]	Mohammed et al. [9]	Baggash & Abdulrahman [10]
Raw material	Waste cooking oil	Frying oil	Jatropha Curcas
Density at 15 °C (kg/m^3)	870	840	N/A
Kinematic viscosity at 40 °C (mm^2/s)	N/A	2.6	N/A
Cloud point (°C)	N/A	5	-10
Pour point (°C)	N/A	2	N/A
Flash point (°C)	100	156	167
Cetane number	N/A	54.4	N/A
Heating value (MJ/kg)	37	N/A	N/A

the biodiesel fuel in Yemen. Finally, Al-attab et al. [5], conducted techno-economic investigation about producing biodiesel from waste cooking oil in Yemen. The highest yield of the biodiesel was 87.2 %

obtained at 166.5 ml methanol and 5 g of NaOH for each liter of purified waste cooking oil. Physicochemical properties of the synthesized biodiesel are shown in **Table 3**. The investigation concluded the possibility of biodiesel production from the waste cooking oil and it will be economically feasible just in case production line is 2000 liter / day and above.

4.2.2 Biogas

Biogas production in Yemen is quite funded. **Table 4** shows 6 biogas production projects in Yemen since 1990. The reasons behind the ample funding in the biogas production projects are the availability of the raw materials, possibility of small biogas plants, the expanding demand on biogas, and for the environmental considerations, particularly for the international donors. Since 1 ton of wastes produces 50 m3 of biogas fuel, experts estimate 5,000 m3/day of biogas production from Sana'a city which produces more than 1,000 tons of wastes every day. This amount of biogas generates 30 MWh. Taking the fact that the average energy consumption for the Yemeni household is 6 kWh would make this amount of energy meets the demand of 5, 000 Yemeni household [3], [4].

Lab-scale biogas production was conducted using cow dungs and wastes of qat plant leaves, a very popular plant in Yemen. Jaml & Ghalibi [25], caried a study to produce biogas from cow dungs through fermentation process. The results of the study showed that flammable gas was synthesized from the anaerobic digestion process of the cow dung. The biogas production process is greatly influenced by the ambient temperature. The biogas produced in summer, measured by water displacement, was 2,880 mL. this quantity was reduced 86.91 % in the winter. The study included isolating and identifying 11 species of methanic and non-methanic bacteria. The study concluded that animal residues can be relied on to produce household biogas. More extensively, Alkatf [26], conducted investigation to enhance the biogas production process from a steady mixture ratio of cow dung and the waste of the qat plant leaves, which is a very famous plant in Yemen used for euphoria. The highest yield of biogas obtained from the experiment was 3,505 ml. This amount of biogas was obtained within mixture ratio 1:1 cow dung to qat plant leaves. The investigation came to say that biogas industry in Yemen can be enhanced through using mixture of animal and plant residues.

Table 4. Projects of biogas production in Yemen [12], [27]

Project	Donor	Construction place	Start	Product	Status
MSW management and biogas project	World Bank	48 cities.	1990	Cooking Biogas	Constructed
Biogas plants project	Local government	2 coastal zones in Shabwah	N/A	Biogas fuel	Constructed
Infrastructure of MSW project	- World Bank - Social Fund Development (SFD)	Shabwah	N/A	Biogas fuel	Infrastructure
MSW management system	Internal fund	- Sana'a - Taiz	2010	Cooking Biogas	Feasibility study
Treatment plant for fecal sludge and kitchen wastes	Internal fund	Sana'a	2012	Household biogas	Promotion
Enhancement project of biogas production from manure in the villages	World Bank	Sana'a	2014	Household biogas	Constructed

4.2.3 Bio-oil

Bio-oil was synthesized in Yemen in the lab-scale as a part of the mutual agreement between Sana'a university represented by water and environment center and the Dutch MetaMeta research center. The

initial objective behind this common project is to suggest an approach to treat the wastewaters. It includes extracting activated carbon (AC) from the sewage sludge and checking the characteristics of the extracted AC. Pyrolysis process, within temperature range between 400–800 °C, was conducted for this purpose. The condensable volatiles tars, or what is called liquid bio-oil, was the product of the pyrolysis process. Based on the outcomes of the project, the bio-oil production can be flourished on industrial basis to meet some of the expanding energy demands in Yemen [12].

4.3 Comparing renewable energy technologies

Yemen land is rich in potential renewable energy resources. In addition to bioenergy, the solar, wind, and geothermal energies are promising to meet the energy needs of Yemeni people. The vast desert areas that receive daily solar radiation range between 5.21 – 7.23 kWh/m2 have estimated potential production of solar energy around 2.5 TWh [3], [28]. Comparing with solar energy, the estimations of potential wind energy is higher more than three times where it reached around 8.3 TWh [3]. This higher estimation comes from the long coastal line and wide mountainous areas that receive wind speed 8 and 6 m/s for the coastal line and mountains, respectively [4], [29]. In contrast, the estimation of potential geothermal energy is lower. It was estimated as 0.0285 TWh. Although estimation of potential bioenergy is 0.114 TWh, it has the advantage of close physicochemical properties of fossil fuel which does not require additional modifications. Moreover, the utilizing biomass toward biofuel production is a good initiative to reduce the accumulated MSW. **Table 5** compares between the potential renewable energies in Yemen.

Table 5. Comparison of possibility of bioenergy with other potential renewable energies in Yemen

Solar energy	Wind energy	Geothermal energy	Bioenergy
- Average solar radiation is 5.21 - 7.23 kWh/m^2/day [3].	- Yemen has wide mountainous areas and 2500 km of coastal line [3].	- Yemen is one of 10% of the world's regions with geological hot spots [30].	- 3.8 million tons of MSW are generated annually [12].
- Averages sunshine is 7.3 – 9.1 hours/day [3].	- Average wind speed is 8 m/s in autumn [4].	- Yemen has heat flow potential 60 MW/cm^2 [31], [32].	- 65% of generated wastes are organic.
- The annual average temperature is 21 - 31◦C [28].	- Average wind speed in mountainous areas is around 6 m/s in July [3], [29].	- The temperature of some geothermal reservoirs ranges between 70-140 ◦C [4].	- 1 ton of wastes can generate 0.03 MWh.
- Theoretically, the potential solar energy is 2.5 TWh [28].	- The potential average of wind energy is around 8.3 TWh [3].	- The potential geothermal energy is 0.0285 TWh [33].	- Based on estimations, the potential bioenergy production is 0.114 TWh.

5. Conclusion

Yemen is one of the developing countries experiencing insufficient energy resources long time ago. The armed conflict in 2015 made the matter worse. The oil extraction was almost halted, fuel imports fell to 1%, and 90 % of the Yemeni people lost the public power supplies. On the other hand, Yemen still suffers from accumulated agricultural residues and municipal solid wastes that threatens the purity of the environment. However, the bright side is that the discarded biomass wastes can be used to synthesize eco-friendly biofuel. A few studies and projects were conducted to produce biodiesel, biogas, and bio-oil on both lab and industrial scales. Even though utilizing biofuel from the discarded biomass will impact positively on the environment, it will also help to reduce the gap between demand and supply for the energy resources in Yemen.

Acknowledgement

The authors would like to thank the Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia (UTHM) for its support.

References

[1] YMOM, "Oil Production," Yemeni Ministry of Oil and Minerals, 2021. http://mom-ye.com/site-ar/القطاعات-الإنتاجية/ [Accessed Jul. 25, 2021].

[2] S. Twigg, "Yemen: the devastation of a nation, largely ignored," The Guardian, 2016. https://www.theguardian.com/global-development/2016/jan/27/yemen-devastation-nation-largely-ignored-uk-paradox-aid-arms-saudi-arabia [Accessed Jul. 26, 2021].

[3] A. Q. Al-Shetwi et al., "Utilization of Renewable Energy for Power Sector in Yemen: Current Status and Potential Capabilities," IEEE Access, 2021, doi: 10.1109/ACCESS.2021.3084514.

[4] A. Q. S. Qasem, "Applications of renewable energy in Yemen," J. Fundam. Renew. Energy Appl., vol. 8, no. 1, 2018, doi: 10.4172/2090-4541.1000254.

[5] K. Al-attab, A. Wahas, N. Almoqry, and S. Alqubati, "Biodiesel production from waste cooking oil in Yemen: a techno-economic investigation," Biofuels, vol. 8, no. 1, pp. 17–27, 2017, doi: 10.1080/17597269.2016.1196326.

[6] S. J. Malode, K. K. Prabhu, R. J. Mascarenhas, N. P. Shetti, and T. M. Aminabhavi, "Recent advances and viability in biofuel production," Energy Convers. Manag. X, vol. 10, p. 100070, 2021, doi: 10.1016/j.ecmx.2020.100070.

[7] S. Sharma, A. Kundu, S. Basu, N. P. Shetti, and T. M. Aminabhavi, "Sustainable environmental management and related biofuel technologies," J. Environ. Manage., vol. 273, p. 111096, 2020, doi: https://doi.org/10.1016/j.jenvman.2020.111096.

[8] M. A. Hannan et al., "Waste collection route optimisation model for linking cost saving and emission reduction to achieve sustainable development goals," Sustain. Cities Soc., vol. 62, p. 102393, 2020, doi: https://doi.org/10.1016/j.scs.2020.102393.

[9] B. G. Mohammed, A. M. Badiea, and S. Q. Moad, "Production of Biodiesel Fuel From Cooking Oil Waste," no. July, pp. 582–588, 2016.

[10] M. Baggash and A. Abdulrahman, "Production and testing of biodiesel fuel from Jatropha Curcas (Al-Sharb) in Yemen," Int. J. Renew. Energy, vol. 5, no. 2, 2010.

[11] N. L. Jaml, S. M. Ghalibi, and K. Biogas, "Research Article Biogas Production From Cow Dung and Isolation of Methanogenic Bacteria in Yemen," vol. 1, no. 2, pp. 105–110, 2020.

[12] B. Zabara and A. A. Ahmad, "Biomass Waste in Yemen: Management and Challenges," in Waste Management in MENA Regions, Springer, 2020, pp. 313–336.

[13] L. El-Katiri and B. Fattouh, Energy Poverty in the Arab World : The Case of Yemen, vol. 44, no. 0. 2011.

[14] C. Breisinger, W. Engelke, and O. Ecker, "Petroleum subsidies in Yemen: Leveraging reform for development," World Bank Policy Res. Work. Pap., no. 5577, 2011.

[15] United Nations, "2016 Humanitarian Needs Overview," vol. 1, pp. 1689–1699, 2016.

[16] M. Al-Saidi, E. L. Roach, and B. A. H. Al-Saeedi, "Conflict Resilience of Water and Energy Supply Infrastructure: Insights from Yemen," Water, vol. 12, no. 11, p. 3269, 2020, doi: 10.3390/w12113269.

[17] F. Hussain et al., "Microalgae an ecofriendly and sustainable wastewater treatment option: Biomass application in biofuel and bio-fertilizer production. A review," Renew. Sustain. Energy Rev., vol. 137, p. 110603, 2021, doi: 10.1016/j.rser.2020.110603.

[18] K.-R. Hwang, W. Jeon, S. Y. Lee, M.-S. Kim, and Y.-K. Park, "Sustainable bioplastics: Recent progress in the production of bio-building blocks for the bio-based next-generation polymer PEF," Chem. Eng. J., vol. 390, p. 124636, 2020, doi: 10.1016/j.cej.2020.124636.

[19] M. Athar and S. Zaidi, "A review of the feedstocks, catalysts, and intensification techniques for sustainable biodiesel production," J. Environ. Chem. Eng., p. 104523, 2020, doi: 10.1016/j.jece.2020.104523.

[20] F. Binhweel, M. Bahadi, H. Pyar, A. Alsaedi, S. Hossain, and M. I. Ahmad, "A comparative review of some physicochemical properties of biodiesels synthesized from different generations of vegetative oils," J. Phys. Conf. Ser., vol. 1900, no. 1, p. 12009, 2021, doi: 10.1088/1742-6596/1900/1/012009.

[21] R. E. Guedes, A. S. Luna, and A. R. Torres, "Operating parameters for bio-oil production in biomass pyrolysis: A review," J. Anal. Appl. Pyrolysis, vol. 129, pp. 134–149, 2018, doi: 10.1016/j.jaap.2017.11.019.

[22] A. Molino, V. Larocca, S. Chianese, and D. Musmarra, "Biofuels production by biomass gasification: A review," Energies, vol. 11, no. 4, p. 811, 2018, doi: 10.3390/en11040811.

[23] A. Briones-Hidrovo, J. Copa, L. A. C. Tarelho, C. Gonçalves, T. P. da Costa, and A. C. Dias, "Environmental and energy performance of residual forest biomass for electricity generation: Gasification vs. combustion," J. Clean. Prod., vol. 289, p. 125680, 2021, doi: 10.1016/j.jclepro.2020.125680.

[24] M. M. K. Bhuiya, M. G. Rasul, M. M. K. Khan, and N. Ashwath, "Biodiesel production and characterisation of poppy (Papaver somniferum L.) seed oil methyl ester as a source of 2nd generation biodiesel feedstock," Ind. Crops Prod., vol. 152, p. 112493, 2020, doi: 10.1016/j.indcrop.2020.112493.

[25] N. L. Jaml and S. M. Ghalibi, "Biogas production from cow dung and isolation of methanogenic and non-methanogenic bacteria in Yemen," Electron. J. Univ. Aden Basic Appl. Sci., vol. 1, no. 2, pp. 105–110, 2020.

[26] A. A. Y. Alkatf, "Generation of Biogas from Qat and Cow Dung using Anaerobic Co-digestion." University of Gezira, 2018, [Online]. Available: http://repo.uofg.edu.sd/handle/123456789/3325.

[27] O. Forni, A. Short, B. Grundy, M. Bjerregaard, and R. Salemdeeb, "Emergency Waste Assessment in Yemen," Undp, no. August, p. 60, 2015, doi: 10.13140/RG.2.1.3255.6880.

[28] M. Hadwan and A. Alkholidi, "Solar power energy solutions for Yemeni rural villages and desert communities," Renew. Sustain. Energy Rev., vol. 57, pp. 838–849, 2016, doi: 10.1016/j.rser.2015.12.125.

[29] A.-B. Mahyoub H and A.-H. Ahmed, "Monthly and seasonal investigation of wind characteristics and assessment of wind energy potential in Al-Mokha, Yemen," Energy Power Eng., vol. 2012, 2012, doi: 10.4236/epe.2012.43017.

[30] A. Minissale et al., "Geothermal prospecting by geochemical methods in the Quaternary volcanic province of Dhamar (central Yemen)," J. Volcanol. Geotherm. Res., vol. 249, pp. 95–108, 2013, doi: 10.1016/j.jvolgeores.2012.09.013.

[31] M. Adele et al., "Geothermal Energy Use, Country Update for Italy," 2019.

[32] M. L. Parisi, N. Ferrara, L. Torsello, and R. Basosi, "Life cycle assessment of atmospheric emission profiles of the Italian geothermal power plants," J. Clean. Prod., vol. 234, pp. 881–894, 2019, doi: 10.1016/j.jclepro.2019.06.222.

[33] A. M. Al-Ashwal, "Energy efficiency and conservation indicators in Yemen," Futur. Cities Environ., vol. 2, no. 1, p. 3, 2016, doi: 10.1186/s40984-016-0016-0.