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Utilization of Renewable Energy for Power Sector in Yemen: Current Status and Potential Capabilities

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ABSTRACT A severe energy crisis has plagued Yemen for decades, and most of the population lack access to electricity. This has harmed the country's economic, social, and industrial growth. Yemen generates electricity mainly from fossil fuels, despite having a high potential for renewable energy. Unfortunately, the situation has recently been compounded by the country's continuing war, which has been ongoing since early 2015. It has impacted the country's energy infrastructure negatively, resulting in power outages. Therefore, this paper aims to provide an updated perspective on Yemen's current energy crisis and explain its key issues and potential solutions. Besides, it examines the potential, development, and current state of renewable energy sources, such as solar, wind, geothermal, and biomass. Based on the findings, Yemen is one of the world's wealthiest countries in terms of sunlight and wind speed, and these two resources are abundant in all regions of the country. In addition, this paper sheds light on the solar energy revolution that has arisen since the war started due to the complete outage of the national electricity. Within a few years, solar energy in Yemen has increased its capacity by 50 times and has recently become the primary source of electricity for most Yemenis. Furthermore, the paper discusses the difficulties and challenges that face the implementation of renewable energy investment projects. Numerous recommendations for potential improvements in Yemen's widespread use of renewable energy are also provided in this paper. All of the ideas presented in this paper are hoped to increase the efforts to grow renewable energy production in Yemen, thereby solving the issues of energy poverty and reducing environmental effects. The presented analysis can be used as a scientific reference for researchers and industrial companies looking for suitable solutions to advance Yemen's renewable energy.

INDEX TERMS Renewable energy sources, Yemen electricity, energy access, power sector, barriers, wind energy, climate change, Yemen's solar revolution.

I. INTRODUCTION

The main concern in today's world is to meet the sustainable development goals (SDGs) and contribute to the well-being of societies around the world. In this regard, certain SDGs im to reduce poverty, provide affordable and clean energy, and reduce climate change by 2030. One key strategy to attaining those goals is to expand the share of renewable energy sources (RESs) in the global energy mix. For better livelihoods and growth, access to adequate, sustainable, and cost-effective

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energy supply is necessary. It is an effective way of reducing poverty, income improvement, better education, improving healthcare, and other areas of development [1]. In 2019, more than 200 GW of new renewable power generating capacity was installed, raising the global total to 2,588 GW by year's end. Overall, the installed renewable energy (RE) capacity is estimated to provide 27.3% of the global electricity generation. Hydropower still made up the majority (58%) of this estimated generation share, followed by wind power (22%), solar PV (10%), bio-power (8%), and others (0.4%). Considering cumulative RE capacity, China remained the global leader, followed by the United States, Brazil, India, and Germany [2]. Some developing and underdeveloped countries starts to increase RE capacity to cover the lack of grid supply. For instance, RE installed capacity accounts for 22.5% of India's total installed capacity for power production and planning to achieve 40% by 2030 [3]. Bangladesh is unable to provide sufficient support for grid extension and supplying electricity to remote or rural areas. Therefore, RE was an optimal solution in powering irrigation systems and rural electrification [4]. Although the RE can enhance the electrification in rural communities, unfortunately, based on the United Nations (UN) [5], electricity is still unavailable for one in seven people, where the bulk of them live in the developing world's rural areas. In this context, the World Bank figures show that 67% of rural inhabitants live without electricity in developing countries across the globe [6].

Similar to other developing countries, 75% of the Yemeni people reside in rural areas, and electricity is only available to about 23% of those areas. In general, only 40% of the country's population have electricity access. Nearly half of those communities are linked to the public grid, while the other half gain access via private sources such as home photovoltaic (PV) systems and diesel generators that normally operate in lighting and low-intensity electrical appliances over a few hours a day [7]. However, those having access to the electrical grid suffer from long hours of power cuts because of the gap between generation and loads and sporadic vandalism of power lines and power plants. This became worse in 2015 when the condition in Yemen did turn into external and internal conflicts. Throughout the conflict that is still going on until now, the UN estimates that more than 90% of the country's population lost electricity, and most cities are in complete darkness [8]. Among this darkness, solar energy appeared as an effective solution to the total power outage. According to [9], nearly 85% of households in the mountainous areas around the capital (Sana'a) own solar panels, an example of the solar revolution during the war.

Nonetheless, if the conflicts and war are left aside, Yemen's power sector still has many real obstacles and a huge gap that need urgent solutions. According to the study conducted by [10], Yemen faces a grave problem in the electricity sector in the upcoming ten years more than ever before. One of the issues and obstacles of power generation in Yemen is its dependency on fossil fuels such as diesel, liquefied natural gas, and heavy crude oil (Mazot) [11]. Such resources are of significant concern for the environment and the economy [12]. Another obstacle is the ageing of most existing generation plants, as the majority of them are outdated and have long since reached the end of their life [13], [14]. In addition, electricity in Yemen is currently available to only about 40% of the population, whose geographical distribution represents another challenge to the distribution of electrical energy. According to [15], three-quarters of the population live in rural and remote areas, some of which may be high mountain or desert areas, and get only a fifth of the power supply. Furthermore, the main current use of power in Yemen is for domestic purposes [16], and in order to fulfil industrial production requirements, a new challenge must be tackled by increasing generating capacity through the installation of several new generation plants in the future. These challenges contribute to leaving a huge power supply gap in Yemen. Overall, Yemen is going from darkness to darkness in the power sector for over 25 years.

The lack of electricity contributed to making Yemen the weakest country in the Middle East in terms of economy, education, trade, and tourism [17]. Therefore, to develop the country and alleviate its crises, a comprehensive solution to the electricity problem is required. Fortunately, the solution is in the hands of the Yemenis because the country is rich in renewables such as solar, wind, geothermal, and biomass [18]–[20]. Such plentiful renewable resources are theoretically enough to generate electricity and then fill the current energy gap. In addition, utilization of these renewable sources can contribute towards achieving SDG and provides multiple long-term benefits, including job creation, energy security, economic prospects, environmental development, and global warming prevention [21]. Despite the high potential of RESs in Yemen, there are no precise RE technology trajectories and utilization. Moreover, many constraints or barriers (e.g. technical, social, economic, policy factors, etc.) hinder effective RE development in Yemen. To highlights the RE role, there are some review and research studies were published on Yemen's renewable energy axis as in [10], [18], [15], [22]–[25], however, these studies are outdated and the RE sector does not have sufficient coverage. Therefore, the main aim and key contributions of this paper can be summarized as follows:

- Providing an up-to-date review of the potential and status of renewable energy sources and their possibility to fill the shortage gap of the power sector in Yemen.
- Reviewing and discusses the development and future target of main RES in Yemen.
- Examining the current condition of the country's power sector and the need for transferral into RE. Besides, the revolution in solar energy installation and use in the last five years, which increased to 50-fold, is also highlighted.

On the other hand, the outcomes of this research toward RE development are:

- This study may serve as a useful forum and guide for researchers and industrial companies, as well as

decision-makers, to encourage investment in RE and academic research by providing relevant information on the potential of this type of energy, obstacles, context, and challenges in Yemen.
- The information provided may help state organizations, investors, the private sector, and individuals to choose the best measures that will increase the use of RE sources toward solving the power poverty in Yemen with green electricity.

The rest of this review is organized as follows. Section 2 describes how the review is conducted. The geographical and demographic conditions of the country are covered under section 3. A comprehensive review of the electrical energy status in Yemen is presented in section 4. Potentials and current status of main RES in Yemen, especially solar, geothermal, wind, and biomass, are discussed in Sections 5 and 6. Section 7 presents the obstacles and barriers to RE development in Yemen. Finally, the conclusion of this review and some selected recommendations for further research are presented in Section 8.

II. SURVEYING METHODOLOGY

This academic research explores the RE sector by highlighting renewable energy source (RESs) prospects, progress, status, and use in Yemen via providing detailed renewables data to draw local people and foreign investors and encourage greater awareness. It also includes information gathered from many sources such as the Web of Science, Scopus, Science Direct, Researchgate, and Google Scholar databases. In addition, many other sources were utilized for gathering information used in this research study, such as: (*a*) Ministry of Electricity and Energy (MEE), (*b*) the public electricity corporation (PEC), (*c*) national office of statistics (NOS), (*d*) plans of Yemen government about RE-based hybrid power system, (*e*) the world bank, (*f*) international renewable energy agency, and (*g*) statistical review of world energy, and (*h*) UN development program (UNDP)-Yemen. The selected references have been read carefully to derive useful information about the RES potential, status, utilization, and future prospective in Yemen. To search suitable studies within the purposes and scope of this review, the authors used keywords such as Renewable energy sources, Yemen electricity, Energy access, Power sector, Barriers, Wind energy, Energy production, Climate change, and Yemen's solar revolution. The results achieved were structured into six groups. Firstly, the geographical and demographic conditions of the country were described. Secondly, the energy sector status in Yemen prior to the conflict of 2015 and the present situation were comprehensively reviewed. Thirdly and fourthly, renewable energy potential and status in Yemen, including wind, solar, geothermal, and biomass, are discussed, explained, and analyzed in detail, respectively. Next, barriers and obstacles that may prevent RE development, including technical, social, economic, institutional, and policy-related barriers, are also discussed and highlighted. Finally, a conclusion with some significant recommendations for future improvement on the wide use of RE to solve power shortage and toward sustainability and green electricity are provided. The review process can be divided into two phases as shown in Fig. 1 and summarized as follows:

A. SELECTION PROCESS

- A sum of 307 references was chosen after the primary search.
- The first assessment and screening were carried out using the appropriate keywords, title, abstract, content, and journal's main subject of interest, and accordingly, 166 references were identified.
- The second evaluation and screening were conducted using the articles' impact factor, the review process, purpose and scope of the review, and citation.
- Finally, a total of 86 references were selected for the review at this stage.

B. RESULTS OF THE REVIEW

- Geographical and demographic conditions, including the location, essential regions, environmental differences, weather conditions, and populations, were broadly reviewed.
- A comprehensive review and detailed explanation of the energy situation in Yemen before and after the conflict and civil war, types of power plants, generation capacity, electricity consumption, load types, CO_2 emission, energy access, types of fuel used, and damage on the electricity sector.
- The current status and potential RE in Yemen, especially in solar, geothermal, wind and biomass, were broadly analyzed.
- Availability of solar radiation, wind speed, geothermal, and biomass with their capacities was analyzed in detail.
- The critical obstacles and barriers of RE development in Yemen were highlighted.
- Selected suggestions for further utilization of RE to minimize cost, reducing fuel consumption and carbon emissions, achieving SDG, and fill the shortage gap of the power sector in Yemen with sustainable sources were provided.

III. GEOGRAPHICAL AND DEMOGRAPHIC CONDITIONS

The Republic of Yemen is located in Western Asia, on the southwest edge of the Arabian Peninsula, with a total area of 527,970 km^2, and is generally known as Yemen. Geographically, it is located between (43.2-53.2) longitude and (13-16)N latitude, bordered by Oman to the east, north by Saudi Arabia, south by the Gulf of Aden and Arab Sea, and west by the Red Sea, as shown in Fig. 2. The country comprises three essential regions: the coast, the desert, and the mountains. In Yemen, the sunshine is predicted to be one of the highest classes in the world, whereas; in much of the state zones, the weather is composed of two seasons: spring and summer [23], [26].

Yemen's population size rose from 7.9 million in 1980 to about 29.2 million in 2019, with an annual increase of up to 5.30% in 1992 and then dropped to 2.33% in 2019.

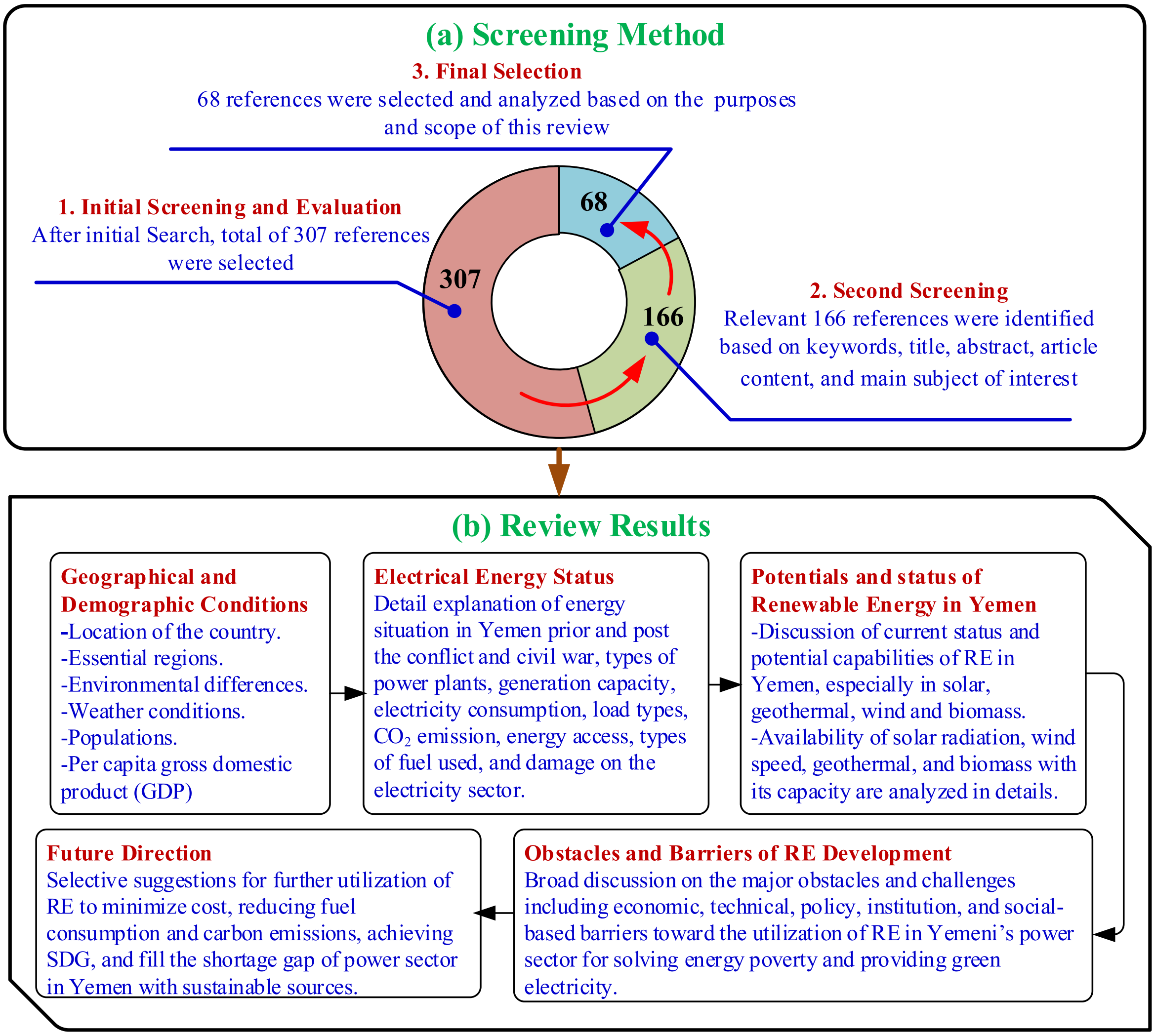

FIGURE 1. Schematic diagram of the review selection process.

FIGURE 2. Yemen location.

The majority of the population with a current ratio of 75% (21.9 million) considers rural and 25% (7.3 million) urban, as shown in Fig. 3. The population is expected to continue to rise to nearly 42.5 million by 2050 [27]. Based on the World Bank reports, Yemen is the least developed country with the per capita gross domestic product (GDP) of 1375.626 US $ in 2014; however, as a result of the civil war that started in 2015, GDP per capita decreased to 660.28 US $ in 2019 [6].

IV. ELECTRICAL ENERGY STATUS IN YEMEN

To discuss the energy situation in Yemen, this research divides the discussion into two parts. The first part is the energy status before the conflict and civil war, which is the period before 2015, while the second part would include energy from 2015 onward (during the war, which continues till now). It is important to mention that mostly all grid power supply is shut down during the war period.

A. SITUATION PRIOR TO THE CONFLICT OF 2015

The MEE in Yemen is responsible for formulating energy policy and strategy of power electricity in the country, including the licensing and control of private and industrial auto-generation. As a semi-independent part of the MEE, the PEC is responsible for transmitting, generating, and distributing electrical power via several grids [28]. The PEC generates electricity depend on conventional power plants, which rely on fossil fuels, petroleum, and its derivatives. Oil power plants are the country's largest distributed generation plants with a cumulative generating capacity of 600 MW,

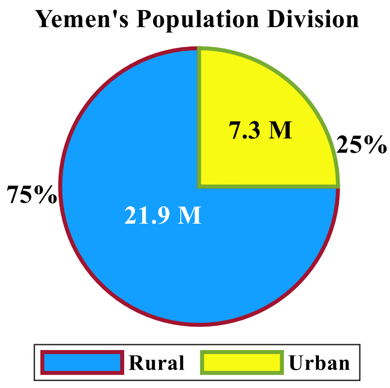

FIGURE 3. Division of Yemen population.

followed by steam and gas power plants, generating roughly 495 MW and 350 MW. Along with several small power plants located in many different regions of the country (as described in Table 1), there are four major power plants in Yemen, one gas power plant located in Ma'rib, and three other steam stations located in the Al-husoh, Mokha and Ras-katheeb regions. The Ma'rib gas power plant is the largest, with a generating capacity ranging from 340 MW to 380 MW [29]. Although Yemen has the fourth largest population in the Middle East region, its generating capacity is one of the lowest and only enough to satisfy 40% of electricity demand in the country. In general, the total generation of the power plants that follow the national grid is around 1100 GW, however; the average load demand for only load-connected national grid reaches 1400 MW (total country demand around 2650 MW). As an example, Fig. 4 shows the average load demand in June 2014 for one day based on the national control center [10], [30].

TABLE 1. Generation power plant of electrical grid.

The Station	Location (City)	Service Years	Nominal Capacity	Actual Capacity	Fuel type
Marib	Marib	10	400 MW	340-380 MW	Gas
Al-husoh 1	Aden	34	125 MW	75 MW	Mazot
Al-husoh 2	Aden	21	60 MW	60 MW	Mazot
Mokha	Taiz	34	160 MW	120-140 MW	Mazot
Ras-katheeb	Hodeidah	38	150	100-120 MW	Mazot
Hiziaz 1	Sana'a	16	30 MW	20-25 MW	Diesel
Hiziaz 2	Sana'a	15	70 MW	65-70 MW	Mazot
Hiziaz 3	Sana'a	12	30 MW	30 MW	Mazot
Dhahban 1	Sana'a	39	21 MW	10 MW	Diesel
Dhahban 2	Sana'a	19	30 MW	20-15 MW	Diesel
Sana'a 1	Sana'a	47	5 MW	5 MW	Diesel
Sana'a 2	Sana'a	15	10 MW	10 MW	Diesel
Al-Mansora 1	Aden	37	64 MW	45 MW	Diesel
Al-Mansora 2	Aden	13	70 MW	70 MW	Diesel
Khor Maksar	Aden	16	18 MW	18 MW	Diesel
Osaifirah	Taiz	16	10 MW	10 MW	Diesel
Al-Hali 1	Hodeidah	39	5 MW	5 MW	Diesel
Al-Hali 2	Hodeidah	16	10 MW	10 MW	Diesel
Ja'ar 1	Abyan	38	2 MW	2 MW	Diesel
Ja'ar 2	Abyan	13	4 MW	4 MW	Diesel

The electric power plants generate electricity at various levels of voltages and then transmit it at 400 kV and 230 kV transmission voltage. Generally, most of the beneficiaries

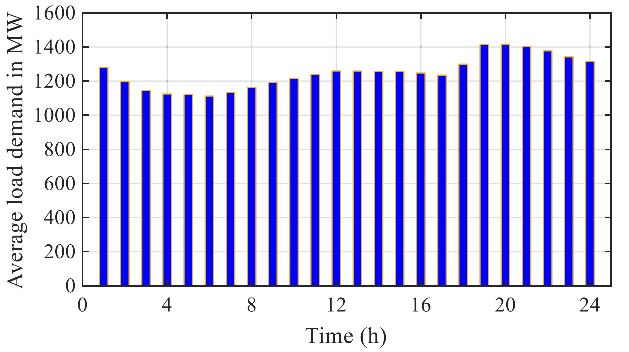

FIGURE 4. Average of load demand in June 2014 for 24 hours.

of the electricity supply in Yemen are from urban areas. In contrast, only 23% of the rural and remote areas that make up three-quarters of the country's population have access to electricity. It is worth mentioning that due to the continuous power cuts, the country's industrial activities are minimal; therefore, as evident from Fig. 5 [15], the majority of electricity services go to households' electrification by approximately 58%, followed by the commercial sector and others [14]. The electricity tariff in Yemen depends on the system of rising block tariffs. In this context, after 2011, the electricity company introduced a price change as shown in Table 2. The rates for low-demand urban private customers were increased up to 44%, tariffs for small rural consumers rose up to 122%, and commercial users also have to cope with a rise of 110% [10].

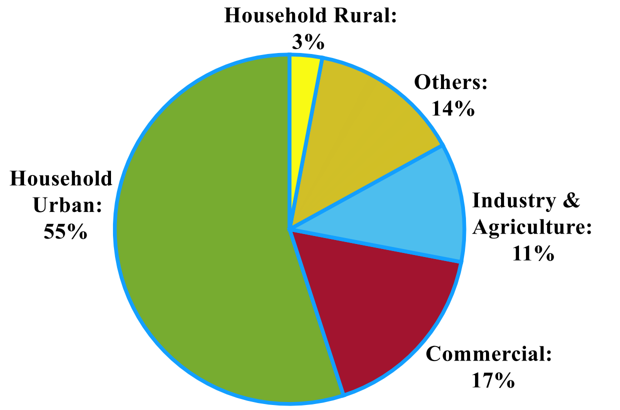

FIGURE 5. Profile of electricity consumption.

The key issue with Yemen's electrical system is the heavy use of diesel power plants, which consume around 79,000 tons of diesel per year to generates a low amount of MWs [28], [31]. As a result, the power sector produces a high amount of CO_2 emission, e.g., in 2012, the power generation emission factor was averaged at 633 TCO_2 /GWh. Besides, although the generation capacity is limited, the electricity losses are high due to vandalism against transmission lines and power plants, resulting in blackouts. Furthermore, other issues are related to the lack of maintenance and obsolescence of most outdated stations and transmission lines that have exceeded their service life [32]. To mitigate these issues, there

TABLE 2. Public energy corporation market rates.

Sector Supply	Period	Consumption in kW				
		100	*200*	*350*	*700*	*>700*
Urban residential	Before 2011	2.5	2.5	3.6	4.8	6.7
	After 2011	3.3	3.6	6	10	32
Rural residential	Before 2011	3.6	7.6	7.6	7.6	7.6
	After 2011	8	12	12	12	12
Commercial sector	Before 2011	11	11	11	11	11
	After 2011	32	32	32	32	32

The price groups of commercial users omitted
Tariff in USD-Cent for each kWh (1 USD-Cent ≈ 2.534 YER)

was a tendency by the government to build and operate most of the new power plants with natural gas fuel and therefore move away from burning oil. However, due to the political instability in recent years, the construction of a new gas-fired generating power plant called Marib II with a capacity of 400 MW has been delayed.

B. ELECTRICITY SECTOR SITUATION AFTER 2015 UP TO DATE

Even before the conflict, Yemen had the lowest electricity access rate in the Arabic area, and most of the population in Yemen had been deprived of basic power services [30]. With the outbreak of war, the county's population plunged into a serious crisis, and several services have collapsed. Public power plants were shut down, causing the Yemeni capital and several country's cities to drown in complete darkness. This shallow level of electricity supplies has had severe implications on water, sanitation, hygiene services, and, thus, on overall health. Even as diesel generators were introduced during the conflict for emergency power supply, fuel shortages severely constrain service delivery. Overall, the percentage of Yemen's population with access to public power fell from around60% in 2014 to below 10% by the end of 2017 [33]. For instance, Sana'a, the biggest city in Yemen, with nearly 2 million, has no public electricity. Most cities have zero access to public electricity; however, a few cities under government control, such as Aden, only have a few hours of electricity a day. Attacks on infrastructure have also affected some of Yemen's electricity supply. According to a general assessment of the damage to the electricity sector in 16 Yemeni cities conducted by international organizations in 2017, different rates of damage have been reported, as detailed in Fig. 6. Physical damage to urban power infrastructure in those cities was estimated at US$ 524–640 million [34].

To make matters worse, fuel shortage rendered it difficult (or at least unfeasible) to rely on diesel generators, which caused the night-time light emissions from Yemen to drop drastically to darkness levels. Amidst the darkness, and despite the blurred lines of territorial and governmental jurisdictions, the solar sector in Yemen has appeared as a rare and remarkable success story, growing in just a few years roughly 50 times [35]. Commercial home solar systems have become popular on the market, and solar panels have spread across rooftops in nearly every town and village, even

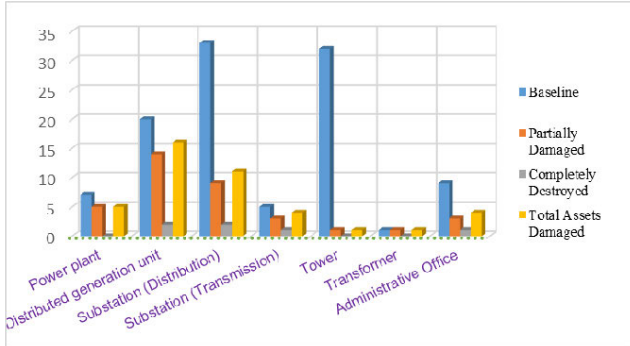

FIGURE 6. Damage inventory by type of asset for 16 Cities.

areas not already linked to electricity. The revaluation of solar energy usage is discussed in detail in Section 6.1.

C. IMPACTS OF COVID-19 ON YEMENI POWER SECTOR

The latest COVID-19 pandemic has dramatically reduced the electricity demand. Governments all over the world were forced to decrease business activity in order to minimize the danger of Coronavirus. Because of this situation, people are mainly staying at home and working from home if possible. As a result, residential load demand has increased, while commercial and industrial load demand has decreased [36], [37]. However, the situation in Yemen is entirely different due to the extreme poverty and the interruption of the network from work due to the ongoing war. In addition to the absence of a government, the lockdown was not a choice, and people are still installing solar energy panels on the rooftops to meet their necessary need for electricity.

V. RENEWABLE ENERGY POTENTIALS IN YEMEN

Yemen is gifted with abundant renewable energy sources, with the majority of these sources untapped despite the great potential of these clean sources. Recent studies conducted by the clean development mechanism (CDM), NOS, and MEE have shown that renewable energy sources, especially solar, geothermal, wind and biomass, are promising [14]. To meet the country's growing energy demand, enabling these sources to be harnessed and utilized is an inevitable choice. The theoretical and technical prospects for renewable energy potential in Yemen are shown in Table 3. On the other side, energy poverty in Yemen is extremely high, even prior to the war. The country, for instance, suffered a severe shortage in the electricity sector, with an annual per capita energy consumption of only 0.22 MWh [38]. However, despite this energy shortage, the share of RES did not grow until 2015 and it was steady at around 0.09% as it had been since the early stages of its deployment in the country. For this reason, the government planned to increase this figure up to 15% by 2025 [39]. Fig. 7 shows the predicted RESs capacity of total power (in MW) by 2025 according to the government plan. Regrettably, the government plan has been stalled since the beginning of the war; the electricity has been cut off, and almost the whole country became dark. Amid this darkness, however, renewable energy, especially solar energy, emerged

TABLE 3. Yemen's renewable energy potential in mw.

Renewable Energy Resource		Theoretical Prospect	Technical Prospect Potential	Technical Prospect Gross
Solar	Power	2,446,000 MW	18,600 MW	1,426,000 MW
	Thermal-SWH	3,014 MW	278 MW	278 MW
Wind		308,722 MW	34,286 MW	123,429 MW
Geothermal		304,000 MW	2,900 MW	29,000 MW
Biomass		10 MW	6.0 MW	8.0 MW

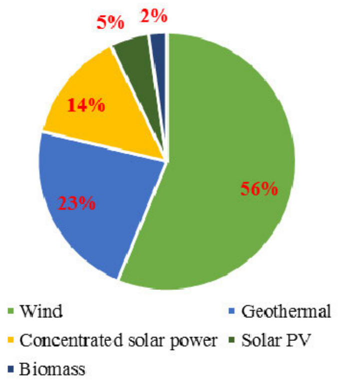

FIGURE 7. Targets of Yemen's share of the renewable energy mix.

and witnessed unprecedented development in providing the energy needed for homes. This indicates the abundance of this type of energy that could solve the current energy crisis.

A. SOLAR ENERGY

As one of the high solar radiation regions in the world, Yemen is an arid and semi-arid country with high inland mountains, desert upland, and a long coastal semi-desert plain across the Arab Sea and the Red Sea. The country is characterized by its warm and clear weather with mostly high-temperature levels in desert and coastal regions [20]. Yemen's solar energy richness is because of its location in the solar belt between the Tropic of Cancer and Equator, as illustrated in Fig. 8 [40]. It is endowed with high solar radiation ranging in average from (5.21-7.23) kWh/m^2 a day and an annual average daily sunshine ranging from 7.3 to 9.1 hours per day. Fig. 9 shows the average solar radiation for Yemeni regions located in Latitude 15 and Longitude 45, estimated on the basis of NASA's one-year record [41]. Based on ground measurements, the average sunshine hours across the country range from 7.3 hours per day in the Northern Region of the country to 9.1 hours per day in Socotra Island. For instance, the capital of Yemen (Sana'a) has daily average sunshine hours of 7.7 hours. Even during the coldest period of the year (winter), the average of sunshine daily hours is evaluated to be around 8.2 hours a day.

The longer average hours of sunshine throughout the year enable high-power generation of solar energy technologies even during winter, which may be a significant additional advantage for Yemen. More interestingly, the annual average temperature in Yemen ranges from 21°C to 31°C, which is considered a perfect condition for generating electricity using the PV system [7], [40]. This ideal location, characterized

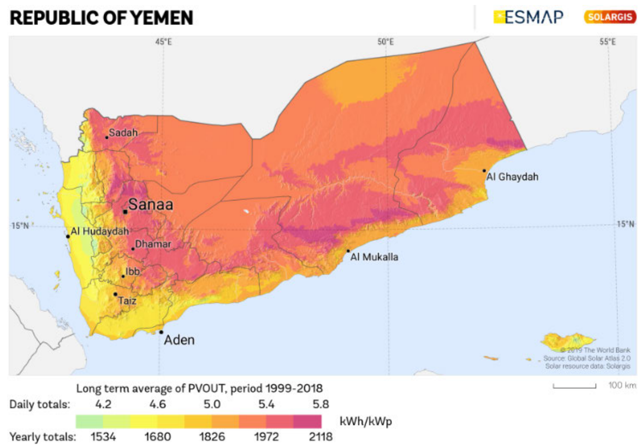

FIGURE 8. Solar resource distribution in Yemen [40].

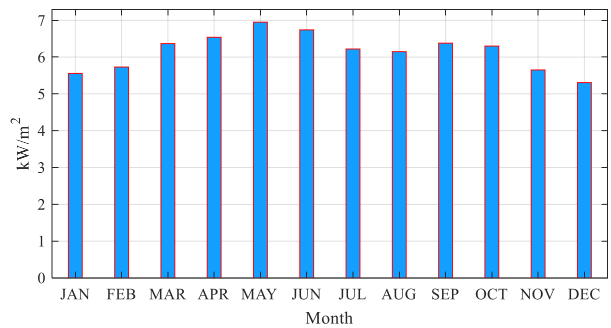

FIGURE 9. Solar radiation on a horizontal surface: Monthly average 2018.

by an abundance of solar irradiation, longer sunshine hours, and the proper generation temperature, offers a high potential for exploiting solar energy to generate most of the electricity needed in the country [42]. It is feasible to use either centralized (on-grid) solar power applications that could be used in large-scale farms or decentralized (off-grid) applications that could be used for small-scale generation of electricity. It is also feasible to utilize solar energy for rural electrification, which suffers a high electricity shortage.

The study conducted in [15] compared the solar radiation in Yemen to Iran, as an example country from the middle east, concluding that Yemen has 200% more radiation than Iran. It is unfortunate that although Yemen has not exploited this precious resource, Iran has recently generated around 342 MW of power from solar energy [16]. Yemen must now take advantage of the vast uninhabitable regions like valleys and deserts that are not agricultural in order to establish large solar power plants for electricity production. The area of 20 km^2 is eligible for producing approximately 1.5 GW of power. According to [7], Yemen's theoretical potential for solar harvesting using concentrated solar power (CSP) is high, about 2.5 million MW. In addition, the study [42] conducted about the publics behavioral toward solar power showed that most Yemenis live in remote and mountainous regions and are interested in employing solar power as the only available source, at least in the near future. Overall, the weather of the country divided mainly

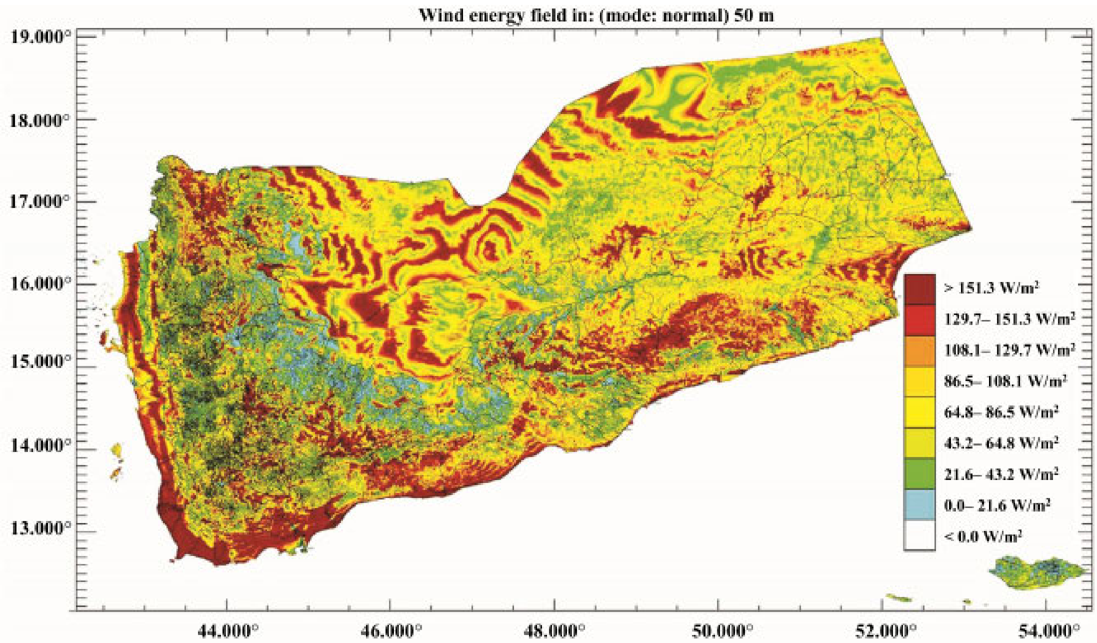

FIGURE 10. The wind energy density (50 m above ground level) [10].

into summer and winter. The desert and coastal regions show high summer temperatures, and the mountainous regions get a hot summer. However, the temperature of the winter is decent [10], [43]. The bulk of the Yemeni population living in the western parts, known as mountainous regions. At the same time, most areas to the east and north with less population are characterized as desert regions. Consequently, since the levels of radiation are an essential feature in the economic viability of PV systems, the high degree of radiation in Yemen is extremely promising to use solar energy as a major power production source across the country [44]. Another significant factor is the average number of dark/cloudy days each year; since the country is arid and/or semi-arid, it is difficult to identify a full overcast day in many areas of Yemen [45].

B. WIND ENERGY

Yemen encompasses more than 2500 km of long coastline with an average width of 45 km along the Arab Sea and the Red Sea. The average wind speed in these coastal regions is over 8 m/s per annum. There is strong potential for creating wind farms both on the coastal strip and offshore. The geographic nature of Yemen with reasonable speed and duration of wind should help to generate a suitable amount of power. Yemen is obviously home to the well-known phenomenon of local wind patterns such as mountain-valley wind and sea breezes wind [15]. The 50 m map of wind energy density above ground level in Yemen is shown in Fig. 10 [10].

It is worth noting that, Mountain-Valley areas are Yemen's most populous areas. On the top of the mountains, many small villages shuttered where the altitude is 1200 m above or less sea level. Therefore, the power supply of these areas can be most economically produced via wind turbines [46]. The wind is available virtually all year round, allowing wind turbines to generate electric power for household use in rural areas in a decentralized way. Based on the report conducted in [47] about RE resource assessment by the department of RE strategy and action plan in Yemen, the most economically attractive areas are Taiz, Aden, Lahj, coastal plains of Hodeidah, and Abyan. These areas have more than 3500 full load hours per year, corresponds to more than 2,507 MW of installed capacity with an average annual power generation of around 8,293 GWh. With its coastal areas in Al-Mokha and the surrounding mountains in Arrous, Taiz alone is an ideal environment for installing wind farms. According to different studies and MEE experts, an area of only 300 km^2 in Al-Mokha can generate approximately 1.8 GW. At the same time, mountainous areas are also able to generate enormous energy thanks to their high wind speed that reaches 21.7 km/h in July [47], [48]. Other promising areas for wind generation are the valleys and mountains (Dhamar, Sana'a, and Sayun) and coastal regions (Hodeidah, Aden, Al Mukalla, and Mokha) [10], [28], [49]

What is more surprising is the availability of both sun and wind in most of these areas, allowing wind-PV hybrid systems to be proposed in these regions. A high wind speed in the coastal regions continues over six months (September to March) [35]. This circumstance is a good predictor for offering a hybrid system consist of wind farms with PV system, Diesel generation, or grid connections.

Fig. 11 shows the average of wind speeds during all year's months in four areas in Yemen. However, unfortunately, the meteorological data available for different locations in the country does not provide adequate wind information. Therefore, further studies, investigations, and more data collection about the availability of wind, its daily speed, the potential

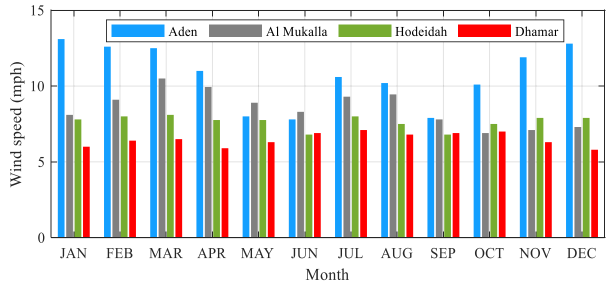

FIGURE 11. The average of hourly wind speeds in four cities.

and exact estimation of wind energy for various places in Yemen should be conducted in order to aid precisely in wind generation economics.

C. GEOTHERMAL ENERGY

The thermal energy generated and stored in the Earth is called geothermal energy. Fortunately, Yemen is one of 10% of the world's regions with geological hot spots. The volcanic activities in Yemen are extremely high, leading to increased heat flow. This heat flow could be exploited to generate power from under the ground using superheated water [50]. Besides, Yemen is located close to three of the world's most active tectonic boundaries (Red Sea, Gulf of Aden, and East African Rift). In a triple junction, these three tectonic plates meet and create a significant geothermal gradient, producing geothermal energy of approximately 28.5 GW [43]. In addition, Yemen has several areas marked by volcanic character and also more than seven areas with natural hot water springs. Furthermore, it was identified as one of the high-temperature flow countries where this flow reflects the temperature of the ground [51]. In sum, these situation demonstrates the potential of geothermal energy.

The world heat flow map showed that Italy and Yemen have the same heat flow potential (60 MW/cm^2). However, in Italy, the total capacity of geothermal energy installed for electricity production is reached around 915.5 MW [52], [53]. This is another indicator that Yemen has an encouraging level of geothermal energy potential. A study was conducted and funded by the World Bank to examine geothermal energy potential in Dhamar region [10]. The study revealed that it is possible to construct a power plant employing geothermal energy capable of delivering power with a capacity of 125 to 250 MW. Compared to the total power generated in the country, this amount of energy is beneficial. Several other geothermal areas in Yemen are easily accessible for application in geothermal energy. These areas are accessible in provinces like AlDhala, Ibb, Gulf of Aden, and Red Sea coastal areas [54]. Damt (Al-Dhala) share the same characteristic as California and Iceland where hot water erupts to the surface. Overall, the average temperature of the reservoir in Ibb, Dhamar, and Al-Dhala is between 70-140 °C. Thus, the geothermal power plants in such regions are potentially applicable where surface temperature is about 150°C. Therefore, it is practically possible to install plants with an overall capacity of 600 MW in these locations [15]. In sum, the country has good geothermal energy potential, but it has not been exploited yet.

D. BIOMASS ENERGY

Yemen is famous throughout history for being an agricultural country representing the country's primary economic sector. A large amount of waste is being produced through agricultural activities [55]. Other biomass sources also exist in Yemen like crops, wood, industrial and municipal solid waste (MSW), sewage of municipal, tire waste, and food industry. Such sources of waste could be used for biomass potential to be utilized for various purposes like gasification for electricity production or for cooking [56]. This technology could generate electricity from biogas in major urban areas such as Sana'a, Aden and Taiz instead of diesel fuel or heavy fuel (Mazots) mainly used in Yemen's current power stations. Fig. 12 shows the estimated composition of MSW produced in Yemen, which can be used to produce energy at waste-to-energy plants [57].

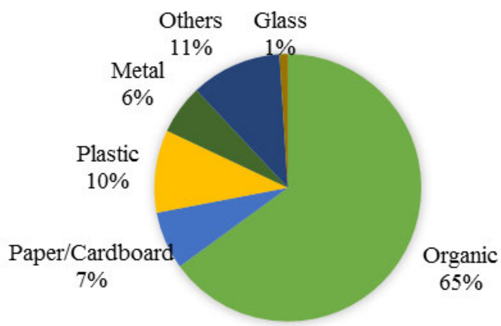

FIGURE 12. The estimated composition of municipal solid waste (MSW) produced in Yemen.

For example, in Sana'a alone, which has a population of two million people, it is possible to collect a large amount of waste, up to 1000 tons per day, only by gathering all the waste collected by mobile waste trucks in the city. This waste could be provided to specialized digesters to generate biogas which is made up of 40% carbon dioxide (CO_2) and 60% methane (CH_4). It is estimated that 50 m^3 of biogas can be generated for every ton of waste. Consequently, the 1,000 tons of Sana'a waste can produce approximately 5,000 m^3 of biogas per day, equivalent to 30 MWh. This production capacity could supply 5,000 households whose average electricity need is 6 kWh [15], [35]. Unfortunately, the utilization of biomass conversion technology is still limited and needs further investigation and investment.

E. COMPARATION WITH NEIGHBOURING COUNTRIES

This section provides a brief comparison of Yemen's RE situation with some of its neighbours. Yemen is surrounded by the oil-rich Arab Gulf states of Oman, Saudi Arabia, Bahrain, Kuwait, Qatar, and the United Arab Emirates. Despite their vast geographical potential, these countries' current generated RE is still relatively low. However, with the support of governments, significant efforts are being made to develop several strategic RE projects in these countries to meet the increasing demand for electricity and proportion to their geographical location and economic potential. For example, the Saudi government recently announced a $ 108.9 billion project that will produce a total of 41 GW of solar energy by 2032, enough to meet a third of building energy consumption. When we equate the enormous budget devoted to this project to Yemen's total budget, we find that $ 108.9 billion is the equivalent of Yemen's budget for 15 years [58]. As a result, any comparison between Yemeni projects and their counterparts in the Arab Gulf states would be unfair. The majority of RE projects in Yemen are funded by individual efforts, with a few financed by international organizations providing humanitarian aid to Yemenis. Table 4 provides a brief comparison for the Arab Gulf states to demonstrate the complete picture of the renewable energy situation in the neighbouring countries. Table 4 shows a brief comparison of the RE development with neighbouring countries of Yemen [59], [60].

TABLE 4. A brief comparison of re with neighbouring countries of Yemen [59]–[63].

Country	Population (Million)	Power production(GW/h)	Solar (MW)	Wind (MW)	Other RE (MW)
Oman	4.5	37,300	4180	1210	-
KSA	33.5	383,800	20750	3500	2000
Bahrain	1.6	13,086	660	20	-
Kuwait	4.2	74,200	6800	200	200
Qatar	2.6	39,500	3000	-	-
UAE	9.5	136,900	29100	300	15
Yemen	30.1	5,834	2600*	650*	-

*In the event that the growth in these sectors has been the same as in the last two years

VI. CURRENT STATUS OF RE IN YEMEN

A. YEMEN'S SOLAR ENERGY REVOLUTION

As mentioned earlier, despite the escalation of the electricity crisis in Yemen at the beginning of the conflict, it was existed long before the war, with only 40% of the population having access to the electricity. Even more than that, the majority of those who had access to electricity experienced regular service interruptions, as the disconnection hours in the capital, for example, were two or three hours a day. To address this issue, many solar PV projects have been implemented in the residential sector by individuals and some organizations. It was challenging to find the exact number and capacity of these projects; however, the projects implemented by the government are summarized in Table 4.

On the other hand, when the war began in March 2015, a complete shut-down of power generation occurred across the country, and what made matters worse were the airstrikes that damaged some power stations. This challenging situation has geared the Yemeni society to rely on solar photovoltaic (PV) as an alternative solution to meet their basic electricity needs. In one of the few positive stories that emerged from the conflict, the lack of public power supply and limited availability of diesel fuel in combination with the rapidly falling cost of solar globally has spurred a booming industry for solar

TABLE 5. Governmental solar pv initiatives in residential sector [64].

Name of project	Project Area	Capacity	Hrs.	Year
Alsafirah Alsufla	Sana'a	135 kW	120	2014
Alnashm	Dhamar	100 kW	70	2014
Alglahib	Sana'a	100 kW	100	2014
Wadi Jamilah	Dhamar	95 kW	65	2014
Almuhajab II	Sana'a	60 kW	35	2014
Zaheq	Soqutra	120 kW	92	2013
Shizan	Soqutra	100 kW	74	2013
Haif	Soqutra	90 kW	40	2013
Aftlamh	Soqutra	80 kW	26	2013
Deshal	Soqutra	80 kW	24	2013
Almuhajab I	Sana'a	100 kW	90	2012
Magzar	Maareb	100 kW	73	2012
Ara'af	Lahj	120 kW	100	2011
Hesn Balid	Abyan	50-100 kW	40	2010
Qawa	Aden	100-200 kW	75	2009

Source: Regional Center for Renewable Energy and Energy Efficiency (RCREEE) [65].

systems, serving homes, farmers, small to medium-sized businesses, and solar lamps for basic lighting. A market assessment conducted by the World Bank in 2016 estimated that the market penetration of solar energy for lighting and appliances reached 75% of households in selected urban areas, including the capital city [9]. According to a world bank report on Yemen emergency electricity access project [65], more than US$ 200 million has been invested annually in the residential off-grid solar sector since the outbreak of the conflict. The solar market in Yemen is operating on a commercial basis and is driven by the private sector, with a supply chain ranging from trading companies importing panels, charging controllers, and batteries to small-scale retailers that have expanded their business to solar panels. This solar supply chain shown in Fig. 13 represents the quickest and most reliable solution to the country's extreme power shortages, supplies households with electricity, and restoring service delivery of electricity-dependent services [22], [65].

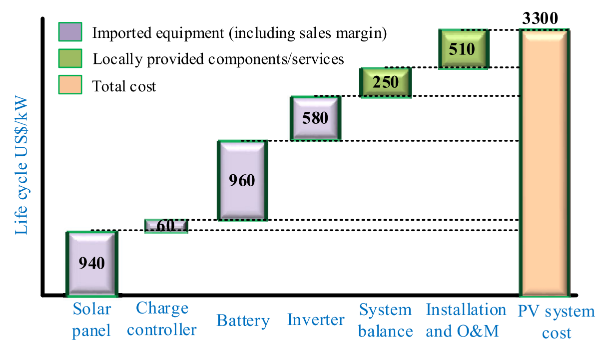

FIGURE 13. Supply chain and approximate cost reduction.

The UNDP-Yemen report [8] highlights that, over the past five years, a tremendous amount of money has been invested in residential solar PV systems, estimating the market penetration of PV systems to be around 50% of households in rural areas and 75% in urban areas. In many cities and villages, solar panels became part of their rooftops. Overall, solar energy usage in Yemen could bring enormous hard currency economic returns to the Yemeni economy by saving 675 thousand tons of fossil fuels, worth about US$ 600 million per each 1 GW of electricity produced. Based on the preliminary estimates, around 600 MW of PV plants were mounted since the war began in 2015, as shown in Fig. 14 [34].

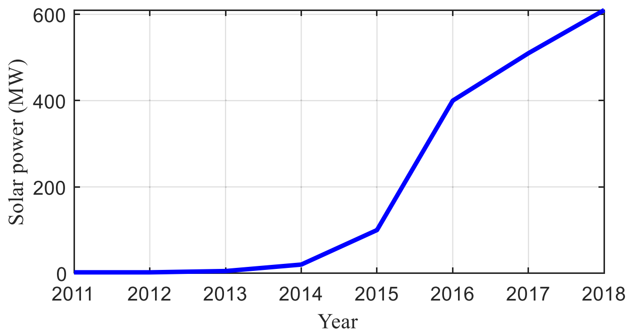

FIGURE 14. **Unprecedented rise (revolution) of solar energy in Yemen.**

The installed PV capacity of the country can, however, be even higher. Therefore, solar generation production has grown nearly fiftyfold within only a few years, and solar energy is now the primary source of electricity in most Yemeni governorates. It is worth mentioning that owning a solar system is higher for urban households than in rural areas. According to [9], up to 85% of households powered by solar panels are in the mountainous areas around the capital. At the same time, other governorates in eastern and southern Yemen have only limited shares of PV systems. This signals a booming potential not only in the residential sector but in other dynamic sectors as well. Many farmers, for instance, have resorted to solar pumping schemes. Estimates of the technical market potential in essential sectors give promising figures for further deployment and expansion in the PV market in Yemen, which could trigger a multibillion market, sustaining the PV business for at least two decades to come. Nonetheless, certain assumptions were considered when developing the technical potential, and that the actual potential could be, to variable degrees, less than the stated figures.

B. STATUS AND FUTURE OF WIND ENERGY

There is almost no application of wind energy in Yemen. However, prior to the war, the PEC planned to implement wind farms in Al-Mocha-Taiz (13.3203° N, 43.2473° E). This region is located on the coastal Red Sea zone, and the PEC preliminary study has shown that the region experiences an average wind speed of 7.4 m/s per annum. The PEC had already installed an experimental wind turbine in the place [14], [66]; however, due to the ongoing conflict for five years, the turbine has not been operationalized, and it is hard to predict the actual launch and commissioning of the project. Upon completion, the project is anticipated to generate 65 MW of grid-connected wind energy, strengthening the national grid system.

Several studies and reports were conducted to investigate wind energy resources in Yemen; they all confirmed that this energy type is available in various parts of the country [10], [18], [35], [39], [67]. Fortunately, most of the regions promising with wind energy are located in good locations where there are already high-voltage transmission lines, such as Al-Mokha, Aden, Abyan, Hodeidah, Lahej, and Dhamar [20]. The expected economic potential of wind energy from these regions is illustrated in Fig. 15, which indicates the promising future of this energy and the necessity for the PEC and MEE to take serious steps to invest in such a clean source. According to MEE, Yemen can theoretically produce between 17 and 19 GW of wind power. This means that Yemen will not only be rich in energy but will also be able to sell it to its neighbors [14]. Indeed, to achieve this amount of energy production, PEC must open up the electricity sector market not only to investors in Yemen but also to the international level. However, given that the current conditions are not suitable for investors, and instead of waiting for the country to stabilize, studies recommend that the PEC should at least begin developing a short-term plan (over 3 to 5 years) to generate 2 GW of electricity from wind energy, thereby sparing Yemen from an inevitable disaster represented by the collapse of the electricity sector.

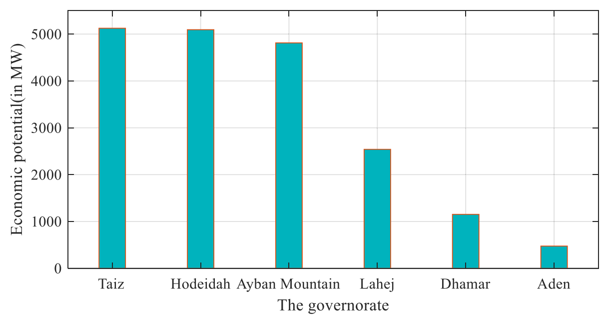

FIGURE 15. **The expected economic potential of wind energy in Yemen.**

C. OTHER RENEWABLE SOURCES PROGRESS

In addition to the solar and wind energies as main renewable sources in Yemen, geothermal and biomass can also contribute to the electricity mix and has potential, as discussed early. In this regard, it was estimated that about 2900 MW of power from geothermal sources could be available [10]. A tentative survey in the 1980s found some geothermal potential in the south of Sana'a, the most promising of which is situated at Al-lissi Mountain and Hamam Ali in Dhamar governorate [68]. This source is thought to be adequate to produce a minimum of 50 MW, and the ultimate source could be reached 500 MW. Therefore, MEE signed with an Icelandic company to develop a 10 MW plant on the site, but during the financial crisis, the company went bankrupt, and the project did not materialize [54]. Overall, it can be concluded that the geothermal power production did not see the light yet maybe because it requires significant investment, whereas Yemen is a poor country.

On the other hand, concerning biomass, there are different biomass sources in Yemen, still unutilized. In addition, the usage of biomass conversion technology is still limited. Based on the report introduced in [69], theoretically, about 10 MW of electricity could be generated from the current levels of municipal solid waste (MSW) output in Yemen's main cities. Suppose only cities that produce over 100 thousand tons of solid waste a year are to be considered. In that case, the figure falls to about 8 MW. 6 MW could even be acquired from the landfill sites in Sana'a, Taiz, Aden, and Hodeidah (Main four largest cities) and is most likely to be economical. Finally, it is important to notify that the Yemeni potential for other types of RESs such as hydropower and tidal energies has not been examined yet.

VII. RENEWABLE ENERGY IN YEMEN: OBSTACLES AND BARRIERS

The intergovernmental panel of climate change (IPCC) [70] defined the obstacle in its recent reports as ''any stumbling block or barrier to developing and deploying a renewable energy potential that can be overcome or attenuated by a policy, program or measure''. As mentioned earlier, in Yemen today, there are many reasons to encourage the use of RESs at least to address the problem of acute electricity shortages and contribute towards grid de-carbonization and sustainability. However, there are major obstacles and challenges. Thus, this study defined five categories of such barriers, all of which have applied to a greater or lesser degree towards the utilization of the available RESs in Yemen's power sector as follow:

A. ECONOMIC BARRIER

One significant obstacle in developing any project is the financial barrier because the project will not succeed without sufficient funding. However, in developing countries like Yemen, funding for large infrastructure projects is mainly provided by international assistance grants or concessional loans from bodies [71]. It is well known that in comparison to fossil-fuel systems, the costs of RE systems projects are high. This has made it difficult to secure a loan for rural households that are cash poor and regards installing even small PV systems as one of the major obstacles. The purchases made regularly by these households for lighting kerosene are simpler for them to pay, as they are not aware of their overall cost. The trick is to find a method that helps the household pay for RE lighting in similarly small installments at a much lower total expense. For example, recently, efficient LED lights have been considered the key component of reducing PV systems cost compared to the older PV systems and considerably reduces this barrier worldwide [72]. Moreover, the lack of credit facilities and high-interest rates on credit facilities could be considered as a significant barrier to RE development. Although there is support from UNDP for some PV projects in Yemen [9], there are bounded financial instruments, investment mechanisms, and organizations for RE project financing. Additionally, the absence of coordination between local communities and central governments about the planning and financing of RE projects is another obstacle.

B. TECHNICAL BARRIERS

One of the technical barriers to RE development in Yemen is the lack of the necessary infrastructure to upholding this technology. In addition, there is a rareness of trained personnel to train, maintain, demonstrate, and operate RE structures. Therefore, for fear of failure, people may not be willing to import and install renewable technologies. Besides, lack of transmission and distribution network physical infrastructure along with the required services and equipment of a national electrical company [20], [73]–[75]. Furthermore, insufficient management and equipment maintenance, combined with low technological reliability, lower customer confidence in certain RE technologies and thus hinder their deployment and adoption [76], [77]. That is because several RE equipment is imported from advanced countries to developing countries like Yemen. Thus lack of spare parts and sufficient skills to service/repair the equipment contributes to the failure of the equipment, which in turn stops the energy supply.

Moreover, based on investors' perspectives [78], there are inadequate procedures, standards, and guidelines for RE regarding reliability, durability, efficiency, etc., that prevent commercialization of large-scale RE power plants. Finally, energy storage is a big technological issue facing renewable energy today [79]–[81]. Despite their limitless abundance, the wind or sun supply is not constant, and power grids cannot work unless they can balance demand and supply. In order to solve this issue, large batteries must be built which can compensate for the periods if there is no renewable resource available [82]. However, the cost, periodical maintenance, fast discharge, capacity, and lifetime of the batteries need to be improved for the efficient operation of RE.

C. POLICY-RELATED BARRIERS

Lack of RESs technologies, national policies, and regulations, administrative hurdles, unrealistic government targets, inadequate incentives may impede the drastic expansion of these technologies in the Yemeni power sector [83]. For instance, there is no grid code for identifying the regulatory instrument used and coordinating various electricity supply activities of the electricity operators, producers, distributors, and consumers in Yemen yet [43]. It is well known that the Feed-in-Tariff (FiT) scheme is the mechanism that governments use to subsidize RESs and render them more cost-efficient with technology-dependent on fossil fuels [84]. However, unfortunately, this policy is still absent in Yemen [42]. Consequently, the lack of such proper economic incentives leads to high costs, which influence the growth of RE in the future. Moreover, the government to date has no tax policy for RE. Therefore, the Yemen government must have tax incentives for the purchase of RE equipment and granting tax exemptions for the use of renewable sources services. The tax incentives policy will attract potential investors and industry players to invest in RE. In addition, standards and certificates shall be used to ensure compliance with importation country standards of equipment and parts manufactured or procured from overseas. Such certifications guarantee that the products are imported and operated under local law. The lack of these standards leads to confusion for energy producers and unnecessary difficulties.

D. INSTITUTIONAL BARRIERS

The shortage of functioning institutions is the major cause of minimizing any technique's dissemination [85]. In Yemen, there is no institutional framework or a working mechanism for the Yemeni RE sector, which results in the unavailability of information for both consumers and producers. Furthermore, the absence of a research and development (R&D) culture and lack of stakeholders' participation may make an adaptation of technology difficult and lead to misplaced decision-making priorities. Finally, the lack of professional institutions and labs is another institutional barrier [10], [86].

E. SOCIAL BARRIERS

There are some factors that may lead to public opposition to the transition from conventional resources to renewable resources such as the lack awareness and knowledge about the benefits of RE, purchase of agricultural lands to establish RE stations, and uncertainties regarding financial feasibility and ecological benefits of RE installation projects.. For instance, in Yemen, most people in rural communities are uneducated and thus have no awareness about the idea or concept of RE [42]. Besides, there is insufficient public understanding of RE benefits in everyday life and a lack of understanding of traditional sources' social and/or environmental impacts. Moreover, the perception of unrealistically high costs of RE is also another barrier [39]. Therefore, community awareness and a critical emphasis on socio-cultural practices are necessary for the community. In addition, no direction or desire from specialists in the upper levels of society to decide to buy renewable generators such as solar PV systems instead of buying diesel generators [22]. Finally, the lack of a solid foundation of the local skilled labour force to build, design, operate, and maintain a RE plant is another social barrier [66].

VIII. CONCLUSION AND RECOMMENDATION

The goal of this paper was to evaluate the potential, status, and barriers of renewable energy applications for electricity generation in Yemen, with a quick presentation of the conditions and chronic issues of the Yemen electricity sector. Yemen has unexplored potential to harness renewable resources as a way of bridging the country's energy gap. Therefore, the major role for RE in Yemen should be exploited to cover the electricity shortage and reduce the high import costs of fossil fuel currently in use. Besides, exploitation of RE in Yemen will contribute to the global effort to escape the future impacts of climate change and achieve SDG 2030. Based on the review, the potential of energy sources from wind, solar, geothermal, and biomass in Yemen is widely available and technically exploitable. Yemen is one of the wealthiest nations globally in terms of the availability of solar radiation and wind speed and is characterized by the availability of these two key sources in most parts of the country. Although wind and solar energies have begun to generate electricity with limited capacities, geothermal energy and biomass are still untapped and need a great deal of concern. As a result of the war conditions that Yemen has been going through since five years, there was a complete collapse of the national electricity system. However, there has been a revolution in exploiting solar energy, and the population has increasingly shifted to use it. Statistics have shown that solar energy generation increased by almost 50 times in only a few years (during the war). The capacity increased from less than 15 MW in 2014 to about 600 MW in 2019, making solar energy the main source of electricity for most Yemenis nowadays. Despite the vast improvements in the RE systems technology, there are numerous barriers to the growth of RE in Yemen, including technical, social, economic, institutional, and policy-related barriers. Considering all the mentioned barriers, this review puts forward some significant and selective suggestions to promote further use of RE for electricity generation in Yemen, such as:

- Given that Yemen is one of the wealthiest nations in RE sources, especially solar and wind, the Yemeni government must create an encouraging investment climate to attract domestic and foreign investment to this sector by providing more investment facilities and incentives.
- Bridging the wide gap between the growing electricity demand and the suspension of government power plants, individuals need to be made aware of the value of RE and encouraged to shift to its sources as an alternative to fossil fuel.
- Developing geothermal and biomass projects in those regions affluent in these sources potential in Yemen. Until now, no geothermal and biomass-powered project is operational or in the pipeline.
- The RE strategic policy shall cover four key aims: security of energy, social equity, economic benefits, and environment protection.
- The government is encouraged to reduce the high cost of RE systems via offering a new policy of taxes with respect to RE technology, subsiding the dependency on conventional energy, and providing more attention to rural and desert communities for the use of RESs.
- Strengthening the technical capabilities of national authorities, institutions, and associations in RE and requested aid from international organizations.
- In some regions, the wind and sun availability could encourage the proposal of hybrid PV-Wind systems.
- Addressing social barriers by raising awareness among students on RE topics through educating, at various educational levels, their concepts and benefits for the environment, energy security, and the economy.
- Developing plans and start implementing smart microgrids consisting of different renewable and non-renewable sources.
- Enhancing the culture of R&D through expanding research and higher education institutes and technology centers.

- Establishing clear rules governing grid connection costs to allow private operators to connect on a non-discriminatory basis and determine fair levels of costs.
- Renewables targets should be set with a clear purpose in mind (such as CO_2, air pollution reduction, or energy security) and align with other strategic policy goals to avoid perverse outcomes, and
- Resource data for different renewables should be freely available by the government.

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