

# Renewable Energy Resources in Yemen: Growth, Challenges, Potential Opportunities and Strategies

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## Abstract

Yemen faces a critical energy crisis exacerbated by political instability, reliance on fossil fuels, and inadequate infrastructure. However, the country possesses vast untapped renewable energy potential, particularly in solar, wind, biomass, and geothermal resources. This study evaluates Yemen's renewable energy capacity and synthesizes empirical data from existing reports and studies to analyze solar radiation, wind speeds, biomass availability, and geothermal viability. Key findings reveal exceptional solar potential (1800 - 2200 kWh/m<sup>2</sup>/year) and significant wind energy prospects (6 - 10 m/s in coastal regions), alongside underutilized biomass and geothermal resources. Despite these merits, challenges such as financial constraints, technological gaps, and governance deficits hinder development. The paper proposes actionable strategies, including policy reforms, private sector incentives, international collaboration, and community engagement, to harness renewable energy for sustainable development. By transitioning to renewables, Yemen can mitigate energy shortages, enhance energy security, and contribute to global climate goals. This research provides critical insights for policymakers and investors committed to addressing Yemen's energy crisis through scalable and sustainable solutions.

## Keywords

Solar Power, Wind Energy, Biomass, Geothermal, Challenges, Policy, Sustainable Development

## 1. Introduction

Renewable energy has become a critical component in the global effort to reduce carbon emissions and promote sustainable development. Countries worldwide are

transitioning towards cleaner energy sources, and Yemen is no exception. Given its geographic location and climatic conditions, Yemen possesses significant potential for renewable energy, particularly in solar and wind energy. The growing energy demand, combined with the scarcity of conventional energy resources and the current instability in fossil fuel supply, highlights the urgent need for alternative solutions.

This paper aims to explore the renewable energy resources available in Yemen and those applicable in the future. It will present empirical data on solar radiation, wind speed, temperature, and weather conditions, which are crucial for evaluating the feasibility of renewable energy projects. The paper will also discuss the challenges and opportunities facing Yemen's renewable energy sector, providing recommendations for a sustainable energy future. It also seeks to identify the key challenges impeding the widespread adoption of renewable energy and to propose viable solutions to overcome these hurdles. By shedding light on Yemen's renewable energy prospects, this research endeavors to contribute to the global discourse on sustainable energy and offer valuable insights for policymakers, researchers, and industrial stakeholders committed to addressing Yemen's energy crisis.

## 2. Overview of Yemen's Energy Sector

Yemen's energy sector is predominantly dependent on fossil fuels, with the majority of its electricity generation relying on diesel and heavy fuel oil in addition to light crude oil in the last few years. The ongoing conflict and political instability have further exacerbated the country's energy crisis, leading to frequent power outages and a significant decline in energy production and distribution. Rural areas, which constitute a large portion of Yemen's population, suffer from a severe lack of access to electricity, relying on expensive and environmentally harmful diesel generators.

Despite these challenges, Yemen is endowed with abundant renewable energy resources that remain largely untapped. Solar energy potential is immense due to high solar radiation levels throughout the year. Similarly, coastal regions, particularly in the Gulf of Aden and the Red Sea, have strong wind energy potential, with average wind speeds sufficient for power generation.

Transitioning to renewable energy could play a transformative role in Yemen's recovery and development. It would not only address the current energy shortage but also reduce reliance on fossil fuels, improve energy security, and contribute to environmental sustainability.

Four main sources of renewable energies are available in abundance in Yemen and which can be harnessed and utilized. A recent study for the "Renewable Energy Strategy" for Yemen carried out by the Ministry of Electricity and PEC showed that Yemen has very high potential of renewable energy (summarized in **Table 1**), which can be obtained from Solar, Wind, Biomass, and Geothermal sources [1].

**Table 1.** Potential power of renewable energy.

Resources	Theoretical potential (MW)	Technical potential	
		Gross (MW)	Practicable (MW)
Wind	308,722	132,429	34286
Geothermal	304,000	29,000	2900
Solar electric			
* CSP	2,446,000	1,426,000	18,600
Biomass			
* Landfil gas	10	8	6
Hydro power			
* Existing	1	–	–
* Major wadis	12 - 31	11 - 30	–
Solar thermal			
* Domestic SWH	MW <sub>thermal</sub> 3014	MW <sub>thermal</sub> 278	MW <sub>thermal</sub> 278

The average solar radiation is about 18 - 26 MJ/m<sup>2</sup>/day over 3000 hours per year clean blue sky and the theoretical potential for solar electric using Concentrated Solar Power (CSP) reaches about 2,446,000 MW, Wind Energy on the other hand reaches a potential of 308,722 MW and Geothermal Potential of about 304,000 MW [2].

### 3. Available Renewable Energy Resources

#### 3.1. Solar Energy

Yemen receives an average of 9 hours of sunshine per day, making solar energy a viable option. The country's solar radiation levels range from 1800 to 2200 kWh/m<sup>2</sup> per year [3]. Several studies have explored the potential of solar energy in Yemen, highlighting its cost-effectiveness and profitability [4].

Ground measurements indicate that the country's average daily sunshine hours vary from 7.3 hours in the Northern Region to 9.1 hours on Socotra Island. For example, Yemen's capital, Sana'a, enjoys an average of 7.7 hours of sunshine per day. Even during the winter, the average daily sunshine remains approximately 8.2 hours [5].

The solar radiation per day for the main Yemeni's cities are shown in **Figure 1** and the map sunshine location is shown in **Figure 2** as well.

The extended hours of sunlight throughout the year facilitate the high-power generation of solar energy technologies, even in winter, presenting a notable advantage for Yemen. Additionally, with annual average temperatures ranging from 21 °C to 31 °C, the climate is ideal for electricity generation using photovoltaic (PV) systems [3] [6].

This prime location, with its plentiful solar irradiation, extended sunshine hours, and optimal temperatures for energy generation, holds great promise for harness-

ing solar power to meet most of the country’s electricity needs [7]. Both centralized on-grid solar power systems for large-scale farms and decentralized off-grid systems for smaller-scale electricity generation are viable options. Additionally, utilizing solar energy for rural electrification can address the significant electricity shortages in those areas.

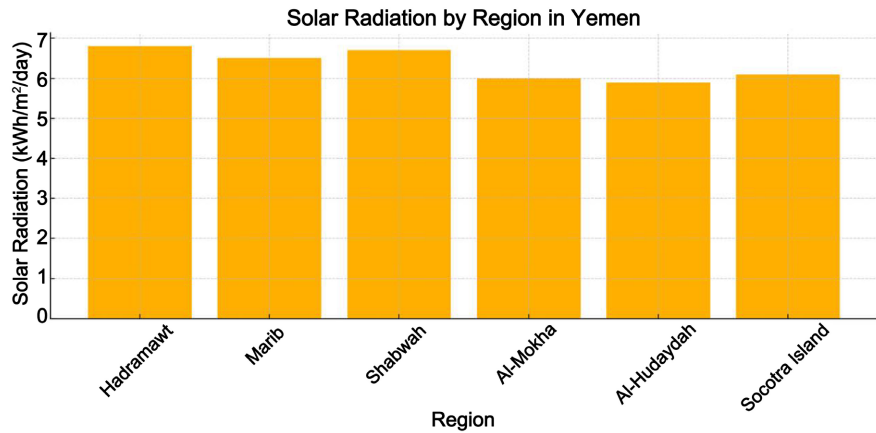


Figure 1. Solar radiation range for main areas.

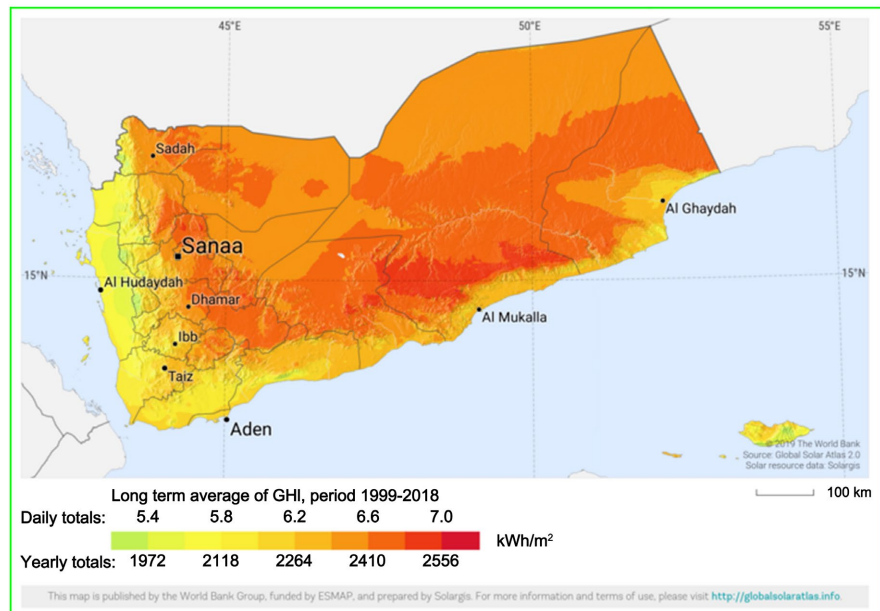


Figure 2. Sun shine location map.

As previously mentioned, the electricity crisis in Yemen intensified at the start of the conflict, but it had been an issue long before the war began, with only 40% of the population having access to electricity. Furthermore, those who did have access faced frequent service disruptions, with the capital experiencing power outages lasting two to three hours daily.

The complete shutdown of power generation across Yemen was exacerbated by airstrikes that damaged several power stations. This dire situation prompted Yem-

eni society to turn to solar photovoltaic (PV) systems as an alternative means to meet their basic electricity needs. Among the few positive developments during the conflict, the lack of public power supply and limited availability of diesel fuel, combined with the rapidly decreasing cost of solar technology globally, led to a thriving solar industry. This industry now serves homes, farmers, small to medium-sized businesses, and provides solar lamps for basic lighting.

According to the UNDP-Yemen report [8], significant investments have been made in residential solar PV systems over the past five years. The report estimates that these systems have penetrated around 50% of rural households and 75% of urban households. In many cities and villages, solar panels have become a common feature on rooftops.

The country's installed photovoltaic (PV) capacity has the potential to grow even more. Solar energy production has surged nearly fiftyfold in just a few years, positioning it as the main source of electricity in most Yemeni governorates. Notably, urban households are more likely to own solar systems compared to rural ones. According to [9], up to 85% of households using solar panels are situated in the mountainous regions around the capital, while other governorates in eastern and southern Yemen have a smaller share of PV systems.

In 2022, a paradigm shift has occurred in Aden city by construction of a 120 MW solar power plant (PV), that funded by MASDAR UAE company and implemented by ELECTROMICA Company, was initiated in Aden (Bir-Ahmed) 5 Kilos apart from the center of Aden city. Moreover, at the end of 2024 this solar power plant has been put in service to mitigate the shortage of power in the city and played a crucial role during the severe shortage in the fossil fuel type at the beginning of 2025.

In 2024 the same sponsor (MASDAR UAE) Aden solar power plant started constructing an integrated solar power plant (PV) with capacity of 120MW in Shabwah province and recently its in its final stage.

In May, 2025, the same company (MASDAR UAE) approved officially and signed the extension phase of the project with a capacity of 140 MW PV system, part of it (30MW) will have a storage facility (Nickel Cadmium Batteries). Moreover, the civil activities of this project (Phase#2, 120MW) have already been launched.

### 3.2. Wind Energy

The coastal areas of Yemen offer significant potential for wind energy, particularly along the Red Sea and the Gulf of Aden. Average wind speeds in these regions range from 6 to 10 m/s, refer to the wind map in **Figure 3** and the average wind of the main cities in **Figure 4**, making them ideal for wind energy projects. Al-Mokha, Al-Hudaydah, and Socotra Island are some of the most promising areas for wind energy development [10].

Certainly! Yemen's western coastline, spanning from Bab Al-Mandab to Al-Mokha, ranks among the most wind-prone areas worldwide, making it an ideal

location for harnessing wind energy. The coastal plains and some mountainous regions in Yemen experience exceptional wind conditions, with speeds exceeding 7.5 meters per second and power densities surpassing 200 watts per square meter, making these areas highly suitable for power development [11]. According to a 2009 report by Yemen’s Ministry of Electricity and Energy (MEE), the total technical potential for wind energy in the country is estimated to be around 14,200 megawatts, which could generate approximately 42,300 gigawatt-hours of electricity annually. This significant potential underscores the opportunity for Yemen to develop its renewable energy sector and reduce its reliance on fossil fuels.

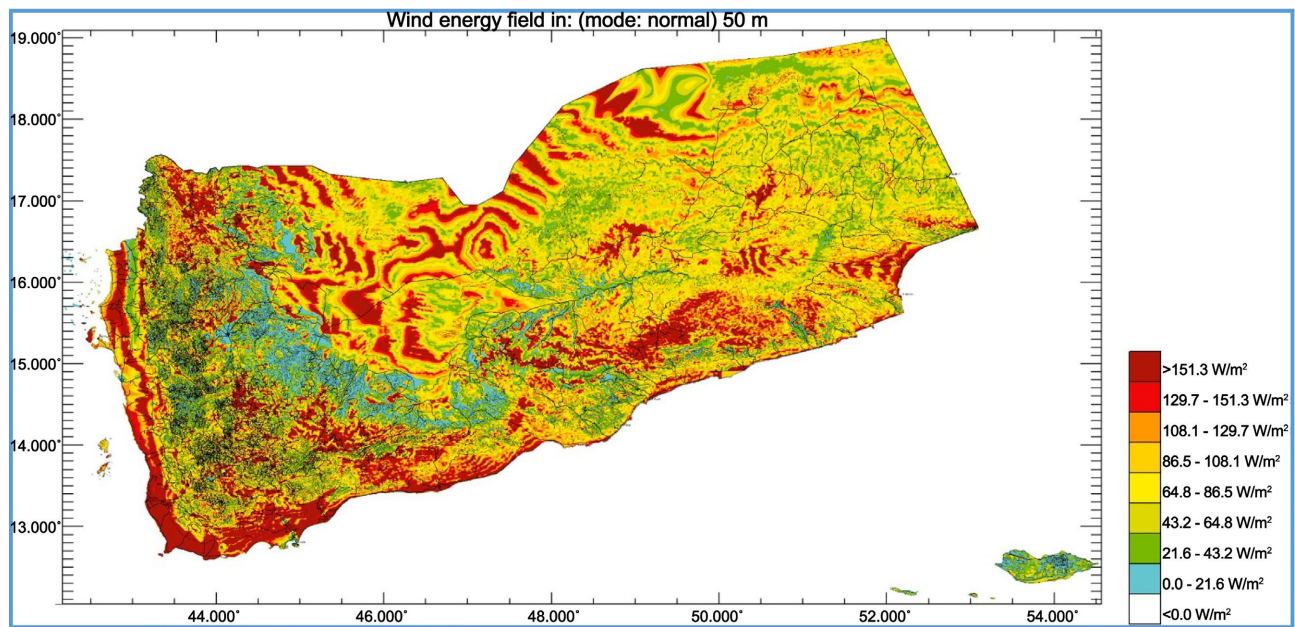


Figure 3. Wind speed locations map.

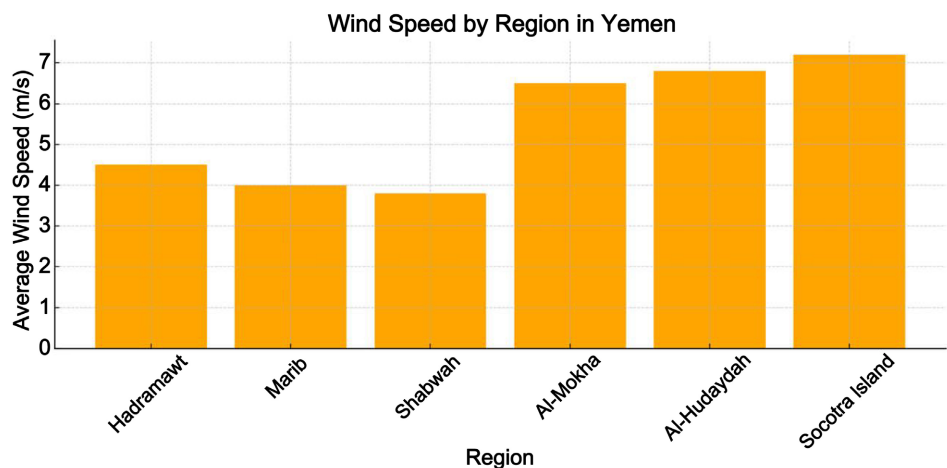


Figure 4. Average yearly wind speed for main areas.

The PEC had already installed an experimental wind turbine in the area [12]. However, due to the ongoing five-year conflict, the turbine has not been put into

operation, making it challenging to predict when the project will be launched and commissioned. Once completed, the project is expected to generate 65 megawatts of grid-connected wind energy, thereby strengthening the national grid system.

Moreover, the average wind speed of most of the main cities for the whole year are depicted in the coming chart (Figure 5).

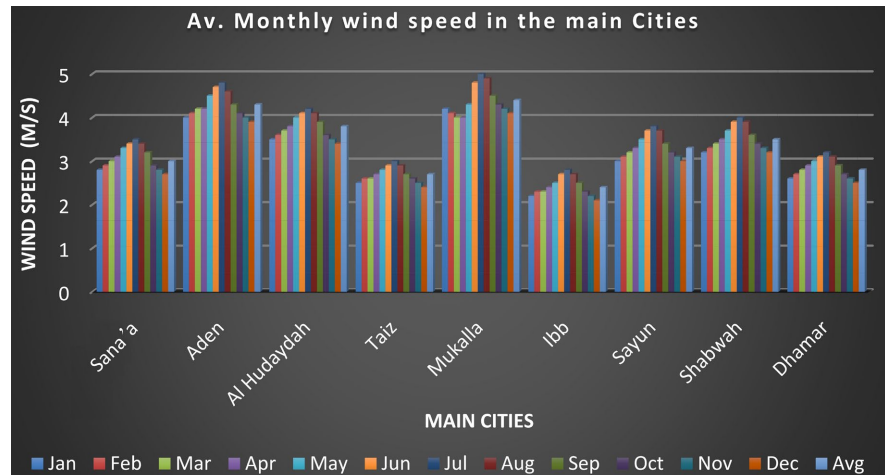


Figure 5. Average monthly wind speed main area.

According to the Ministry of Electricity and Energy (MEE), Yemen has the potential to produce between 17 and 19 gigawatts of wind power, which would not only make the country energy-rich but also enable it to sell surplus energy to neighboring nations. To reach this level of energy production, the Public Electricity Corporation (PEC) needs to open the electricity sector market to both domestic and international investors. However, given the current unfavorable conditions for investors, rather than waiting for the situation to stabilize, studies recommend that PEC should develop a short-term plan (spanning three to five years) to generate 2 gigawatts of electricity from wind energy. This approach would help Yemen avert an inevitable crisis resulting from the collapse of the electricity sector.

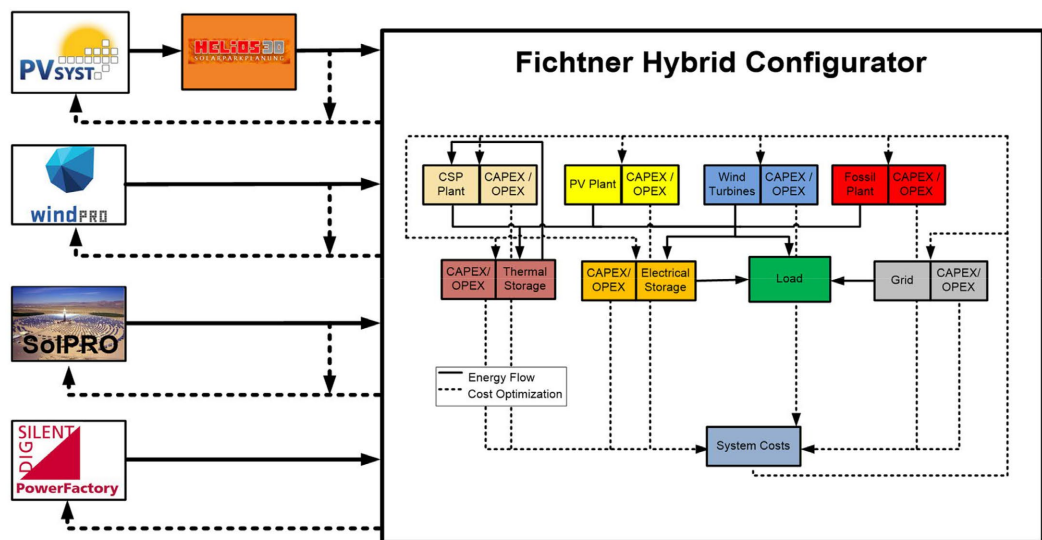
Impact investments are designed to achieve not only financial returns but also positive social and environmental impacts. Given its numerous social and environmental advantages, renewable energy stands out as a highly attractive sector for impact investors. In 2018, the Global Impact Investing Network reported that energy was one of the top three sectors where impact investors allocated their capital. Renewable energy, in particular, aligns well with the goals of impact investing by offering substantial benefits for communities and the environment. Impact investing is most needed in regions facing significant challenges. Yemen, grappling with the world's largest humanitarian crisis, presents a compelling case for impactful investment. By directing capital towards renewable energy projects in Yemen, impact investors can address both the urgent energy needs and broader humanitarian issues, contributing to the country's recovery and sustainable development. Investing in renewable energy in Yemen holds the promise of not only improving

access to electricity but also fostering economic growth, creating jobs, and enhancing the overall quality of life for its citizens.

In the city of Al-Jazirah and Al-Khaleej in Abyan, few tens of miles from Aden city, the installation of the first wind turbine (Phase#1, 1 MW) marks the beginning of an ambitious initiative to establish the country’s first wind power station. This project is designed to provide clean and sustainable electricity to the local community while significantly reducing reliance on fossil fuels.

The deployment of the initial wind turbine represents a foundational step toward promoting sustainable development and addressing the region’s growing energy demands. The broader aim of the project is to supply reliable, environmentally friendly energy, lower electricity costs, and enhance the area’s appeal for residential and investment opportunities. By delivering clean energy to households, businesses, and public facilities, the project supports environmental sustainability and energy independence. Guided by a clear vision for sustainable development through renewable energy, the initiative aspires to serve as a pioneering model for similar efforts both within Yemen and the wider region.

On October, 2019 one of the leading engineering companies called Fichtner conducted short and long-term studies (2018 to 2040) for envisaging the electrification of the Sahel (Mukalla) and Wadi (Syuan) Hadramoot and connecting both areas in unified grid, mentioned that there is also a promise future for the wind energy to be implemented along with PV as a hybrid system shown in **Figure 6**. Moreover, Fichtner recommended for wind turbines of total capacity 20 MW to be invested within the fast-track subprojects [13].



**Figure 6.** Hadramout renewable energy Fichtner proposal.

### 3.3. Biomass Energy

Yemen has an abundance of organic waste from agriculture and livestock, which can be converted into energy through biomass technology [14].

It was estimated that there is a considerable quantity of biomass waste which

can be generated annually, derived from agricultural residues, livestock manure, and organic municipal waste. Current estimates indicate an annual production of approximately 3.8 million tonnes, positioning Yemen as one of the leading biomass waste producers within the MENA region. Scholarly research further reveals that municipal solid waste in major urban centers such as Sana'a can reach up to 1000 tonnes per day. This volume has the potential to produce around 5000 cubic meters of biogas daily—equivalent to approximately 30,000 kWh of energy—which could meet the electricity demands of nearly 5000 households [15].

However, this kind of renewable energy source has not been harnessed in any place in the country, yet and even no any actionable plans have been constituted as compared with the solar and wind sources.

### 3.4. Geothermal Energy

Yemen exhibits considerable geothermal energy potential, attributable to its geologically strategic position at the convergence of the Red Sea, the Gulf of Aden, and the East African Rift system. Empirical assessments indicate an estimated geothermal heat flow of approximately 28.5 GW, with high-enthalpy zones—characterized by temperatures exceeding 190°C—primarily located along the Red Sea coast, and moderate-enthalpy regions, reaching up to 89°C, identified in areas such as Al Lisi-Isbil and Alsyani [16]. Initial exploration initiatives, facilitated through collaborations with German and Italian agencies, encompassed geophysical investigations and exploratory drilling, with a particular focus on the Dhamar-Rada'a and Damt regions [17]. Although these efforts yielded promising indicators, including hydrothermal alteration and elevated subsurface thermal gradients, key development programs—such as the Global Environment Facility (GEF)-sponsored drilling project—were ultimately discontinued due to persistent political instability and financial limitations. In recent advancements, the application of machine learning techniques has significantly enhanced the precision of subsurface temperature modeling, thereby advancing the characterization of geothermal reservoirs and informing future exploration strategies.

### 3.5. Renewable Energy Resources Status Summary

The summary of the status of the renewable energy sources capacities which is available or projects in progress are given in **Table 2**.

**Table 2.** Renewable energy Status summary.

Renewable energy resources summary status			
Renewable source	Area/City	Power	Status
Solar power	Aden phase#1	120 MW	Connected to the grid
	Aden phase#2	120 MW	Project in progress
	Shabwah	120 MW	Project in progress
Wind power	Abyen phase#1	1 MW	Supplying the new city
	Abyen phase#2	19 Mw	Preparation

## 4. Challenges and Opportunities

Basically, the primary challenges in developing renewable energy in Yemen include political instability, lack of infrastructure, financial constraints, and an underdeveloped regulatory framework. However, the abundant renewable resources, international support, and potential for decentralized energy solutions present significant opportunities.

Unanimously, it can be said that the solely outstanding challenge in implementing the solar and wind energy renewable sources is the upfront capital cost for investment central projects as the country faces a fragile economy and limited access to international financing, especially due to political instability and credit risks

A key obstacle to utilizing biomass as a renewable energy source in Yemen lies in the limited availability of advanced conversion technologies. The country currently lacks broad access to systems such as gasifiers and anaerobic digesters, restricting biomass utilization to small-scale pilot initiatives. Moreover, logistical issues and inconsistencies in resource availability—driven by seasonal fluctuations in biomass feedstock and disjointed waste collection infrastructure—pose further challenges to establishing reliable and sustainable biomass supply chains.

Developing the geothermal sector in Yemen faces several challenges. These include high upfront drilling costs, limited infrastructure, technical risks such as well mineralization and fluid sustainability. Despite these obstacles, geothermal energy holds great promise for addressing Yemen's energy deficits, supporting electricity generation, water desalination, and agricultural heating. To realize this potential, the country needs a robust policy framework, investment in scientific capacity-building, and the revival of exploratory drilling programs. Harnessing geothermal resources could contribute significantly to Yemen's sustainable development and energy security.

## 5. Implementation Strategies for Renewable Energy Projects

Implementing renewable energy projects in Yemen requires a well-structured approach that addresses key challenges while maximizing available opportunities. Below are proposed strategies for effective implementation.

### 5.1. Policy Framework and Institutional Support

The government should establish a clear policy framework that supports renewable energy development. This includes enacting renewable energy laws, setting up regulatory bodies, and offering tax incentives to encourage private sector participation. Accordingly, encouraging the private sector investment can help bridging the financing gap and drive growth in the renewable energy sector.

### 5.2. Infrastructure Development

Investment in advanced infrastructure—such as utility-scale solar farms and wind turbine systems—is essential for the effective deployment of large-scale renewable

energy projects. Collaborations with international institutions can play a pivotal role in addressing existing infrastructure deficits and accelerating the transition to sustainable energy systems.

### 5.3. Capacity Building and Training

Establishing technical training programs is vital for cultivating local expertise in renewable energy technologies. Strategic partnerships with universities and vocational institutions can facilitate the development of a qualified workforce capable of supporting and sustaining the renewable energy sector.

### 5.4. Community Involvement

The participation of local communities in the planning and implementation processes is critical for ensuring the sustainability of renewable energy initiatives. Public awareness programs can effectively communicate the benefits of these projects to community members. This participatory approach helps address potential barriers such as local resistance, mistrust, or lack of understanding, and is particularly important for ensuring the long-term viability of off-grid renewable energy systems by promoting local ownership, responsibility, and acceptance.

## 6. Conclusions and Policy Recommendations

Yemen holds significant untapped potential in renewable energy, particularly in solar, wind, biomass, and geothermal resources, which—if effectively harnessed—could play a transformative role in mitigating the country's persistent energy crisis and advancing its sustainable development goals. The integration of these resources into the national energy mix presents a strategic opportunity to reduce dependency on fossil fuels, enhance energy security, and promote economic resilience, especially in remote and underserved areas. However, achieving this transition requires more than technical deployment; it demands comprehensive and inclusive governance frameworks, long-term strategic planning, strong institutional capacity, and sustained international cooperation. Equally important is the active participation of local communities, which is essential to overcoming social resistance, building trust, and ensuring the long-term success and maintenance of renewable energy systems. In light of these challenges and opportunities, this study concludes with a set of actionable policy recommendations designed to guide Yemen toward a resilient, inclusive, and sustainable energy future.

- Establishing a comprehensive national renewable energy policy.
- Encouraging private sector investment to bridge the financing gap and drive growth in the renewable energy sector.
- Providing financial incentives and tax exemptions for renewable energy projects.
- Prioritizing off-grid solutions to expand access to electricity in rural areas.
- Collaborating with international organizations to secure funding and technical support.

By adopting these measures, Yemen can create a sustainable energy future that promotes economic growth, energy security, and environmental protection.

### Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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