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ANALYSIS OF THE PLANNING INFORMATION OF THE YEMEN REGIONAL SOURCE NETWORK LOAD AND STORAGE

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ABSTRACT
Yemen possesses a system of geographically distinct power networks that are mostly fueled by natural gas and oil. The civil unrest in Yemen has caused significant damage to both the national energy system and regional networks. The investigation seeks to find areas that can be enhanced in order to offer consistent and trustworthy energy. Similarly, there is a requirement for an increase in efforts aimed at improving energy efficiency. More precisely, this requires the cultivation of expertise and the acquisition of abilities to guarantee the successful execution of the plans on a broader scale. Yemen is currently in the early stages of its energy transition and is facing many challenges in expanding renewable energy sources. However, it would be wise for the country to develop a more sustainable energy framework that can offer both immediate and long-term benefits to its people. The results obtained from the transition phase model towards obtaining full dependence on renewable energy sources can act as a catalyst for sparking and promoting discussions regarding Yemen's potential energy system. To achieve this goal, we build a comprehensive guiding vision for the transition of energy systems and implement appropriate policy efforts.

1. INTRODUCTION
The objective of analyzing the planning information of the Yemen Regional Source Network Load and Storage is to have a thorough comprehension of the network's present condition and future requirements. This analysis will investigate multiple facets pertaining to load and storage planning, methods for expanding the network, and the incorporation of renewable energy sources. Through the implementation of this analysis, significant knowledge can be acquired to guide decision-making procedures and facilitate the provision of efficient and dependable energy in Yemen.

1.1 Purpose of the Analysis
The objective of this analysis is to assess the planning information of the Yemen Regional Source Network Load and Storage with the aim of identifying areas that can be improved and suggesting ideas to enhance load and storage planning. This analysis aims to address current issues and limitations, enhance network performance, and contribute to the advancement of more efficient laws and regulations regarding energy planning in Yemen. It will achieve this by conducting a comprehensive examination of the available data and utilizing advanced analysis tools.

1.2 Analysis Scope
This analysis covers multiple facets of load and storage planning inside the Yemen Regional Source Network. The document provides a comprehensive analysis of the network and its crucial role in guaranteeing a reliable and robust energy provision. The analysis also examines the difficulties and limitations encountered in load and storage planning, as well as the various types of storage facilities and their capacity evaluation. Moreover, it includes strategies for expanding the network, planning for transmission and distribution, and integrating renewable energy sources. The objective is to offer a thorough evaluation of the planning information and pinpoint areas for enhancement.

1.3 Used Methodology
The analysis employs a methodical way to gather and examine planning data. The process involves identifying and utilizing trustworthy sources of data pertaining to load and storage planning. Data collecting methods encompass the acquisition of historical load patterns, load forecasting techniques, as well as load variations and

peaks. The acquired data will be analyzed using various techniques, including statistical models and trend analysis, to extract valuable insights. The methodology encompasses network planning evaluations, incorporating network growth strategies, transmission and distribution planning, as well as the incorporation of renewable energy sources. By adhering to this rigorous technique, a comprehensive analysis may be carried out to substantiate evidence-based decision-making.

2. BACKGROUND

Yemen's electrical infrastructure is fragmented into multiple regional grids, with restricted connections among them. The national grid encompasses densely populated western areas such as Sana'a and Hodeidah. Other cities have separate power distribution networks. The production of power relies heavily on fossil fuels. Marib's natural gas was the primary source of fuel for significant power plants until the conflict caused disruptions in gas supply. Following the gas shortages, there has been an increased utilization of diesel and heavy fuel oil. Renewable energy sources such as solar, wind, and hydropower contribute a modest yet expanding portion of electricity output. The majority of renewable energy generation capacity has been installed in the past few years. The availability and dependability of electricity have significantly decreased since the escalation of the conflict in 2015. Numerous regions have prolonged power outages. The network has been significantly affected by the destruction of power lines, substations, and other infrastructure as a result of airstrikes and conflict. The system has also deteriorated due to a lack of maintenance and repair. Load shedding and rolling blackouts are prevalent in numerous urban areas due to the insufficiency of generation capacity to meet the high demand. Hospitals have experienced significant adverse impacts.

The electricity situation has been exacerbated by fuel shortages, insufficient money, technical problems, and disruptions caused by conflicts. Donor-funded external assistance initiatives, such as those provided by the World Bank, have the objective of repairing and reconstructing the sections of the grid that have been destroyed. However, the progress achieved thus far has been exceedingly restricted.

2.1 Overview of the Yemen Regional Source Network

The national electricity grid and regional networks in Yemen have suffered extensive damage due to prolonged fighting, scarcity of fuel, and inadequate maintenance. Preceding the ongoing civil conflict, Yemen has a network of geographically separate power networks, with limited interconnectedness, predominantly powered by natural gas and oil. Since 2015, the destruction caused by airstrikes and combat to power lines, power plants, and substations has severely impaired the ability to generate and transmit electricity. The interruption of gas supplies has led to a greater dependence on diesel and heavy fuel oil for operational power plants. The occurrence of blackouts has been frequent in large cities such as Sana'a and Aden due to an increase in technical losses. Hospitals experience prolonged disruptions in essential infrastructure. Insufficient fuel supplies often result in the need to cease operations. The level of damage has exceeded the rate at which external support for repairs has been provided. Yemen's electricity infrastructure has been severely damaged by the war and is at risk of complete collapse in numerous regions. To achieve recovery, extensive reconstruction, establishment of fuel access, and peacebuilding initiatives are necessary, with technological enhancements to the fragmented regional grids that are now operating at limited capacity.

2.2 Importance of Load and Storage Planning

Strategic coordination of electric load and storage capacities will be essential in the reconstruction of Yemen's severely damaged power infrastructure. Utilizing demand forecasting and implementing metering systems facilitates accurate load planning, enabling the appropriate determination of generation capacity expansions and the identification of critical areas for maintenance or enhancement of transmission lines, substations, and distribution networks. Strategically incorporating storage assets such as pumped hydro or utility-scale batteries enables better integration of renewable energy sources like solar PV, thereby mitigating supply variations. Storage systems also offer contingency power during periods of power outages or fuel supply interruptions. Inadequate load and storage planning will result in persistent shortages during periods of high demand, erratic voltage fluctuations, and unreliable service. Efficient planning enhances the dependability and robustness of the system.

In Yemen, using a synchronized strategy for load and storage planning across different areas could enhance the exchange of reserves and ultimately assist in connecting the separate power systems. Through a thorough evaluation of the increase in demand, the various possibilities for generating power, and the capacity for storing energy, planners can ascertain the most suitable strategy for reconstructing the electricity system to make it stronger and more stable.

- Load planning using demand forecasting assures sufficient generation and transmission capacity to satisfy peak power demands at various times of day and seasons. Inadequate load planning can lead to shortages and outages when demand surpasses supply.
- Strategizing for energy storage enables better incorporation of sporadic renewable output, such as solar and wind. Storage systems play a crucial role in mitigating the variability of renewable energy production and serve as a reliable source of backup power during periods when renewable resources are not accessible.
- Storage assets such as pumped hydro and batteries offer reserve capacity that may be used when major fossil fuel facilities or transmission lines unexpectedly become inoperative. This enhances the robustness of the grid.
- Efficient load and storage planning enhances the optimization of power plant operations and efficiencies. For instance, the utilization of storage enables baseload plants to maintain a consistent level of output, while effectively addressing peak demand through the use of dispatchable storage.
- Implementing load levelling through storage systems effectively decreases the peak demand on the electrical grid, hence diminishing the necessity for peaking power units and transmission infrastructure enhancements.
- Load and storage planning enables the sharing of surplus resources and the consolidation of capacity across different areas. This enhances the grid's overall resilience and dependability.
- Coordinated planning facilitates the development of smart grid capabilities, such as demand response, which allows for load shifting and better integration of renewable power.

In summary, implementing thorough load and storage planning results in a more adaptable, robust, and environmentally friendly electrical grid that ensures a consistent power supply, even in the face of disruptions and fluctuations in renewable energy sources. Effective planning is particularly crucial when it comes to reconstructing grids that have been devastated by war, such as the one in Yemen.

2.3 Challenges and Constraints

The absence of up-to-date and dependable information regarding the present condition of grid infrastructure and power plants is attributed to the destruction caused by war and the absence of regular maintenance. Obsolete equipment records.

Insufficient data available regarding the electricity consumption patterns in various regions due to population displacement and economic disruption. (fig.1)

The instability and war have created uncertainty over future demand estimates. Limitations imposed by technical factors: Airstrikes have caused extensive damage to the transmission and distribution systems, resulting in limited connectivity between different locations. Thermal power plants face a lack of fuel supply, particularly due to interruptions in the delivery of natural gas. Inadequate availability of skilled staff for the purpose of repairs and maintenance. Lack of spare components. Significant technical losses resulting from the deterioration and impairment of equipment.

Financial Constraints:

Inadequate finance for significant reconstruction and necessary upgrades is lacking. Reduced tariffs and the process of collecting revenue.

Dependence on external financial assistance that has proven to be inadequate. The diversion of resources from vital electricity infrastructure due to war economy and corruption.

Security and Geopolitical Risks:

The ongoing violence hinders the process of repairing existing infrastructure and constructing new facilities, posing significant risks and challenges. The existence of political divides among competing factions hinders the ability to engage in coordinated planning. There is a potential for resumption of hostilities and further deterioration of infrastructure, even after repairs have been made.

Environmental Constraints:

Certain places have a scarcity of renewable energy resources such as sun, wind, and hydropower. The limited availability of water may impede the production of hydropower and thermal electricity. (fig.2)

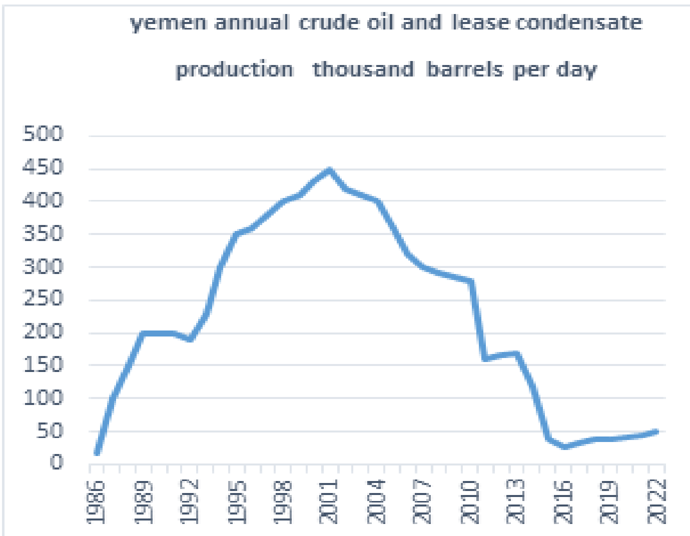

Fig .1

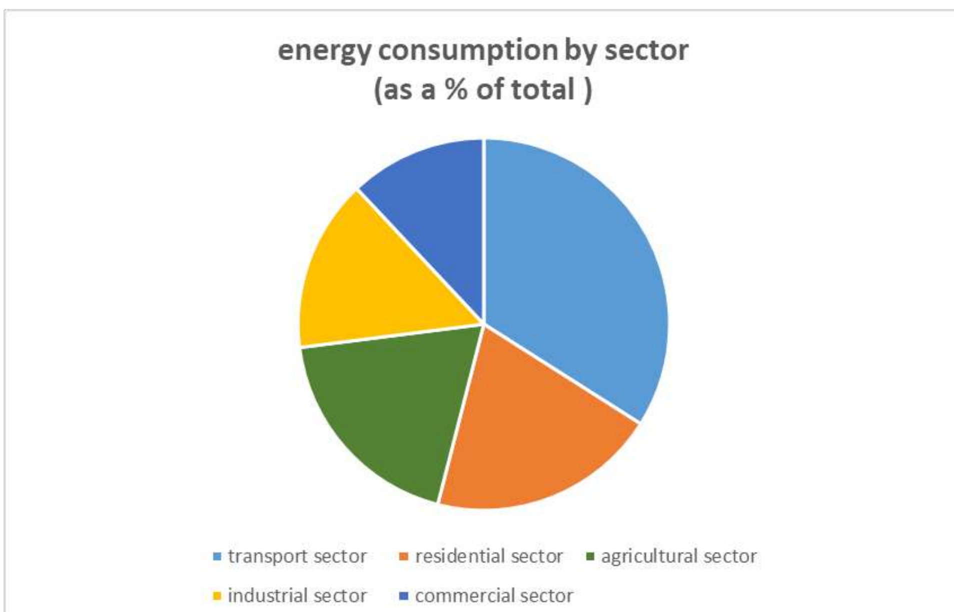

Fig.2

3. DATA COLLECTION AND ANALYSIS

Yemen's population increased by almost 61% from 17,409,072 in 2000 to 28,498,687 in 2018 . Yemen's GDP increased nearly thrice from US$ 9,652 billion in 2000 to US$ 26,914 billion in 2018. GDP per capita growth (annual percentage) was approximately -5% in 2018

Between 2000 and 2012,

- Annual population growth averaged 3.1%.
- Annual GDP Growth between 2000-2012 averages about 2.6%,
- GDP per capita in 2012 was US$1,37710
- GDP Structure in 2012 Overall Average Figures are:

o Agriculture 10%

o Industry 38%

o Services 52%

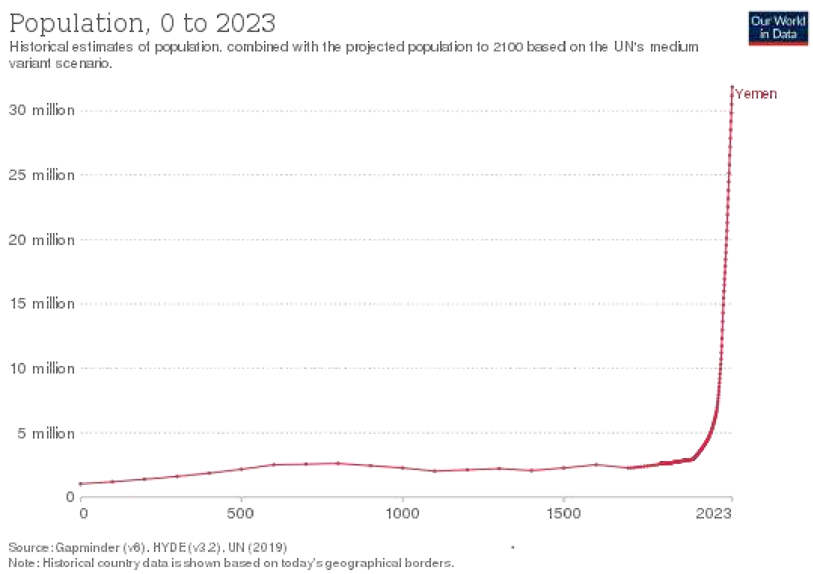

Fig.3

Demography of Yemen

Yemen (/jmn/), also known as the Republic of Yemen, is a country in Western Asia that occupies the southern and western ends of the Arabian Peninsula. Saudi Arabia to the north, Oman to the east, the Red Sea to the west, the Gulf of Aden and Arabian Sea to the south. Sana'a is the nation's capital and largest city. More than 200 islands may be found in Yemen, the largest of which is Socotra, which is located 354 kilometers south of the main land of Yemen. With a total area of 527,970 km2, Yemen is the second-largest country on the peninsula.

Yemen's population expanded from 7.9 million in 1980 to over 25.5 million in 2015, with about 35% of the population living in cities and the rest in rural areas. In 20501, the population is projected to continue growing to a total of about 42.5 million.

Yemen's population growth rate grew from 3.99 percent between 1980 and 1985 to 4.84 percent between 1990 and 1995. It subsequently began to fall to an average of 3.30 percent between 2005 and 2015, while the Yemen Central Statistic Organization (CSO) reported population growth of about 3.0% in 2013.1 The Yemeni population is expected to expand at a slower rate in the next years, reaching 0.82 percent between 2045 and 2050.

Macroeconomic Development

Yemen's government was working to enhance its monetary policy and monetary system in order to preserve exchange rate stability and manage inflation. In 2006, the Yemeni Rial (YER) fell by less than 2% versus the US dollar. Between 2007 and 2009, the local currency was generally steady, before weakening by roughly 10% versus the US dollar in the first quarter of 2010. The Yemeni Riyal was trading at YER 219.59/USD in mid-January 2010, and is expected to fall slightly to YER 214.9/USD in 2014, although inflation has risen gradually from 8.8% in 2009 to 17.5% in 2013.

Most foreign currencies, particularly US dollars, are widely accessible and easily exchanged at market prices. Investors may transfer funds in hard currency from overseas to Yemen for investment purposes and may re-export invested capital, whether in kind or cash, upon project liquidation or sale. Net proceeds from foreign fund investments may be freely moved outside of Yemen. The maximum cash transfer amount is $10,000 USD. Transfers in excess of that amount require approval from the Central Bank of Yemen (CBY).

The CBY intervenes in the currency market on a regular basis, selling off US dollar reserves in order to strengthen the local currency. The CBY sold USD 1.1 billion in 2008 to curb currency depreciation, up from USD 1.077 billion in 2007.

The CBY has interfered at least seven times by the end of 2009, putting about USD 1.24 billion into the exchange market.

Over the same time period, interest rates were relatively steady, with the benchmark interest rate on deposits set at 20% and lending rates ranging around 22%3.

The GDP increased from YER 1,662 billion in 2001 to YER 5,374 billion in 2009 (about $24.5 billion at 2009 exchange rate), and it now stands at $43.23 billion (as of 2014). During that time, the non-oil industry grew gradually at a rate of 4.5 to 5.5 percent per year (in constant prices). Government revenue grew from YER 553.1 billion to YER 2,109 billion, (about $9.59 billion at the 2008 currency rate) between 2001 and 2008. Expenditure grew in lockstep with revenue, rising from YER 506.7 billion to roughly YER 2,342 billion (about $10.7 billion at 2008 exchange rate) during the same period2.

Yemen is one of the Arab world's poorest countries. Poverty has already been rising previous to the current political crisis, rising from 42% of the population in 2009 to 54.5% in 2012. Yemen has one of the world's fastest population growth rates, with an estimated 3.0% increase in 20134.

Yemen initiated an ambitious economic reform program in August 2014, with the goal of eliminating fuel subsidies, expanding public service reforms, and strengthening the country's social safety net. Progress on the political and security fronts, as well as the execution of these key changes, will determine economic prospects.

3. Issues and obstacles faced in the development of renewable energy in Yemen As previously stated, there are numerous justifications for promoting the adoption of renewable energy technology in Yemen, primarily to address the issue of severe electricity scarcity [14–16]. Furthermore, it is important to take into account the aspect of clean energy and other relevant factors.

Nevertheless, numerous obstacles and limitations exist concerning the technology depicted in Figure 4. These include insufficient data, as well as national challenges such as financial constraints, security risks, and regulatory issues. An examination of this fact entails a thorough analysis of the obstacles presented by the following barriers

3.1. Obstacles Related to Finance

The presence of a financial barrier is a significant impediment in the implementation of any project. The project's success is contingent upon sufficient funding. The primary economic obstacles include the precariousness of investing in an unstable state, the substantial capital costs, the challenges in accessing finance, and the absence of domestic financial institutions [34–37].

3.2. Obstacles in the Market

The primary challenges impeding the widespread implementation of renewable energy technology as state-sponsored projects include the continued support for conventional energy sources (such as fossil fuel power projects and gas), inadequate market infrastructure, and the state's inclination towards traditional energy sources [14–39].

3.3. Obstacles Related to Institutions

The absence of functional institutions is the primary element that significantly reduces the dissemination of any technique. There is an absence of an institutional framework and a deficiency in the functioning of institutional mechanisms in this sector. Furthermore, the absence of appropriate legal and regulatory structures to support the execution of these initiatives and the coordination among many parties involved, including stakeholders and investors, is a significant concern [13–36].

The absence of a research and development (R&D) framework and the failure to engage with the private sector to undertake such studies and development initiatives. Ultimately, the lack of proficient establishments (specialized) [38].

3.4. Obstacles of a Technical Nature

This pertains to contemporary technology and necessitates a thorough understanding of its functionality in order to effectively train and equip proficient personnel for its operation. In addition to the supply of standards and certification. The absence of technical obstacles hinders the development centers or production of these technologies within the state, as well as the inadequate state of energy transfer [22–34].

3.5. Obstacles Related to Social Interactions, Safety, and Additional Factors

These hurdles are equally crucial as their predecessors. It is imperative to acknowledge the dearth of public awareness among residents, attributable to the persisting tribalistic tendencies in numerous regions. This could have a negative effect on the execution of such projects, as well as due to the lack of government authority in these areas [39].

The absence of consistent governmental policies ultimately hinders the dissemination of awareness and endorsement for green energy initiatives.

The Energy Situation

According to the International Energy Agency, oil accounted for 98.4% of Yemen's total primary energy supply in 2000, with the remaining made up of biofuels and trash. Natural gas and coal entered the energy mix around 2008, and wind and solar energies, among other things, entered the energy mix around 2015. In 2017, oil accounted for approximately 76% of total primary energy supply, natural gas for 16%, biofuels and waste for 3.7%, wind and solar energies for 1.9%, and coal for 2.4%. According to the International Energy Agency, Yemen's final power consumption in 2017 was 4.14 TWh. This amount was also broken down by industry, with transportation accounting for the most. Residential consumption was 891 ktoe (39.5%), while industry consumed 320 ktoe (14.2%). commercial and government services 105 ktoe (4.7%), undefined (88 ktoe (3.9%), agricultural and Forestry contributed 41 ktoe (1.8%) while non-energy usage contributed 7 ktoe (0.3%). The amount of electricity consumed was 0.15. In 2017, MWh/capita was used.

Total Energy Production in 2012 Averaged 14 Mtoe,

- Annual Primary Energy Demand Growth between 2000 and 2012 Averaged at 1.2%,
- Annual electricity Demand Growth between 2000 and 2012 Averaged at 5.6%,
- Primary Energy mix in 2012:

o Crude Oil Product 94%

o Natural Gas 4%

o RE and Others 2%

- Final Energy Demand by Sectors in 201216:

o Transport 34%

o Residential 20%

o Industry 15%

o Agriculture 19%

o Commercial 12%

- Share of Fuel for Electricity Generation in the Primary Energy Mix in 2012 Averaged at 10%,

- Share Final Electricity in the Final Energy Consumption Energy Mix in 2012:

o Residential 62%

o Services 15%

o Industry 4%

o Others 19%

Macro Policy Indicators

• Primary energy intensity in 2000 and 201217

o Energy Intensity in 2000 0.46 Toe/$1000$05

o Energy Intensity in 2012 0.38 Toe/$1000$05

• Energy bill to GDP in 2000 and 201218

o Energy Bill to GDP in 2000 13%

o Energy Bill to GDP in 2012 17%

• Energy subsidy to GDP in 2011 averaged at 4.8%19 ,

o Energy subsidy compared to the budget allocated to education in 2011

o Energy subsidy 4.8%

o Education subsidy 4.6% • Energy Subsidy per Energy Product in 2011,

o Oil Products 4.8%

o Electricity 1.2%

• Share of Electricity in Household Expenses in 2012 Averaged at 0.7

Oil and Gas Resources

In relation to Yemen's oil reserves, the commencement of production occurred in 1986, reaching its highest point in 2001, and afterwards experienced a fall as a result of field maturity, inadequate development of additional fields, labor strikes, and political instability.The number 23 is the subject of discussion. The Ministry of Oil and Minerals in Yemen is responsible for the oversight of the oil and natural gas sectors. This governmental body establishes policies and handles the management of relationships with foreign operators through product sharing agreements. The operators encompass Total, Occidental Petroleum Corporation, and Nexin, which is a subsidiary of China National Offshore Oil Corporation. The transportation of exports is aided by the utilization of tanker vessels, which are deployed through an internal pipeline system and export terminals.

Regarding Yemen's natural gas resources, production commenced in the early 1990s. However, it was not until 2009 that the country achieved significant commercial volumes of dry natural gas production. This milestone was accomplished with the operation of a newly established liquefied natural gas (LNG) facility, which was run by Total25. However, the primary purpose of the produced natural gas is for exportation, while the utilization of domestic gas remains constrained. According to IHS Global Insight26, Yemen LNG contributed around 3% of the total global liquefied natural gas (LNG) volumes in the year 2013. In the realm of liquefied natural gas (LNG) exports, GDF Suez, Total, and Korean Gas (KOGAS) emerge as the primary purchasers. In the year 2012, Yemen LNG adopted the stance that the contractual rates for LNG fell below the prevailing market price. Consequently, Yemen LNG endeavored to address this issue and seek more favorable pricing terms.

Cases	Average expected electrical energy (kWh/year/per capita)	Average expected electrical energy (kWh/day/per capita)	Average expected electrical energy (Wh/10 h/per capita)
Strategy of case one (minimum demand)	**402kWh/year**	**1.10kWh/day/capita**	110 W/capita
Strategy of case two (medium demand)	730kWh/year	2.0kWh/day/capita	200 W/capita
Strategy of case three (high requirement)	1460kWh/year	4.0KWh/day/capita	400 W/capita

Fig. 4

3.1 Data Collection Methods

- Perform surveys and audits to document the current condition of the existing power production facilities, transmission infrastructure, and distribution networks. Evaluate the extent of damage, identify maintenance requirements, and determine the remaining lifespan.
- Deploy metering technology to quantify electricity demand and load patterns across diverse regions, customer segments, and temporal intervals. Smart meters provide instantaneous monitoring.
- Collect information regarding the current fuel resources and expenses for operational thermal power plants, encompassing the associated transportation and storage systems.
- Evaluate the capacity for renewable energy by utilizing solar and wind mapping, conducting surveys on water resources, and performing geospatial analysis.
- Analyze historical and projected demographic and economic data to predict future power consumption.
- Gather data on prospective storage locations and technologies such as pumped hydro, compressed air, and battery storage.

3.2 Evaluation:

- Create demand forecast models utilizing economic, population, and electrification assumptions. Conducting a scenario test with varying assumptions.
- Perform load flow analyses with measured demand data and established grid parameters to detect congestion problems. Failures and backup plans for models.
- Scale and model the expansion of generating and storage capacity to fulfill anticipated periods of high demand and to accommodate the incorporation of renewable energy sources.
- Calculate the expenses associated with grid enhancement, fuel provision, and upkeep, considering various plan scenarios. Evaluate the choices between costs and benefits.

- The model decreased both technical and non-technical losses through maintenance, equipment upgrades, and anti-theft measures.
- Examine the advantages of enhancing interconnection between regional networks in terms of grid stabilization and resilience.
- Determine the most crucial infrastructure investments by considering factors such as cost, demand, impact on reliability, and feasibility.

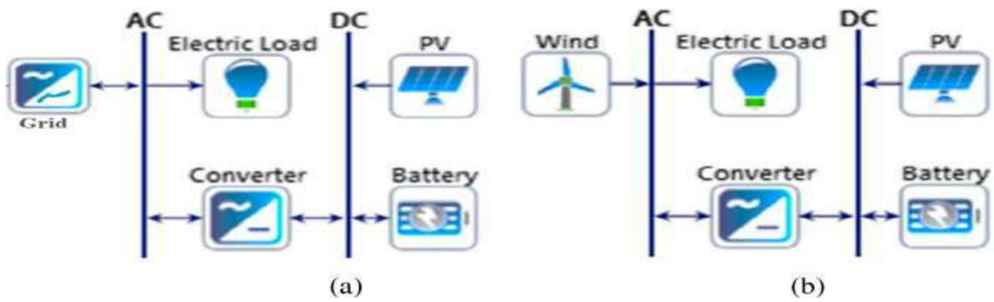

Fig .5

Schematic diagram of different off and on grid renewable energy systems. a PV/BES on grid system. b PV/WT and BES off grid system

From: A review of Yemen's current energy situation, challenges, strategies, and prospects for using renewable energy systems

4. LOAD ANALYSIS

4.1 Load Forecasting Methods

Proposed Strategies Based on Electrical Energy Demand

Based on the electricity map for the Yemeni population as projected to 2050 and based on the least requirement, the strategy of the three cases (minimum, medium, and relatively high demands) leads to the following projections in fig. 5. The strategy of case two is almost about 50% of the share of Tunisian/capita in the year 2014 and is almost about 2.0 kWh/day/capita with a power of 200 W/capita.

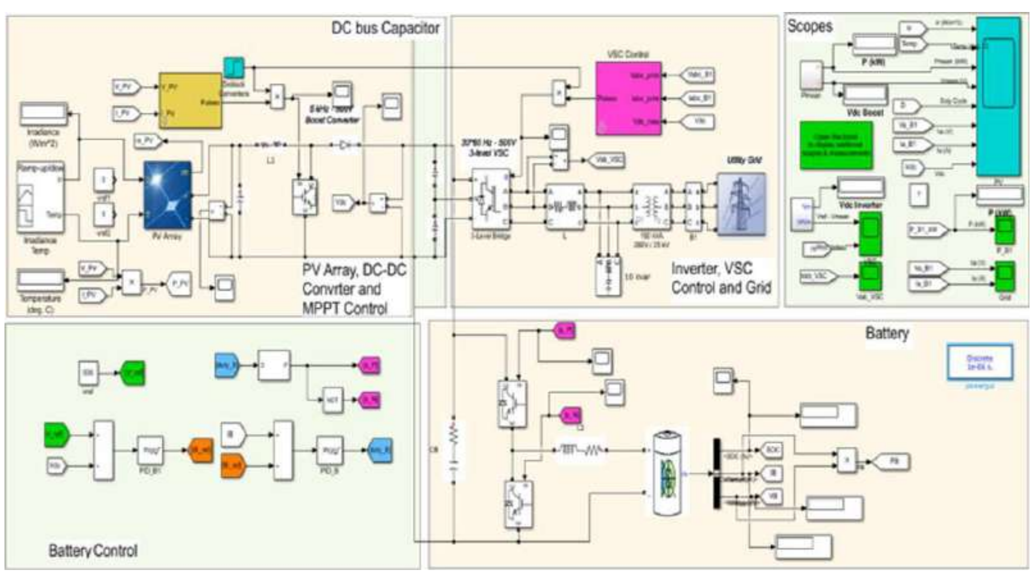

Fig 7

Schematic diagram of on grid renewable energy systems

From: A review of Yemen's current energy situation, challenges, strategies, and prospects for using renewable energy systems

5. DESIGN AND CONFIGURATION OF PROPOSED HYBRID RENEWABLE ENERGY SYSTEMS

As shown in fig. 5 , the Government of Yemen (GOY) has created long-term strategies in the energy sector, based on the assumption that the economy and GDP will grow slowly. The first strategy is to provide 1.10 kWh/day/capita. The second strategy is to provide 2 kWh/day/capita, which is 50% of the average electrical energy/capita in neighboring Arab countries. The third strategy is to electrify 4 kWh/day/capita, which is almost 50% of the global average electrical energy/capita. In Yemen, 25% of the population lives in cities, while 75% lives in rural areas. Yemen has limited access to electricity, with around 85% of the urban population and 23% of the rural population having access. The government has categorized those residing in rural areas into four distinct groups based on their level of connection to the national energy grid. The first kind has convenient grid access, the second type has grid access with a little elevated cost, the third type has grid access with a significant cost, and the fourth type has both a high cost and limited grid access. The project aims to build several arrangements of micro-grid energy systems, incorporating photovoltaic (PV) and wind turbine (WT) technologies, to provide electricity to a wide variety of consumers in Yemen, as seen in Figure 6. Below, we present the simulation findings and debates regarding the two distinct designs of the hybrid renewable energy systems.

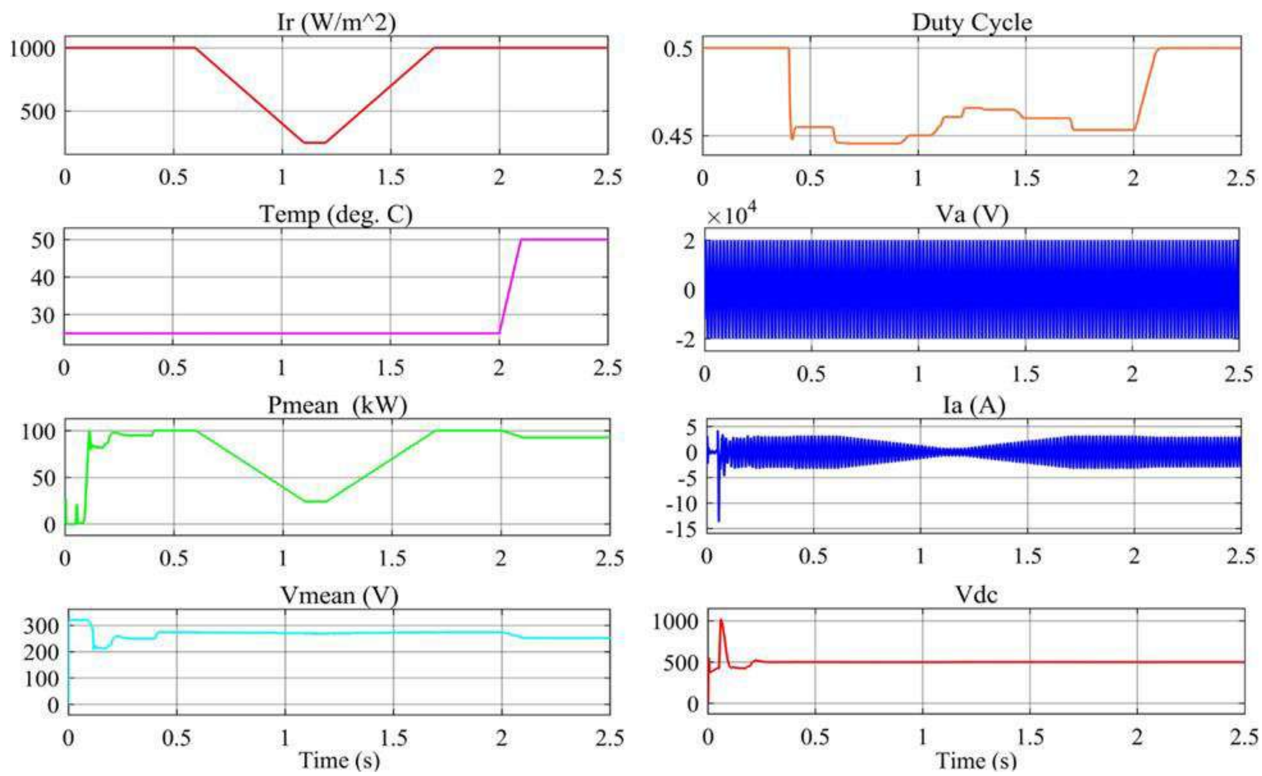

Fig 8

The simulation output results of on grid renewable energy systems

6. PHOTOVOLTAIC/BATTERY ENERGY STORAGE (PV/BES) INTEGRATED INTO A GRID SYSTEM.

Figure 7 illustrates the initial arrangement of the grid-connected hybrid PV/BES systems under consideration. The system comprises a photovoltaic (PV) array connected to the DC bus via a boost DC/DC converter equipped with a maximum power point tracking (MPPT) controller. The maximum power point tracking (MPPT) was achieved utilizing a boost converter in a Simulink model, employing the "Incremental Conductance + Integral Regulator" technique (Al-Wesabi et al., 2022a) (Ibrahim et al., 2020) (Farh et al., 2018). The voltage source converter (VSC) enables the maximum power point tracking (MPPT) operation by controlling the DC bus voltage and transferring power from the DC bus to the utility grid. Furthermore, the VSC facilitates the synchronization of the PV system with the grid when it starts up or reconnects after system islanding (Alturki et al., 2021) (Farh et al., 2020) (Al-Shamma'a et al., 2020).

Figure 7 demonstrates the utilization of BES to improve the regulation of DC bus voltage. BES is connected to a bidirectional buck-boost converter (BES conv.) which manages the charging and discharging operations during challenging situations like sudden variations in solar irradiation and faults. The hybrid subsystem is linked to the utility grid at the point of common coupling (PCC) by a low-pass filter and an interconnection transformer, which is symbolized by an inductor, from the VSC AC output terminals. These components have the function of attenuating harmonics and separating the overall system from the utility grid. The transformer increases the voltage level of the PV system from a low level to a high level, and vice versa. The PV/BES system transfers the total power, PG, to the utility grid, which in this instance operates on a standard medium voltage distribution system (Al-Wesabi et al. 2022b) (Farh and Eltamaly 2020).

Three scenarios are examined to analyze the performance of the system under various test settings, including the Standard Test Condition (STC). Initially, it is postulated that the 100 kW photovoltaic solar system functions under the conditions of 1000 W/m2 solar radiation and 25 °C ambient temperature. Additionally, the system undergoes testing at 250 W/m2 radiation and 25 °C temperature, resulting in a power output of 24.4 kW. Furthermore, the system is tested at 1000 W/m2 radiation and 50 °C temperature, yielding a power output of 92.9 kW. The model parameters can be modified to accommodate different levels of solar radiation. Figure 8 displays the simulation results for all instances. If the peak power voltage (PPV) is less than the power load (Pload), the battery is discharged to supply the additional required power to the load, resulting in a positive direct current (DC) output from the battery energy storage (BES). The primary power grid also functions regularly to supply the shortfall in electricity demand. However, if the photovoltaic (PV) power is more than the load power, then the direct current (DC) output from the PV system is increased, indicating that the battery is in the process of being charged. Therefore, the current of the Battery Energy Storage System (BESS) is negative, indicating an abundance of electricity being supplied to the utility grid. Power feeding into the grid network results in larger current amplitudes for both the inverter and external grid, compared to the scenario where power generated by the photovoltaic system is less than the power used by the load.

7. HISTORICAL LOAD PATTERNS

An essential preliminary examination for developing Yemen's future energy infrastructure is comprehending historical load profiles. However, this task is hindered by the scarcity of available data. Before the conflict, the highest level of energy demand was concentrated in urban regions such as Sana'a, Aden, and Taiz, whilst rural areas had little access. Due to Yemen's population growth and economic development during the 1990s and 2000s, there was a consistent yearly increase of roughly 6% in energy demand. This necessitated the continuous construction of additional generation capacity. The demand reached its highest point during the afternoon and evening hours, coinciding with the peak usage of lighting and cooling systems in residential and commercial buildings. Additionally, there were fluctuations in the load based on the seasons, with elevated peaks during the summer months as a result of increased usage of air conditioning. Nevertheless, the conflict that commenced in 2015 had a profound impact on the level of demand. The transmission line damage resulted in the formation of localized pockets of electricity supply. Due to the limited operation of specific power plants, blackouts became frequent as available resources were insufficient to satisfy high-demand periods. Enforced power outages and controlled distribution of resources were put into effect. Comprehensive historical data is lacking for recent years. Reestablishing the ability to measure and analyze data will be a top priority in order to comprehend the daily and seasonal fluctuations in electricity use, which is crucial for rebuilding the capacity of the network.

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Eins½Lx

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The variables Eins, Aroom, ΦL, UF, and MF represent the installed illuminance, the floor area of the room, the flux of the luminaires, and the utilization and maintenance factors, respectively.

Table 3 provides an estimation of the electrical load for the entire average community. These loads are suitable for determining the dimensions of PV modules. However, those loads that can be operated during daytime and half the load of those that operate consistently can be removed from the sizing of the storage system, as illustrated in Table 4 presents the information regarding the sizing of the PV system, namely in section 3.3.

The size of the PV modules is 3.3.1.

The size of the PV panels is determined using Equation (2).

The list contains the numbers 4, 5, 15, and 17.

The equation represents the relationship between the size of the photovoltaic system (PVsize), the load energy demand (ED), and the average daily solar radiation (Gav) for the month of December, which is known for having the least amount of solar radiation.

The average solar radiation is 5.64 kilowatt-hours per square meter per day, with a range between 18 and 22.

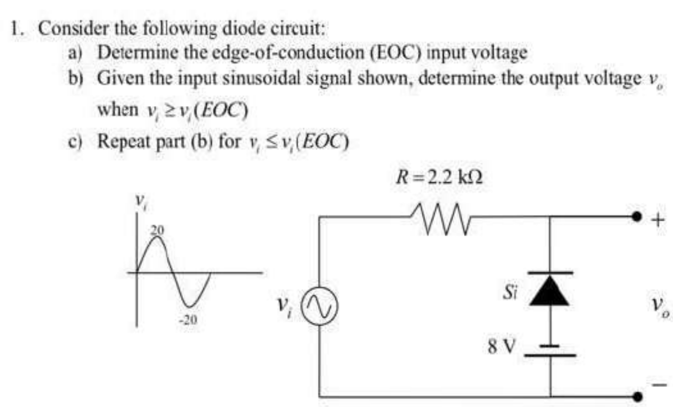
ηL considers the power loss in connection cables and other concealed losses.If ΔPC represents the power losses per unit, then the efficiency ηL is equal to 1 minus PC. The maximum power losses of the PV system, which is 5% (i.e. ηL = 0.95), are optional unless otherwise specified.

The variable ηinv represents the efficiency of the inverter and the maximum power point tracking system (MPPT). The efficiency of the inverters, whether used by individual consumers or for the entire village, is assumed to be 90%. However, manufacturers suggest peak efficiencies of 92-95% [4,5,18,19,20]. In the case of a freestanding DC PV system, this factor will consider only the losses of the MPPT and charging controller, and it will be approximately 0.95.

Dt is the overall reduction factor for PV modules, taking into consideration the impact of aging and temperature on the modules.The calculation is performed as follows:

The aging factor of a photovoltaic module (Dag).

The initial output power of the module (Poini) varies among manufacturers under Standard Test Conditions (STC).The value can be either 5% [26], 3% [27], or 73% [28] of the rated output power (Porated), which is represented as Poini = 0.97 * Porated.



The simplified electrical diagram of the standalone PV system for the entire typical village.

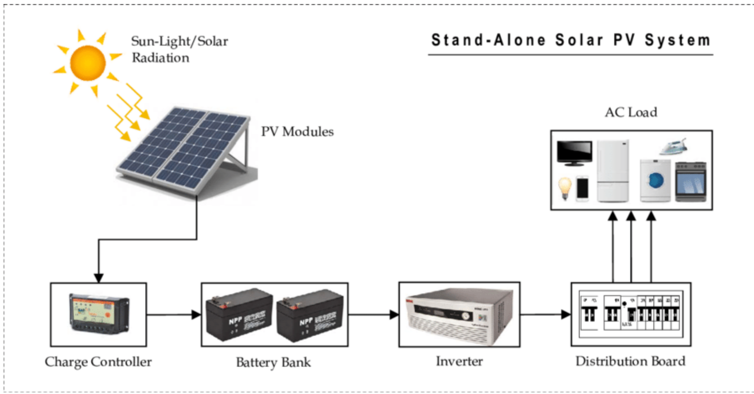


Fig. 9

8. STORAGE ANALYSIS

8.1 Types of Storage Facilities

- Pumped Hydro Storage is a method of energy storage that involves the pumping of water uphill into a reservoir during periods of low demand. Subsequently, the water is discharged to pass through hydro turbines in order to produce energy during periods of high demand. Depends on the presence of appropriate topography and the availability of water.
- Compressed Air Energy Storage (CAES) is a method that utilizes surplus electricity to compress air and store it in subterranean caves or tanks. Subsequently, the compressed air of elevated pressure is subjected to heating and expansion via a turbine in order to produce electricity as required.
- Battery storage involves the use of batteries, such as lithium-ion, to directly store power as chemical energy. This stored energy can then be discharged into the grid at a later time. The prevalence of utility-scale battery installations is increasing.
- Flywheel Energy Storage - The kinetic energy is stored in a rotating flywheel and then turned back into electricity by utilizing the momentum of the flywheel to drive a generator. The power density is high, but the overall capacity is reduced.
- Hydrogen Storage - Utilizes electrical energy to separate water molecules and generate hydrogen through the process of electrolysis. Hydrogen can be stored and subsequently utilized in fuel cells for the purpose of energy generation.
- Thermal Energy Storage involves the storage of energy in high temperature molten salts, ice, or other substances. This stored energy can be later utilized to heat steam and power a turbine or any other heat-dependent operation.
- Electric Vehicles - Battery electric vehicles have the capability to offer distributed storage and grid services by connecting to and communicating with the power grid.
- Self-storage units refer to enclosed compartments of different dimensions that can be rented on a monthly basis by individuals or corporations to store their possessions. These facilities are situated in spacious structures that offer round-the-clock accessibility. Customers possess individual lock and key.
- Mini storage refers to a type of storage facility that is similar to self-storage, except the units are often smaller in size. Mini storage is suitable for storing minimal quantities of objects.

- Climate-controlled storage containers are equipped with temperature and humidity control, making them ideal for storing expensive items that are susceptible to temperature swings, such as artwork, wine, electronics, and more. They have a higher cost compared to standard self-storage facilities.
- Vehicle storage - Certain facilities offer ample spaces for storing various types of vehicles, such as RVs, boats, cars, and so on. Many storage facilities are situated outdoors, while there are some that provide covered or enclosed containers. Convenient for keeping automobiles used during specific seasons.
- Warehouse storage - Certain facilities provide expansive warehouse spaces suitable for storing enormous quantities of items, such as pallets of boxes, business inventory, and equipment. These serve primarily to commercial enterprises.
- Mobile storage entails the delivery of a container to your location for you to fill, after which it is collected and stored at a designated facility. Facilitates the process of loading and unloading.

Analytical Framework and Data Collection Instrument

We employed six criteria, namely relevancy, effectiveness, efficiency, Effects, interconnectedness, and engagement. We omitted other criteria due to the explanations provided in The evaluation approach and criteria utilized in this study have been previously employed in several humanitarian contexts throughout the past twenty years (ODI 2006). More precisely, they were utilized to assess the effectiveness of the Cluster Approach on a global and national scale (Steets et al. 2010). We utilized the analytical framework to create an interview guide for conducting semi-structured interviews. The interview topic guide was categorized into six topics that align with the six evaluation criteria. Each criterion is accompanied by specific, predominantly open-ended questions. Prior to conducting the real interviews, we created the topic guide in English and tested it through a pilot study. Several adjustments were made, mostly focusing on the relevance of the cluster objectives, which were explicitly stated to provide greater clarity to the informants. Additionally, the efficiency criteria were altered to reflect financing considerations.

9. THE DESIGN OF THE PHOTOVOLTAIC (PV) SYSTEM FOR RURAL POPULATIONS, INCLUDING VILLAGES AND BEDOUIN SETTLEMENTS, IS BEING DISCUSSED.

The majority of the Yemeni community predominantly inhabits rural communities.

They are located far away from the national electrical grid or are completely separated from it.Another rural community in Yemen is comprised of the Bedouins, a nomadic tribe of Arabs. These individuals frequently move their living site, making it conceptually and economically impractical to link them to the national grid.This section of the article focuses on the design of electrical supply for these two rural villages.The electrical design is illustrated by subsequent example cases:

A. Electrical design for a typical village of 40 residential houses, a primary-secondary school, a small clinic, and a grocery store.In this scenario, there will be three alternatives available, specifically:

1. A compact independent photovoltaic system that provides each user with 24/48 VDC electrical power.
2. A self-contained photovoltaic system that provides each customer with 220-240 VAC electrical energy.
3. A self-contained photovoltaic system that provides the entire hamlet with 220-240 VAC electrical power.

Electrical Design for the Bedouin Ruhal Settlement. We Shall Examine Two Scenarios:

a) A small Bedouin village consisting of five families, with each family having three tents.
b) Bedouins are nomadic people that do not have a fixed location throughout the year.This category requires a unique and adaptable energy system that can be implemented utilising foldable or flexible photovoltaic panels, which are carried out on a master camel.

The Design of the Off-Grid PV System Consists of the Following Steps.

1. Understanding the characteristics and calculation of the energy needed for electrical loads.
2. Dimensioning of the PV modules.
3. Determining the dimensions of the storage system.
4. Determination and computation of control dimensionsAnd inverting devices. 5. Sizing of connection parts, cables, and accessories as needed.

3.2. Estimation of Electrical Load

1. The Features of the Houses:

The Estimation of Electrical Loads Was Predicated on the Following Assumptions.

a. The houses in the village were presumed to comprise of 1 living room, 2 bedrooms, a hallway, a kitchen and a bathroom.
b. The school is comprised of 6 classes, three offices, a library, a cafeteria, three toilets, a corridor, a clinic room, and a storage room.
c. In remote areas, a health centre is normally a modest clinic that usually consists of a doctor's examination room, a waiting area, a recovery or nurse room, a toilet, and maybe a kitchen.
d. The grocery store is believed to be a corner shop with dimensions of 5 metres in length and 4 metres in width.

The Bedouins are a community of nomadic people. The Bedouin Ruh al community saw each family as residing in a set of three tents within their interiors.

3. Estimation of the Load

The primary purpose is to create an electrical design that meets the goals of the research and the needs of the community, while keeping the system cost as low as possible. Considering this, the load estimation will be determined based on the following considerations:

The minimum permissible electrical load of the system.

Optimal use hours of the device.

Choosing the appropriate electrical devices and accurately estimating their operating hours, such as selecting high-energy-efficient gadgets.The LG 50LB5800 and 50LB6100 are both smart LED TVs with a resolution of 1080p HD and Freeview HD. They consume only 62 kWh annually for 5 hours of daily operation [14].

Utilise Just Essential Gadgets.

The sizing of the PV panels is determined based on the overall energy consumption of the premises [4,5,15] and the total system power loss.

However, the design of the storage system's (batteries) capacity should be determined by the loads that need to function during overnight, excluding daytime loads such as washing machines and water pumps.

Exclude high-current consuming devices and those that are not economically supplied by a PV system, such as air conditioners and electrical space and water heating equipment, from the electrical load assessment procedure.

Utilise the lowered illuminance levels (Ered) provided in Table 2[16], apply the well-established lumen approach described in Equation (1), and incorporate high-efficiency fluorescent and compact fluorescent lights (with an efficacy of 75 lm/W) in the lighting system design.

10. Wiring and electrical properties of the photovoltaic systems

Table 7 presents a concise overview of the primary electrical and wiring characteristics pertaining to case A1. The wiring design for these small freestanding PV systems is intended for a system voltage of 24V for households, clinics, and grocery stores, and 48V for schools. This is to ensure that the percentage voltage drop (ΔV%) remains within the acceptable range of 3% [19], while employing an appropriate cable size.

The variables ΔPpv-bat and ΔPint represent the power loss caused by exterior and internal wiring, respectively.

Figure 3 depicts the electrical diagram for a typical dwelling.

This diagram illustrates the essential components of the system, including the PV modules, junction box, controller, and storage batteries.

The Economic Analysis of the System in Instance A1

The table provides information on the cost of primary system components, annual energy production, annual lifetime cost, levelised cost of energy (LCE) in $/kWh, and the net present value (NPV). Please refer to Table 8 for details.

The results consider the replacement of the batteries twice, first at year 9 and again at year 17, over the anticipated 25-year lifespan of the system.The governing parts will be replaced once.

Let P&A represent the cost of protective devices and accessories, and local refer to the availability of these items in local marketplaces.

The electrical load calculation for the Bedouin Ruh'al community focuses on the essential electrical facilities required by the community and is documented in a list. Table 9. The most convenient system for this community consists of foldable PV modules with a power output of 140W and a choice of either two 60Ah/12V or one 120Ah/12V AGM battery.The diameter of the cables connecting the battery to the loads ranges from 2.5 to 4 mm2. The greatest voltage drop for internal wiring is 0.68%, whereas the voltage drop for the exterior 6mm2 wire was 2.72%.This leads to an equivalent power loss percentage of around 2.72%.The initial assessment, based on a 12-year system lifecycle, a cost of $2 per watt peak (WP) for photovoltaic (PV) modules, and the need for battery replacement twice, suggests that the LCIn this situation, the cost will be approximately $0.75 per kilowatt-hour, which is quite encouraging and will significantly influence the community's well-being.

3.5.3. Standalone AC-PV system DC house appliances are not readily accessible in Yemen.This may provide a significant difficulty for rural communities in replacing and maintaining the components of the system.Furthermore, providing low-voltage electrical systems to small facilities such as schools and clinics might be economically imperceptible, especially when the electrical loads are far away from the storage batteries.This will lead to significant power losses, substantial voltage drops, and the need for larger wire sizes.A standalone AC PV system can be constructed to provide users with electrical power at a voltage of AC 220V.

This necessitates the use of inverters that transform the direct current (DC) energy into alternating current (AC).However, inverters incur an additional electrical loss of 8-10% that must be accounted for, in addition to their cost.The outcome of the design for the standalone ACPV system is presented in Tables 10-12.

Figure 11 examines the necessary quantities of PV modules and batteries for a typical village instance A-2.Hence, the system necessitates a minimum of 200 photovoltaic panels with a peak power of 250W and 200 storage batteries with a capacity of 200Ah.The electrical wiring for this case is illustrated in Table 11. The multiplier of (1.25 x 1.25 x 1.56) was created to adjust for the increased output of PV modules during strong solar radiation compared to the output produced at Standard Test Conditions (STC). It also ensures that the size of cables meets the requirement of being 25% bigger than

Table 12 displays the primary economic metrics of the system, which demonstrate the impact of the inverter on the levelized cost of energy (LCE) of the system.

Compared to the DC scenario, the current LCE value is 9% greater. Nevertheless, the issue with the DC situation revolves with the expense and accessibility of household and common items.

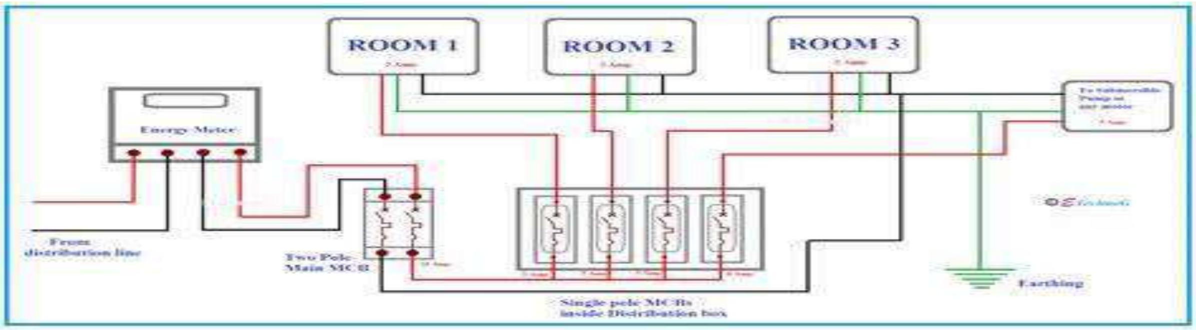


Fig.11 The simplified electrical diagram for the typical house.

11. CONCLUSIONS

A clear knowledge and a defined vision are required for encouraging and guiding the transition to a 100% renewable energy system. The MENA phase model was applied to the country instance of Yemen in order to give information to facilitate the energy system's transition to sustainability. The model, which was based on the German context and supplemented with insights into transition governance, was customized to incorporate distinctions between general underlying assumptions, MENA area features, and the unique Yemen environment.

The analytical framework, comprising of four distinct stages (namely, "Take-off RE," "System Integration," "PTF/G," and "Towards 100% Renewables"), was employed to assess and ascertain the current status of Yemen's energy transition towards renewable sources.

The utilization of the model additionally establishes the foundation for the formulation of a strategic plan outlining the sequential actions required to advance along this trajectory. The analysis indicates that Yemen's "solar revolution" is primarily motivated by conflict and is predominantly focused on the implementation of solar energy in small-scale localized applications. The primary forces behind Yemen's transition to a sustainable energy system are primarily motivated by the imperative to ensure a dependable and cost-effective electricity supply, as well as the potential for long-term economic development through cost-benefit prospects. Yemen faces significant challenges in transitioning towards renewable energy sources, despite the declining prices associated with renewable technologies. These challenges stem from the country's political instability, the absence of comprehensive policies, legislations, and laws, as well as the pervasive influence of patronage within the administration. However, renewable energy sources present a viable and sustainable solution for Yemen in the long run. These sources provide an opportunity for transitioning to a more environmentally friendly energy system, while also aiding in the reconstruction of the country's energy infrastructure following the war. In order to capitalize on this potential, Yemen must enhance its level of ambition, enhance the regulatory and economic environment conducive to renewable energy, and heighten awareness of the advantages associated with its adoption. One crucial aspect involves the necessity of unbundling the electrical sector. Similarly, there is a need for an augmentation of endeavors aimed at enhancing energy efficiency. Specifically, this necessitates the development of capacity and acquisition of skills to ensure the effective implementation of the plans on a larger scope. Although Yemen is now in the nascent phase of its energy transition, encountering numerous obstacles in the process of expanding renewable energy sources, it would be prudent for the nation to develop a more sustainable energy framework that may provide both immediate and long-term advantages to its populace. The outcomes derived from the transition phase model towards achieving complete reliance on renewable energy sources can serve as a catalyst for stimulating and facilitating discourse pertaining to the prospective energy system of Yemen. The attainment of this objective is accomplished by the establishment of a comprehensive guiding vision for the transition of energy systems, coupled with the formulation and implementation of suitable policy initiatives.

REFERENCES

[1] UNDP,PolicyNote2014.ProspectsofsolarenergyinYemen.UNDP-Yemen, Sana'a; 2014.

[2] Agence Françasede Dévelopment(AFC).Ruralelectrification project-republic of Yemen. Paris: Agence Françasede Dévelopment;2013.

[3] Alkholidi AG.RenewableenergysolutionforelectricalpowersectorinYemen. Int JRenewEnergyRes2013;3(4):803–11.

[4] NafehA-SA.Designandeconomicanalysisofastand-alonePVsystemto electrifyaremoteareahouseholdinEgypt.OpenRenewEnergyJ2009;2:33–7.

[5] Oko COC,DiemuodekeEO,OmunakweNF,NnamdiE.Designandeconomic analysis ofaphotovoltaicsystem:acasestudy.IntJRenewEnergyDev2012;1 (3):65–73.

[6] Akikur RK,SaidurR,PingHW,UllahKR.Comparativestudyofstand-aloneand hybridsolarenergysystemssuitableforoff-gridruralelectrification: areview. RenewSustainEnergyRev2013;27:738–52.

[7] KazemHA,SamaraQA,AlwaeliAH,KavishMM.Life-cyclecostanalysisand optimization ofhealthclinicPVsystemforaruralareainOman.In:Pro- ceedings oftheworldcongressengineering.London,UK;2013.

[8] Ulsrud K,WintherT,PalitD,HaraldR.Village-levelsolarpowerinAfrica: accelerating accesstoelectricityservicesthroughasocio-technicaldesignin Kenya.EnergyResSocialSci2015;5:34–44.

[9] ChmielZ,BhattacharyyaSC.Analysisofoff-gridelectricitysystematIsleofEigg (Scotland):lessonsfordevelopingcountries.RenewEnergy2015;81:578–88.

[10] Karen S,VillanuevaS,LuA.Technicaland financial feasibilityofastand-alone photovoltaicsystemforruralelectrification intheAndeanSouthRegionof Peru. JSustainDev2012;5(11):32–45.

[11] OlatzA,IñakiA,ItziarZ.Ruralelectrification basedonrenewableenergies:a review.In:Proceedingsoftheinternationalconferenceonrenewableenergies and powerquality(ICREPQ'12).Spain:SantiagodeCompostela;2012. Table15 Economic analysisresultsforcaseA-3. Item No. of units Price $Other chgs Sub. tot. $ Indicator PV modules.20029,400735036750.0 Eproduct kWh/year 51,083 Batteries 160.069,160100136779.9Lifecycle cost LCC $ 275,184 Inv-Controllers20$985075015162.5O&Mcosts 2% $ 1,604.0 Cables-Local 130035,76010035760.0Levelized Discount Rate $ 8234 P&A-Local 2055082.5632.5ALCC$20,104 Installation 10,000LCE$/kWh$0.394 TotalCost$$235,085 Net present valueNPV $ 63,852 M. Hadwan, A. Alkholidi / Renewable and Sustainable Energy Reviews 57 (2016) 838–849848

[12] FosterRE,CotaAD.Afghanistanphotovoltaicpowerapplicationsforrural development [Online].Available: ⟨http://www.researchgate.net/profile/ Robert_Foster6/publication/259932222_Afghanistan_Photovoltaic_Power_ Applications_for_Rural_Development/links/02e7e52e974ee21236000000. pdf⟩; 8June2012[accessed18.09.15].

[13] Khan MM,AhmadMJ.Estimationofglobalsolarradiationusingclearsky radiation inYemen.JEngSciTechnolRev2012;5(2):12–9.

[14] Energystar.Theenergystarmostefficient. [Online].Available: ⟨https://www. energystar.gov/index.cfm?c ¼ most_efficient.me_tvs_35to50_inches⟩; 2014 [accessed 01.01.15].

[15] Ismail1 MS,MoghavvemiM,MahliaTM.DesignofaPV/dieselstandalone hybridsystemforaremotecommunityinPalestine.JAsianSciRes2012;2 (11):599–606.

[16] CIBSE. Codeforinteriorlighting.London:TheCharteredInstitutionofBuilding Services Engineering;1994.

[17] Skoplaki E,PalyvosJ A.Onthetemperaturedependenceofphotovoltaic module electricalperformance:areviewofefficiency/powercorrelations.Sol Energy 2009;83:614–24.

[18] ShenzhenUpsenElectricCo.Ltd.Inverterdatasheet.ShenzhenUpsenElectric Co.Ltd.[Online].Available: ⟨http://en.ofweek.com/Product/Power-DC-To-AC- Inverter-Convert-12V-24V-48V-DC-To-220V-230-240V-AC⟩; [accessed03.12.14].

[19] Price CR,SmileyE.PVandtheelectricalcode.CanadianSolarIndustries Association (CanSIA);2004,pp1–61.

[20] VictronEnergy.Quattroinverter/chargerdatasheet.VictronEnergy.[Online]. Available: ⟨www.victronenergy.com⟩; [accessed3.12.14].

1 Republic of Yemen, Ministry of Public Health & Population & Central Statistical Organization, Yemen National Health and Demographic Survey 2013, available at: https://dhsprogram.com/pubs/pdf/FR296/FR296.pdf.

2 United Nations, World Population Prospects: The 2012 Revision, Projections (medium variant), available at: http://esa.un.org/unpd/wpp/unpp/panel_indicators.htm.

3 United Nations, World Population Prospects: The 2012 Revision, available at: http://esa.un.org/unpd/wpp/unpp/panel_indicators.html.

4 Republic of Yemen, Ministry of Public Health & Population & Central Statistical Organization, Yemen National Health and Demographic Survey 2013, available at: https://dhsprogram.com/pubs/pdf/FR296/FR296.pdf.

5 Central Intelligence Agency, The World Factbook, available at: www.cia.gov/library/publications/the-world-factbook/geos/ym.html.

6 World Bank, Population, total - Republic of Yemen, available at: https://data.worldbank.org/indicator/SP.POP.TOTL?locations=YE&view=chart.

7 United Nation, Population Division Dataset available via: https://population.un.org/wpp/.

8 World Bank, Population, total – Republic of Yemen, available at: https://data.worldbank.org/indicator/SP.POP.TOTL?locations=YE&view=chart.

9 International Energy Agency, Statistics data browser, available at: https://www.iea.org/statistics/?country=YEM&isISO=true.

10 BP Statistical Review of World Energy 2019, available at: https://www.bp.com/content/dam/bp/businesssites/en/global/corporate/pdfs/energy-economics/statistical-review/bp-stats-review-2019-full-report.pdf.

11 World Bank, Middle East and North Africa Integration of Electricity Networks in the Arab World Regional Market Structure and Design, 2013 available at: http://documents.worldbank.org/curated/en/415281468059650302/pdf/ACS71240ESW0WH0I0and0II000Final

12 Energy Information Agency, Yemen Country Brief 2014, available at: https://www.eia.gov/beta/international/analysis.php?iso=YEM.

13 World Bank, Energy Use Data 2014, available at: https://data.worldbank.org/indicator/EG.USE.PCAP.KG.OE.

14 World Bank, Energy Intensity Level of Primary Energy, Republic of Yemen, data available at: https://data.worldbank.org/indicator/EG.EGY.PRIM.PP.KD?locations=YE.

15 International Monetary Fund, Case Studies on Energy Subsidy Reform: Lessons and Implications (2013) available at: https://www.imf.org/external/np/pp/eng/2013/012813a.pdf.

16 Yemen Crude Oil: Production

https://www.ceicdata.com/en/indicator/yemen/crude-oil-production

17 international energy information administration

https://www.eia.gov/international/analysis/country/YEM

18 (Namany, Govindan et al. 2023)

19 (Al-Wesabi, Zhijian et al. 2022)

20 "<MPRA_paper_101860.pdf>."

Al-Wesabi, I., et al. (2022). "A review of Yemen's current energy situation, challenges, strategies, and prospects for using renewable energy systems." Environ Sci Pollut Res Int **29**(36): 53907-53933.

Namany, S., et al. (2023). "Operationalising transboundary cooperation through game theory: An energy water food nexus approach for the Middle East and North Africa." Futures **152**.

- A-TK. AA-K (2014) Optical communication system. https://doi.org/10.5772/58884
- ACTED (2016) As the water crisis in Yemen deepens, ACTED rehabilitates nine community water points in Al Dhale'e. https://reliefweb.int/report/yemen/water-crisis-yemen-deepens-acted-rehabilitates-nine-community-water-points-al-dhale-e
- OCHA (2017) UNCT Yemen 2018 Humanitarian needs overview. https://reliefweb.int/report/yemen/yemen-2018-humanitarian-needs-overview-enar
- Afrane S, Dankwa J, Emmanuel A, Aboagye M (2022) Investigating evolutionary trends and characteristics of renewable energy research in Africa : a bibliometric analysis from 1999 to 2021. Springer, Berlin Heidelberg

Google Scholar

- Afsharzade N, Papzan A, Ashjaee M et al (2016) Renewable energy development in rural areas of Iran. Renew Sustain Energy Rev 65:743–755. https://doi.org/10.1016/j.rser.2016.07.042

Article Google Scholar

- Aguirre-Mendoza AM, Díaz-Mendoza C, Pasqualino J (2019) Renewable energy potential analysis in non-interconnected islands. Case study: Isla Grande, Corales del Rosario Archipelago, Colombia. Ecol Eng 130:252–262. https://doi.org/10.1016/j.ecoleng.2017.08.020

Article Google Scholar

- Akuru UB, Onukwube IE, Okoro OI, Obe ES (2017) Towards 100% renewable energy in Nigeria. Renew Sustain Energy Rev 71:943–953. https://doi.org/10.1016/j.rser.2016.12.123

Article Google Scholar

- Al-ashwal AM (2005) All renewable energy applications in Yemen are best practice. Isesco 1:45–50

Google Scholar

- Al-Dousari A, Al-Nassar W, Al-Hemoud A et al (2019) Solar and wind energy: challenges and solutions in desert regions. Energy 176:184–194. https://doi.org/10.1016/j.energy.2019.03.180

Article Google Scholar

- Al-Shabi MH, Rami AS (2014) The current situation and future prospects of the energy sector in Yemen ministry of electricity & energy. In Korea–Yemen Energy Forum
- Al-Shamma'a AA, Alturki FA, Farh HMH (2020) Techno-economic assessment for energy transition from diesel-based to hybrid energy system-based off-grids in Saudi Arabia. Energy Transitions 4:31–43. https://doi.org/10.1007/s41825-020-00021-2

Article Google Scholar

- Al-Shetwi AQ (2016) Design and economic evaluation of electrification of small villages in rural area in Yemen using stand-alone PV system. International Journal of Renewable Energy Research (IJRER) 6(1):289–298

Google Scholar

- Al-Shetwi AQ, Hannan MA, Abdullah MA, Rahman MSA, Ker PJ, Alkahtani AA, Muttaqi KM (2021) Utilization of Renewable Energy for Power Sector in Yemen: Current Status and Potential Capabilities. IEEE Access 9:79278–79292

Article Google Scholar

- Al-Wesabi I, Fang Z, Farh HMH et al (2022a) Cuckoo search combined with PID controller for maximum power extraction of partially shaded photovoltaic system. Energies 15:2513. https://doi.org/10.3390/en15072513

Article Google Scholar

- Al-Wesabi I, Fang Z, Wei Z, Dong H (2022b) Direct sliding mode control for dynamic instabilities in dc-link voltage of standalone photovoltaic systems with a small capacitor. Electron 11. https://doi.org/10.3390/electronics11010133
- Al Asbahi AAMH, Fang ZG, Chandio ZA et al (2020) Assessing barriers and solutions for Yemen energy crisis to adopt green and sustainable practices: a fuzzy multi-criteria analysis. Environ Sci Pollut Res 27:36765–36781. https://doi.org/10.1007/s11356-020-09700-5

Article Google Scholar

- Alganahi HS, Kamaruzzaman S, Mohamed A et al (2009) Experimental study of using renewable energy in Yemen. Aust J Basic Appl Sci 3:4170–4174

Google Scholar

- Ali W, Alkadasi F, Khoday K (2014) Policy note prospects of solar energy in Yemen. IOSR J Electr Electron Eng 4
- Alkipsy EIH, Raju V, Kumar H (2020) A review of the challenges of energy sector and prospects of renewable energy utilization in Yemen. Global Journal of Management And Business Research
- Alkholidi FHA (2013) Utilization of solar power energy in the telecommunication sector in Yemen. J Sci Technol n.d. 4 pp 4–11
- Alkholidi AG (2013) Renewable energy solution for electrical power sector in Yemen. Int J Renew Energy Res 3:803–811. https://doi.org/10.20508/ijrer.15185

Article Google Scholar

- Alturki FA, Al-Shamma'a AA, Farh HMH, AlSharabi K (2021) Optimal sizing of autonomous hybrid energy system using supply-demand-based optimization algorithm. Int J Energy Res 45:605–625. https://doi.org/10.1002/er.5766

Article Google Scholar

- Amran YHA, Amran YHM, Alyousef R, Alabduljabbar H (2020) Renewable and sustainable energy production in Saudi Arabia according to Saudi Vision 2030; Current status and future prospects. J Clean Prod 247. https://doi.org/10.1016/j.jclepro.2019.119602
- Annual sunshine hours map of the world (2016) Annual sunshine hours map of the world. https://redd.it/44y90h
- Ansari D, Kemfert C, Al-Kuhlani H (2019) Yemen's solar revolution: developments, challenges, opportunities. DIW Berlin, Berlin, Germany

Google Scholar

- Arab Union of Electricity (2016) Statistical Bulletin 2004–2016, available at: http://www.auptde.org/Publications.aspx?lang=en&CID=36
- Bank W (2005) Household energy supply and use in Yemen [Annexes. Energy Sector Management Assistance Program working paper series; ESM 315/05]. Washington, DC: World Bank; 2005, [Annexes. Energy Sector Management Assistance Program working paper series; ESM
- Bank W (2014) United Nations, European Union, Islamic Development Bank In collaboration with The Government of Yemen, represented by the Minister of Planning and International Cooperation, Joint Social and Economic Assessment for the Republic of Yemen
- Bulut U, Muratoglu G (2018) Renewable energy in Turkey: great potential, low but increasing utilization, and an empirical analysis on renewable energy-growth nexus. Energy Policy 123:240–250. https://doi.org/10.1016/j.enpol.2018.08.057

Article Google Scholar

- Crisis in the Arabian Peninsula. https://carleton.ca/cifp/wp-content/uploads/2019-Yemen-Conflict-Diagnostic.pdf
- Economic Consulting Associates Limited (2009) Exploring the potential for interconnection and electricity trade among Yemen and the GCC countries; study submetted to the world bank in September −41 Lonsdale Road, London NW6 6RA, UK
- El-Katiri L (2014) A roadmap for renewable energy in the Middle East and North Africa. Oxford institute for energy studies. https://www.arabdevelopmentportal.com/sites/default/files/publication/286.a_roadmap_for_renewable_energy_in_the_middle_east_and_north_africa.pdf
- Emission Database for Global Atmospheric Research (2021) Emission database for global atmospheric research. https://www.nature.com/articles/s41597-020-00779-6
- Energy and Renewable Profile R of Y (2004) Energy and renewable profile, Republic of Yemen. Regional Conference for Renewable Energy, Middle East, and North African Countries.(2004)
- Energy SR of W (2020) Statistical Review of World Energy. https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/statisticalreview/bp-stats-review-2020-full-report.pdf

- ESMAP (2020) Global photovoltaic power potential by country. Washington, DC: World Bank
- Farh HMH, Al-Shaalan AM, Eltamaly AM, Al-Shamma'a AA (2020) A novel severity performance index for optimal allocation and sizing of photovoltaic distributed generations. Energy Rep 6:2180–2190. https://doi.org/10.1016/j.egyr.2020.07.016

Article Google Scholar

- Farh HMH, Eltamaly AM (2020) Maximum power extraction from the photovoltaic system under partial shading conditions. Green Energy Technol 107–129. https://doi.org/10.1007/978-3-030-05578-3_4
- Farh HMH, Othman MF, Eltamaly AM (2018) Maximum power extraction from grid-connected PV system. 2017 Saudi Arab Smart Grid Conf SASG 2017:1–6. https://doi.org/10.1109/SASG.2017.8356498

Article Google Scholar

- Fodhil F, Hamidat A, Nadjemi O (2019) Potential, optimization and sensitivity analysis of photovoltaic-diesel-battery hybrid energy system for rural electrification in Algeria. Energy 169:613–624. https://doi.org/10.1016/j.energy.2018.12.049

Article Google Scholar

- Gielen D, Boshell F, Saygin D et al (2019) The role of renewable energy in the global energy transformation. Energy Strateg Rev 24:38–50. https://doi.org/10.1016/j.esr.2019.01.006

Article Google Scholar

- Ibrahim AW, Shafik MB, Ding M, Sarhan MA, Fang Z, Alareqi AG, Al-Rassas AM (2020) PV maximum power-point tracking using modified particle swarm optimization under partial shading conditions. Chinese Journal of Electrical Engineering 6(4):106–121

Article Google Scholar

- IRENA Global Energy Transformation: A Roadmap to 2050. 2018. Available online: https://www.irena.org/publications/2018/Apr/Global-Energy-Transition-A-Roadmap-to-2050. Accessed 26 June 2021
- IEA (2018) Renewable capacity growth worldwide stalled in 2018 after two decades of strong expansion. Available online: https://www.iea.org/news/renewable-capacity-growth-worldwide-stalled-in-2018-after-two-decades-of-strong-expansion. Accessed 26 Dec 2020
- IEA (2016) Key World Energy Statistics. https://www.ourenergypolicy.org/wp/content/uploads/2016/09/KeyWorld2016.pdf
- International Energy Agency International Energy Agency, Statistics data browser, IRENA (2018) Global energy transformation: a roadmap to 2050. 2018
- Islam MS, Akhter R, Rahman MA (2018) A thorough investigation on hybrid application of biomass gasifier and PV resources to meet energy needs for a northern rural off-grid region of Bangladesh: a potential solution to replicate in rural off-grid areas or not? Energy 145:338–355. https://doi.org/10.1016/j.energy.2017.12.125

Article Google Scholar

- Jahangiri M, Ghaderi R, Haghani A, Nematollahi O (2016) Finding the best locations for establishment of solar-wind power stations in Middle-East using GIS: a review. Renew Sustain Energy Rev 66:38–52. https://doi.org/10.1016/j.rser.2016.07.069

Article Google Scholar

- JICA (2010) Power Sector Development |Yemen | Countries & Regions. https://www.jica.go.jp/yemen/english/activities/infrastructure/power.html
- Kaya MN, Aksoy MH, Kose F (2017) Renewable energy in Turkey: potential, current status and future aspects. Ann Fac Eng Hunedoara – Int J Eng 1:65–69

Google Scholar

- Kelly C, Onat NC, Tatari O (2019) Water and carbon footprint reduction potential of renewable energy in the United States: a policy analysis using system dynamics. J Clean Prod 228:910–926. https://doi.org/10.1016/j.jclepro.2019.04.268

Article Google Scholar

- Khan MJ, Yadav AK, Mathew L (2017) Techno economic feasibility analysis of different combinations of PV-Wind-Diesel-Battery hybrid system for telecommunication applications in different cities of Punjab, India. Renew Sustain Energy Rev 76:577–607. https://doi.org/10.1016/j.rser.2017.03.076

Article Google Scholar

- Kougias I, Szabó S, Nikitas A, Theodossiou N (2019) Sustainable energy modelling of non-interconnected Mediterranean islands. Renew Energy 133:930–940. https://doi.org/10.1016/j.renene.2018.10.090

Article Google Scholar

- Kumar A, Rajesh T, Anita S et al (2022) Advancements in solar technologies for sustainable development of agricultural sector in India : a comprehensive review on challenges and opportunities. Environ Sci Pollut Res. https://doi.org/10.1007/s11356-022-20133-0

Article Google Scholar

- LAHMEYER, International GmbH G (2008) Renewable Energy Strategy and Action Plan (RESAP) Final Report prepared for Yemeni Government by LAHMEYER International GmbH, Germany 2008
- Mandal S, Das BK, Hoque N (2018) Optimum sizing of a stand-alone hybrid energy system for rural electrification in Bangladesh. J Clean Prod 200:12–27. https://doi.org/10.1016/j.jclepro.2018.07.257

Article Google Scholar

- Marchenko OV, Solomin SV (2017) Efficiency of hybrid renewable energy systems in Russia. International Journal of Renewable Energy Research IJRER, 7(4)
- McSweeney C, New M, Lizcano G (2010) UNDP Clim Change Ctry Profiles, [Yemen hires report]. http://country-profiles.geog.ox.ac.uk/
- Mekonnen Y, Sarwat AI (2017) Renewable energy supported microgrid in rural electrification of Sub-Saharan Africa. Proc - 2017 IEEE PES-IAS PowerAfrica Conf Harnessing Energy. Inf Commun Technol Afford Electrif Africa, PowerAfrica 2017:595–599. https://doi.org/10.1109/PowerAfrica.2017.7991293

Article Google Scholar

- Ministry of Electricity (2012) Al Mokha (2012) 60 MW Wind Farm Project (MWFP) Ministry of Electricity. Environ Assess 3:116

Google Scholar

- Ministry of Planning & International Cooperation CS, (CSO) O (2004) Ministry of Planning & International Cooperation, Central Statistical Organization (CSO), "Yemen General Census of the Year 2004"

- Ministry of Planning & International Cooperation CS, (CSO) O (2011) Ministry of Planning & International Cooperation, Central Statistical Organization (CSO), "Statistical Year Books for the Years 2009 to 2011"
- Ministry of Public Health and Population (MOPHP) (2013) Central Statistical Organization (CSO)[Yemen], Pan Arab Program for Family Health (PAPFAM) and ICF International. Yemen national health and demographic survey
- Mohammed OH (2018) Optimal hybridisation of a renewable system to fulfill residential electrical load: In Mosul, Iraq. 2018 3rd Sci Conf Electr Eng SCEE 2018 209–213. https://doi.org/10.1109/SCEE.2018.8684206
- Mubaarak S, Zhang D, Liu J et al (2021) Potential techno-economic feasibility of hybrid energy systems for electrifying various consumers in Yemen. Sustain 13:1–24. https://doi.org/10.3390/su13010228

Article Google Scholar

- NECRA (2010) Planning the consolidation of rural electrification activities in Yemen - interim report, submitted to the government of Yemen, Ministry of Electricity and Energy
- Nematollahi O, Hoghooghi H, Rasti M, Sedaghat A (2016) Energy demands and renewable energy resources in the Middle East. Renew Sustain Energy Rev 54:1172–1181. https://doi.org/10.1016/j.rser.2015.10.058

Article Google Scholar

- Nugroho H, Fei-Lu S, Firmansyah (2017) Developing renewable energy in developing countries: a lesson from Indonesia. Energy Sources, Part B Econ Plan Policy 12:318–325. https://doi.org/10.1080/15567249.2015.1072599

Article Google Scholar

- Ocon JD, Bertheau P (2019) Energy transition from diesel-based to solar photovoltaics-battery-diesel hybrid system-based island grids in the Philippines – techno-economic potential and policy implication on missionary electrification. J Sustain Dev Energy, Water Environ Syst 7:139–154. https://doi.org/10.13044/j.sdewes.d6.0230

Article Google Scholar

- Padrón I, Avila D, Marichal GN, Rodríguez JA (2019) Assessment of hybrid renewable energy systems to supplied energy to autonomous desalination systems in two islands of the Canary Archipelago. Renew Sustain Energy Rev 101:221–230. https://doi.org/10.1016/j.rser.2018.11.009

Article Google Scholar

- Rawea AS, Urooj S (2018) Strategies, current status, problems of energy and perspectives of Yemen's renewable energy solutions. Renew Sustain Energy Rev 82:1655–1663. https://doi.org/10.1016/j.rser.2017.07.015

Article Google Scholar

- REN21. (2020) Renewables 2020 Global Status Report. Available online:
- REN21. (2019) Why is renewable energy important?
- Salam MA, Khan SA (2018) Transition towards sustainable energy production – a review of the progress for solar energy in Saudi Arabia. Energy Explor Exploit 36:3–27. https://doi.org/10.1177/0144598717737442

Article Google Scholar

- Saleh Qasem AQ (2018) Applications of renewable energy in Yemen. J Fundam Renew Energy Appl 08:8–10. https://doi.org/10.4172/2090-4541.1000254

Article Google Scholar

- Shahzad K, Lu B, Abdul D (2022) Entrepreneur barrier analysis on renewable energy promotion in the context of Pakistan using Pythagorean fuzzy AHP method. Environ Sci Pollut Res. https://doi.org/10.1007/s11356-022-19680-3

Article Google Scholar

- Singh G, Baredar P, Singh A, Kurup D (2017) Optimal sizing and location of PV, wind and battery storage for electrification to an island: a case study of Kavaratti, Lakshadweep. J Energy Storage 12:78–86. https://doi.org/10.1016/j.est.2017.04.003

Article Google Scholar

- Solaymani S (2021) A review on energy and renewable energy policies in Iran. Sustainability 13(13):7328

Article CAS Google Scholar

- Sufian CT, Barra M (2016) Energy investment and business climate report for observer countries, International Energy Chapter
- Sufian T, Ogutcu C, Barra M (2017) Energy investment and business climate report for observer countries. Retrieved from Energy Charter Secretariat, Boulevard de la Woluwe, 46B_1200, Brussels, Belgium
- Sufian T (2019) International energy charter. Post conflict reconstruction strategy study for the electricity and energy sector of Yemen. Available online: https://www.energycharter.org/fileadmin/DocumentsMedia/Occasional/2019-Yemen_paper_final.pdf. Accessed 2 May 2021
- Sufian T, Asaad (2010) Updating existing and developing new programs that include measures to abate GHG Emission a study submitted by the mitigation team as part of the yemen second national communication (YSNC) Project on Climate Change
- Surroop D, Raghoo P (2018) Renewable energy to improve energy situation in African island states. Renew Sustain Energy Rev 88:176–183. https://doi.org/10.1016/j.rser.2018.02.024

Article Google Scholar

- The World Bank (2013) Yemen power sector reform strategy: towards improved performance and financial sustainability executive. The World Bank, Washington, DC
- Timmons D, Harris JM, Roach B (2014) The economics of renewable energy. Global Development And Environment Institute, Tufts University 52:1–52

Google Scholar

- Towfick S, Abdulraqib A (2012) Stand alone solar pv systems a solution to electrify yemen's rural households, Hayel Saeed Anam Science and Art Prize Award – 16th Award. https://www.energycharter.org/fileadmin/DocumentsMedia/Occasional/2019-Yemen_paper_final.pdf
- Tummuru NR, Mishra MK, Srinivas S (2015) Dynamic energy management of renewable grid integrated hybrid energy storage system. IEEE Trans Ind Electron 62:7728–7737. https://doi.org/10.1109/TIE.2015.2455063

Article Google Scholar

- U.S. Energy Information Administration (2017) available at: https://www.eia.gov/beta/international/analysis_includes/countries_long/Yemen/yemen.pdf. Yemen

- Weir T (2018) Renewable energy in the Pacific Islands: its role and status. Renew Sustain Energy Rev 94:762–771. https://doi.org/10.1016/j.rser.2018.05.069

Article Google Scholar

- World Bank (2009) Exploring the potential for electricity trade and interconnection among yemen and gcc countries. http://documents.worldbank.org/curated/en/829201468051896096/530470ESW0MNA01Official0Use0Only191.pdf
- Xiaohui D (2016) Theoretical analysis of wind turbine tower-nacelle axial vibration based on the mechanical impedance method. J Appl Sci Eng 19:53–64. https://doi.org/10.6180/jase.2016.19.1.07

Article Google Scholar

- Yale Center for Environmental Law and Policy YU, Environmental (2020) Yale Center for Environmental Law and Policy, Yale University. Environmental Performance Index and pilot trend, Full report. Yale Center for Environmental Law and Policy, Yale University Center for International Earth Science Information Network, Columbia
- Yoro KO, Daramola MO, Sekoai PT et al (2021) Update on current approaches, challenges, and prospects of modeling and simulation in renewable and sustainable energy systems. Renew Sustain Energy Rev 150:111506. https://doi.org/10.1016/j.rser.2021.111506

Article Google Scholar