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Assessment of environmental and economic perspectives for renewable-based hybrid power system in Yemen

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ABSTRACT

The critical impacts of climate change have imposed an imperative for accelerated global actions to curb the greenhouse gas (GHG) emission. The "historic Paris agreement" on climate change as well as the Sustainable Energy for All (SE4All) initiative are among the well-known foundations to restrict GHG emission by promoting renewable energy (RE) across the globe. In Yemen, a country with abundant RE resources, feasibility studies to explore RE potentiality are scarce. This paper first reviews the historical development of RE technologies as well as the RE prospects in Yemen. This is followed by a comprehensive feasibility study of an off-grid renewable-based power system for rural electrification in Yemen. Shafar, a key district in Hajjah province, is considered as a case study. Five different cases (various combination of energy resources) of power system have been investigated with a key objective to find out the most suitable hybrid system that yields the minimal system cost as well as environmental impact. In this work, the hybrid optimization model for electric renewables (HOMER) is employed to perform the optimization and sensitivity analysis. The simulation results indicate that combination of photovoltaic and wind energy system achieves potential reduction of 100% in the CO_2 emission, along with 30% decrement in the cost of energy (COE). Comparatively, the photovoltaic/wind/diesel energy system could only achieve 70% reduction in the CO_2 emission but 45% decrement in the COE. Furthermore, the latter case exhibits a superior system robustness to RE variability in comparison with the former case. Finally, the study recommends the deployment of the proposed hybrid system (photovoltaic/wind/diesel) as the means for Yemen (and other similar context countries) to sustainably achieve Paris agreement targets and the SE4All initiatives, simultaneously.

1. Introduction

Significant global interest has been devoted to renewable energy (RE) technologies: latest statistics indicate that 21% of global electricity is produced from RE resources (including solar, wind, hydro, biomass, and others) with expected growth to 25% in 2040 [1,2]. A key drive for the rapid deployment of RE technology is its major contribution to limit the greenhouse gas (GHG) emission, leading to reduce impact of climate change. "The historic Paris agreement" on climate change has been recently approved by 195 countries in an attempt to restrict global temperature increase well below 2°C at the 21st Conference of Parties (COP 21), organized by the UN convention on climate change (UNFCCC) in Paris (Dec. 2015) [3].

In line with the global concerns on climate change, a vast number of studies has been carried out to investigate the potentiality of RE in different locations across the globe. These studies generally are based on a range of different objectives which may include electrification of rural areas [4–7], islands [8–10], agricultural purposes [11,12] sea transportation [13] and RE-based mines [14], just to name a few. More specifically, RE potential in India was reviewed and investigated by authors in [15,16], who concluded that wind-solar-hydro-battery power system (either on- or off-grid) is techno-economically the most efficient option with energy cost of around $ 0.10 per kWh. In China, the world's largest producer of PV power [17], a recent study of RE potentiality [18] showed that a COE of $ 0.03 per kWh is achievable. Another interesting study [13] compared RE potentiality on land and on ship as an attempt to lessen GHG emitted from ships. The study showed a striking fact that a hybrid ship with only 6% RE fraction can avoid as high as 10 million kg of GHG emission during the project lifetime (25 years). In Australia, where renewables account for about 6% of total energy consumption [19], RE feasibility studies have recently revealed that RE deployment can reduce GHG emissions by about 400,000 tons per year [19]. Other studies also discussed advantages and limitation of renewables [20,21], and future prospects [22] in the Australian context.

Focusing on the Middle East and North Africa (MENA) region,

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several research works and projects have been extensively accomplished with the aim of restraining CO_2 emission by integrating REs into the energy sector [23,24]. Different research works explored the potentiality of RE at different locations in United Arab Emirates (UAE) [25–28], Kingdom of Saudi Arabia (KSA) [7,29–31], Oman [32–34] and Iran [35,36]. The research work proposed various RE-based systems that include PV modules and wind turbines as part of the generation mix. The studies also highlighted that the MENA region is rich of great potential of solar energy making the PV technology the most competitive in the region. In addition, they indicated that RE-based hybrid power system (HPS) could effectively help cut off a substantial amount of CO_2 emission as well as minimize the economic costs.

In Yemen, a country located at southern east of the Arabian Peninsula, a few research studies have been done to explore the potentiality of RE resources. Alganahi et al. [37] examined the feasibility of introducing a PV/Wind/Diesel/Battery HPS in Sana'a and Aden. Authors found that Wind/Diesel/Battery could be the best scenario for implementation in both cities. Other research work [38–40] overviewed the status of RE in different locations in Yemen. However, these studies did not specifically concentrate on the feasibility investigation of different HPS configurations.

To this end, this paper aims to investigate the need to introduce the HPS concept to the energy sector in Yemen. In order to build a realistic case study, this review article first looks at the development and prospects of RE technologies in Yemen. It then presents a feasibility study of five different configurations of an off-grid HPS for rural electrification. The considered candidate technologies include PV, Wind, Diesel Generator, and Battery. This study targets a residential load in Shafar, a key district in Hajjah province, with an aim to determine the most suitable HPS in terms of environmental and economic perspectives. It is worth to note that Hybrid Optimization Model for Electric Renewables (HOMER) software is employed.

Two key motivations stand behind this study. These are:

1) The plans of Government of Yemen (GOY) to construct various off-grid RE-based HPS in an attempt to lessen CO_2 emission as stated on its Intended Nationally Determined Contribution (INDC) report, at the Paris COP 21 [41]. GOY targets to increase RE power generation share up to 15% [42] in collaboration with several international organizations such as USAID [43], the World Bank [44] and UN Development Program (UNDP) [45].
2) The UN declaration of 2014–2024 as "the decade of sustainable energy for all" (SE4All initiative). In Yemen, 15.71 million people (i.e. 60% of its population [46]) still have no access to energy since the total installed capacity is merely 850 MW [47].

This article is arranged as follows: Sections 2 and 3 review the historical development and prospects of RE in Yemen, Section 4 discusses the input key parameters, Section 5 outlines the components of the proposed systems, Section 6 discusses the simulation results and Section 7 draws the conclusion.

2. Historical development of RE in Yemen

For the last three decades, the country has witnessed notable development in its energy sector which primarily depends on fossil fuel and natural gas. At present, the major power plants operating in the country are Marib Gas-powered Plant with total capacity of 341 MW, Al-hiswa and Almansoura diesel-Powered plant with capacity of 200 MW and the Ras Kanatib Power plant with 200 MW capacity. Besides, there are some minor diesel powered plants in various locations in the country contributing of about 150 MW [48]. Nonetheless, the current installed capacity cannot meet the increasing energy demand (with an estimated 60% of population without electricity access in the horizon) and therefore further actions need to be made.

Table 1
Summary of RE potential in Yemen [50].

RE resource		Calculated potential (MW)
Solar Energy	PV	2,446,000
	Thermal	3014
Wind Energy		308,722
Geothermal Energy		304,000

It was only after 2000s when GOY took the necessary measures to exploit RE resources and integrate them into its energy sector. At the beginning, several international organizations, such as Lahmeyer International and EnergySolve International, were invited to assess the potential of these resources in the country [49]. This was followed by a formal investigation carried out by GOY in collaboration with UNDP and the World Bank to estimate the actual energy which could be harvested [44]. The results of these assessment studies indicated that RE can play a key role in resolving the chronic electricity shortage. The potential of some important RE resources in Yemen is summarized in Table 1 [50]. Consequently, GOY started funding and supporting a few small-scaled RE projects including several stand-alone PV stations for electrification of remote areas across the whole country.

Moreover, GOY has made further steps in integrating RE into its energy sector. In July 2008, a national electrification plan known as "The Rural Electrification Policy Statement" (REPS) was officially approved by GOY as an attempt to lay the groundwork for more on- and off-grid RE projects across rural areas [51]. Several RE projects have been recently executed throughout the country, such as the 60MW wind farm project [52] and several PV stations for rural electrification [53]. In addition, GOY introduced the "National Strategy for renewable energy and energy efficiency" in 2010, which was backed by Germany and the World Bank [54]. This strategy has two major objectives: (1) On-grid RE-based projects which aims to raise the share of RE to 15%; and (2) off-grid PV-based projects whose target is to electrify 110,000 households by 2025 [50].

Recently, GOY has recognized that global warming and climate change are two central issues which have negatively impacted our environment. On that basis, Yemen has always been an active party to the UN Framework Convention on Climate Change since 1996. More recently, despite the prevailing security challenges, Yemen submitted the country's INDC document as part of world-wide submissions to the Paris Agreement [41,50]. The INDC report drew several measures to cut down the emissions of carbon dioxide by promoting the use of renewable energy at its local energy market.

3. RE prospects in Yemen

Despite the proven potentiality of renewables in Yemen, there has not been any notable progress in their integration process. Since the early stages of RE deployment in the country, the share of RE has not increased and just remained stable at about 0.09%. Nonetheless, GOY aims to raise this figure up to 15% by 2025 [45]. In addition, investments related to RE have not attracted much intention from the private sector. Most of the current RE-based projects are either donor-driven or small-scaled government-driven projects with a limited possibility for expansion. Therefore, the growth of RE deployment in the country is mostly going at a relatively slow pace.

3.1. Public awareness about RE

Apart from the government effort, public awareness about RE technologies and their advantages has noticeably increased in the country. A recent study [50] examined public views, knowledge and attitude toward RE, particularly PV technologies, of 348 and 258 urban