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Abstract
Ghana suffers from inadequate power supply due to increasing demand though it is amongst the African nations with the highest access to electricity. This research aims to assess the techno-economic potential of wind and solar energy potential for Ghana's northern part. We employ the Weibull distribution function, levelized cost of energy, and net present cost metrics for the economic study. The wind and solar energy resource's structure generated 72,284 kWh yearly. Both systems were identified to be too expensive if implemented under the current financing conditions in the country. The PV systems generated 38,859 kWh/year, representing 53.76% of the total electricity generated in a year, generating renewable hydrogen in the country. The findings show that sizing and management of renewable plants will fulfill the basic annual cooking demands of the populations, which are 785 kg H_2 in Ghana. The countries' capacity for developing solar hydrogen plants is further suggested by generating new solar hydrogen opportunity charts. Considering the significance of hydrogen energy under the renewable energy output, we recom-mend using hybrid systems for hydrogen production. The findings reveal which flexibility options are critical in key stages of the energy transition to a 70, 80, 90, and 100% renewable energy system.

Keywords: Solar energy · Techno-economic analysis · Ghana, HOMER · LCOE · Hybrid power plant

Introduction

In today's world, energy plays a critical part in the socio-economic development of any economy (Rehman et al. 2021). The depletive nature of fossil fuels and their negative environmental effects have become a global concern. Problems such as declining air quality, global warming, acidic rain, and climate change result from the continual use of fossil fuels (Yang et al. 2021; He et al. 2020; Mohsin et al. 2020). The need for sustainable and affordable energy and the necessity to reduce greenhouse gas emissions have left policymakers with no option but to explore potential renewable energy resources worldwide (Mohsin et al. 2020; Mohsin et al. 2018b; Mohsin et al. 2021a). Even though renewable energy is growing worldwide, most developing countries are yet to integrate such technologies into their generation mix (Mohsin et al. 2018a). The African continent has tremendous renewable energy (RE) potential; harnessing that could effectively change the continent's overall socio-economic condition. It is estimated that about 600 million people in the

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continent have no electrical power access (Ikram et al. 2019a; Shah et al. 2019).

Research shows that the inability of most African countries to develop RE technologies is because of a lack of funding or the lack of awareness about the cost-effectiveness of such projects (Mohsin et al. 2021b). Ghana has projected to increase RE's total energy supply by about 10% by 2030 (Larscheid et al. 2018; Tiep et al. 2021). Some areas along the country's coast have also been identified to support large-scale commercial wind power plants. Ghana's electricity demand has been increasing by 10% over the last decade increasing. The country's traditional energy-producing sources are under strain. Due to increased industrialization and urbanization, the commercial and residential sectors have had the fastest growth rates (Yilmaz et al. 2020). Since the existing infrastructure is ruing at full capacity, there is an urgent need to expand the energy resources in the country to include RE (He et al. 2020; Akhtari et al. 2020).

The potential contribution of wind and solar energy to the country's electrical grid and the energy storage required to make such contributions were considered. The idea was to see if it was possible to produce hydrogen that could be exported (Anser et al. 2020a, 2020b; Baloch et al. 2020). Renewable energy resources, such as wind, solar, and hydro, are practical for hydrogen generation in many parts of the world (Sun et al. 2020f; Sun et al. 2020d; Sun et al. 2020e). Also, various authors have investigated the application of both off-grid and grid-connected hybrid renewable energy systems with battery storage technology for enhancing energy availability to rural people (Chandio et al. 2020; Sun et al. 2020d). However, only a few authors have looked into account the wind and solar renewable power potential. Furthermore, the South African government is particularly interested in the development of hydrogen-fuel cell pathways. South Africa has the world's largest supply of platinum group metals utilized as catalysts in fuel cells (Iram et al. 2020).

Furthermore, the Paris Climate Agreement opposes fossil fuels and promotes renewable energy development to prevent pollution (RE) (He et al. 2021a; Feng et al. 2020; Tian et al. 2020). Ghana relies primarily on thermal energy sources for electricity generation in West Africa, with thermal energy outnumbering hydropower in the energy mix composition in 2015. Several studies (Alemzero et al. 2020b; Sun et al. 2020d; Alemzero et al. 2020a) have been conducted in response to the need to increase the country's power-producing capability via renewable energy. Atuguba and Tuokuu (2020) investigated Ghana's renewable energy plan's legal structure (Alemzero et al. 2020a; Ankrah and Lin 2020). Partially implemented regulations, a lack of market-driven support programs and restricted access to financing were also highlighted as major causes for the sector's poor performance in their research (Sun et al. 2020b; Sun et al. 2020a).

Globally many researchers have conducted techno-economic assessments on single-type or hybrid power plants for the electrification of rural and remote communities. Agyekum et al. (2021) and Zhang et al. (2021a) analyzed a techno-economic potential for a hybrid energy system for residential neighborhoods in Jubail Industrial City (Hu et al. 2020; Zhao et al. 2020; Quan et al. 2021). Extending electricity to remote and rural areas from the national grid is sometimes seen as an expensive and not a profitable venture due to the more minor load characteristics of such sites (Chien et al. 2021b; Li et al. 2021; Chien et al. 2021b; Iqbal et al. 2021). Stand-alone or off-grid power plants are usually the best options for such areas since they are less expensive to construct. However, there are many technical challenges in standalone RE power generation systems. For example, solar power can only be generated in sunny conditions, and wind power also depends on the season and wind speed. These issues make such systems unreliable for a sustainable power supply (Zhang et al. 2021a, b). Hybrid systems can solve not only some of those challenges but also ensure optimal production cost. On the other hand, hydrogen energy seems to have tremendous potential regarding availability and environmental friendliness (Ehsanullah et al. 2021; Hsu et al. 2021).

To cover the current research gap, the study's four objectives are to give a comprehensive techno-economic analysis of wind and solar power systems of Ghana. The study measures thoroughly economic and technical investigation. (i) The study's first goal is to offer a framework for renewable energy generation in Ghana. We also looked at the economics of hydrogen generation in Ghana. (ii) This research is crucial to the development of Ghana's energy sector; it is expected to reveal the economic viability of such a project to policymakers and decision-makers and local and international investors. (iii) The study also planned to serve as a reference document for decision-making in renewable energy development. (4) This study can be used by policy makers to analyze the influence of significant financial uncertainty on the performance of renewable energy facilities. The findings of this study are projected to be important not just for policymakers and decision-makers in Ghana's solar and wind energy sectors.

The research has four main sections. The "Introduction" section presents the introduction and characteristics of the studied area; the "Background of Renewable Energy Potential in Ghana" section covers the background of renewable energy potential in Ghana; and the "Methodology" section, methodology adopted for the analysis; the "Results and discussions" section also covers the results and discussions. The "Conclusion and policy implications" section concludes the study.

Background of renewable energy potential in Ghana

Current electrification status

Tamale is a community located in the Northern region of Ghana on latitude 9.5° N and longitude–0.9° E at an elevation of 168 m, the National Aeronautics and Space Administration (NASA) reports. According to research, at 2-m heights, wind resource estimates range from 1.7 to 3.1 m/s, and at 12-m heights, 4.8 to 5.5 m/s. Coastal areas in the USA have the most significant wind resource potential (Asumadu-Sarkodie and Owusu 2016). Increased usage of wind turbines in hybrid mini-grid systems may benefit off-grid populations in the coastal area, in particular, because wind speeds more fantastic than 4 m/s are commonly acknowledged as having a power generation potential (Essandoh et al. 2014; Chien et al. 2021c; Chien et al. 2021a).

On the other hand, the bioenergy potential to be around 149 TJ (Grados and Schrevens 2019). Agricultural crop residue has the highest bioenergy potential, ranging from 75 to 90 TJ in the literature (Cai and Lontzek 2019). The most significant stumbling hurdles. The research claims that thermochemical conversion technologies have a better chance of becoming viable shortly (Zhang et al. 2021b; He et al. 2021b; Li et al. 2020). However, due to challenges such as unsustainable earnings, a shortage of dung collecting, and socio-cultural reservations about using digested faucal material as plant fertilizer, the effort was halted (Sun et al. 2020c). Table 1 shows the installed grid electricity capacity.

Wind turbines

The Nordex N100/2500, Vestas V52/850, and Mitsubishi MWT1000 were chosen for economic analysis using RET Screen software in this study. The IEC 61400–1 (Sedaghat et al. 2020) standard is used to select wind turbines (Mi et al. 2021; Peng et al. 2021; Xu et al. 2021). Wind turbines are built to resist a specific amount of loading induced by a strong wind. Another reason for choosing these three wind turbines is their ability to offer a broad spectrum of power. Table 2 and Fig. 1 contain information on these turbines.

Methodology

Mathematical model

The mathematical models for the various components of the hybrid system are presented in this section.

PV sub-system

The output power from the PV energy system can be calculated mathematically using Eqs. (1) to (4) (Nabgan et al. 2017). Technical parameters for the solar module used in this analysis are represented as (Jiang et al. 2021),

$$\mathrm{P_{PV}} = \mathrm{H}_t \mathrm{PVA}\ \mu_\mathrm{c}(\mathrm{t}) \tag{1}$$

where H_t represents the radiation incident on the tilted surface, PVA is the area of the solar cell, $\mu_c(t)$ denotes the instantaneous generating efficiency of the modules of the PV.

$$\mu_\mathrm{c}(\mathrm{t}) = \mu_\mathrm{cr}[1 - \beta_\mathrm{t}(\mathrm{T_c}(\mathrm{t}) - \mathrm{T_{cr}})] \tag{2}$$

where, β_t represents the temperature coefficient, T_{cr} and μ_{cr} are the theoretical solar cell temperature and efficiency, respectively. $T_c(t)$ denotes the instantaneous PV cell temperature at ambient temperature (Nematollahi et al. 2019).

$$\mathrm{T_c}(t) = \mathrm{T_a} + 3\mathrm{H_t}(\mathrm{t}) \tag{3}$$

The needed PVA to feed the load demand with an average load $P_{L,\ av}$ it can also be calculated using Eq. (4).

$$\mathrm{PVA} = \frac{1}{24} \sum_{i=1}^{24} \frac{\mathrm{P_{L,av}}(\mathrm{t})\,\mathrm{F_s}}{\mathrm{H}_t \eta_\mathrm{c}(\mathrm{t}) \eta_\mathrm{pc} \mathrm{V_F}} \tag{4}$$

where, F_s denotes the safety factor, which includes an allowance for a probable inaccuracy in the insolation data, V_F Represents the factor of variability that factors the variation in radiation from one year to another. η_{pc} is the power conditioning system's efficiency (Glenk and Reichelstein 2019). Table 3 contains the technical parameters of the selected PV module.

Wind sub-system

The Weibull distribution is a probability rule that is utilized inaccurate data modeling of electronic tubes, capacitors, ball bearings, relays, and material resistance, among other things. It may also be used to construct a risk function that describes all stages of a product's life cycle (Schnuelle et al. 2020). The density function and the cumulative distribution function define the Weibull distribution location parameter is often ignored, resulting in the simplified two parameter equations, Eqs. (4) and (5), representing the probability density function and the cumulative probability distribution with zero displacements, respectively. The Weibull distribution of wind is usually used in calculating this parameter Eq. (5) (Kuo et al. 2021).

$$f(v) = {}^{k}/_{c} \cdot \left({}^{v}/_{c}\right)^{k-1} \cdot \exp\left[-\left({}^{v}/_{c}\right)^{k}\right] \tag{5}$$

Table 1 Electricity production capacity (installed)

Generation plant	Fuel type	Capacity				Total production		
		Installed (name plate)	% share	Average dependable	Average available	GWh	% share (incl. embedded)	% share (exl. embedded)
Hydro power plants								
Akosombo	Hydro	1020		900	505	4282	30.5	30.6
Bui	Hydro	400		340	205	528	4.1	4.2
Kpong	Hydro	160		140	115	752	5.3	5.4
Sub-total		1580	35.9	1380	760	5616	39.9	40.2
Thermal power plants								
Takoradi Power Company (TAPCO)	Oil/NG	330		300	200	686	4.9	4.9
Takoradi International Company (TICO)	Oil/NG	340		320	260	1880	13.4	13.4
Sunon–Asogli Power (SAPP)	NG	560		520	180	1417	10.1	10.1
Kpone Thermal Power Plant (KTPP)	Oil/Diesel	220		200	20	124	0.9	0.9
Tema Thermal Plant1 (TT1P)	Oil/NG	110		100	70	365	2.6	2.6
Tema Thermal Plant2 (TT2P)	Oil/NG	80		70	1	0.5	0	0
CENIT Energy Ltd (CEL)	Oil/NG	110		100	30	59	0.4	0.4
AMERI	NG	250		230	200	1229	8.7	8.8
Karpower	HFO	470		450	225	1814	12.9	13
AKSA	HFO	260		220	100	799	5.7	5.7
Sub-total		2730	63.3	2510	1286	8373.5		
Trojan	Diesel/NG	44		40	30	52	0.4	
Genser	Coal/LPG	22		18	0	0	0	
Sub-total (including embedded generation)		2796	63.6	2568	1316	8425.5	59.9	
Renewables								
VRA Solar	Solar	2.5		1.5	1.5	3	0.02	
BXC Solar	Solar	20		16	10	25	0.18	
Sub-total		22.5	0.5	11.5	11.5	28	0.2	
Total (including embedded generation solar)		4398.5		3966	2198	14,069		
Total (excluding embedded generation and solar)		4310		3890	2156	13,989		

Source: Obeng-Darko 2019

Table 2 Details cost information of wind turbines

Manufacturer	Nordex (Germany)	Vestas (Denmark)	Mitsubishi (Japan)
Rated power	2500 kW	850 kW	1000 kW
Rotor diameter	100 m	52 m	57 m
Turbine cost	3,023,000 ($)	928,000 ($)	1,012,000($)
Initial cost	4,232,200 ($)	1,299,200($)	2,116,800 ($)
O and M cost	52,902.5 ($/year)	16,240 ($/year)	26,460($/year)
Hub height	80 m	40 m	60 m
Lifetime	20 years	20 years	20 years

Data Source: Dixon et al. 2016

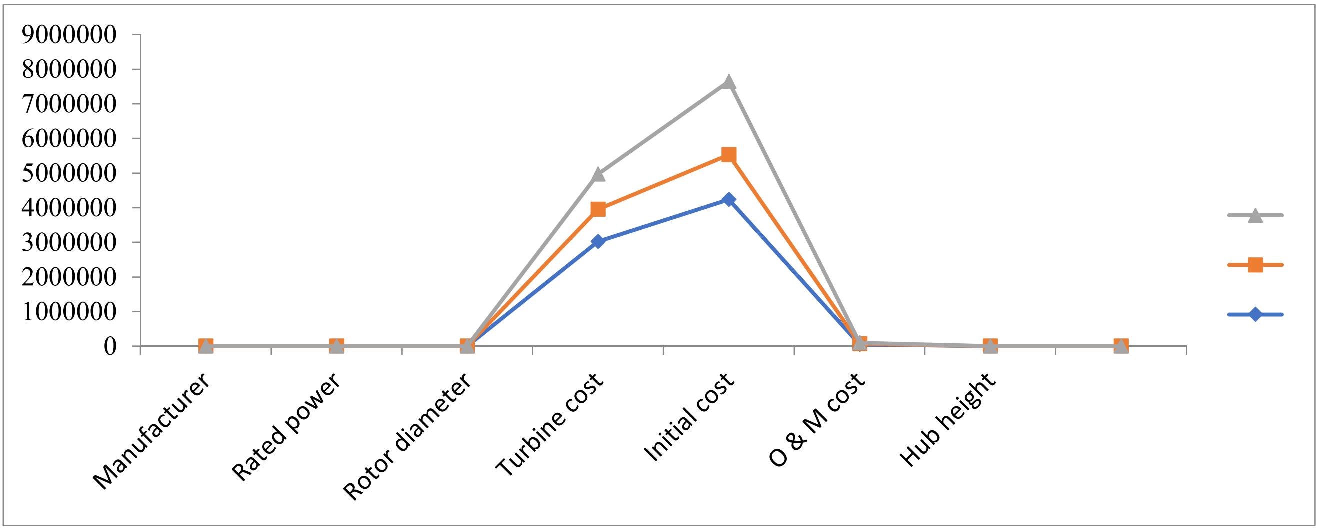

Fig. 1 The power curve of wind turbines (Nedaei et al. 2014)

where k represents the Weibull shape factor, c is the Weibull scale parameter (m/s), and v denotes the wind speed (m/s). Equation (7) gives the model used in calculating the turbine's output power.

The Weibull shape parameter and the Weibull scale parameter is being used to measure the wind power potential. The abscissa scale of the data distribution plot is described by the scale parameter c, which is in m/s.

This contradicts the widely held belief that the Weibull parameters are material properties unaffected by specimen shape or loading mode. X is the variable under consideration, fi is the probability density function, and k and c are the shape and scale parameters. The shape (k) and scale (c) parameters are dependent on the variable x and the data being examined, and they need a long-term database with data sorted by value classes (bin size or bin width). These Weibull parameters may be determined using a variety of techniques based on the recorded actual data distribution. Graphical, moment (or Justus empirical technique), and maximum likelihood methods are the most used. Table 4 shows the technical parameters of wind turbines.

Table 3 Technical parameters for the selected PV module

Description	Value
Panel type	Flat plate
Abbreviation	Conext CL25000 E
Rated capacity (kW)	25
Temperature coefficient	−0.41
Derating factor (%)	80
Operating temperature (°C)	45
Efficiency (%)	17.3
Lifetime (years)	25

Economic evaluating indicators

Several indicators are available to assess distributed energy systems' technological, environmental, and economic performance (Amores et al. 2021). The electricity production by the various components is used to evaluate the technical performance of the hybrid system. The NPC is the system's life cycle cost when considering values such as the cost of electricity purchases from the grid and cash flows. The NPC can be calculated using Eq. (6) (Do and Kim 2020).

$$\mathrm{NPC} = \frac{\mathrm{TAC}}{\mathrm{CRF}} \tag{6}$$

where TAC is the total annual cost of the components ($), and CRF represents the capital recovery factor which is the number of uniform payments received in n years. The CRF can convert a present value to equal annual or yearly payments stream at a specified discount or interest rate in a specified period and computed using Eq. (7) (van der Roest et al. 2020).

$$\mathrm{CRF(r,n)} = \frac{r(1+r)^n}{(1+r)^n-1} \tag{7}$$

where r represents the interest rate, n is the number of years. The COE is the ratio of the summation of the whole cost accrued throughout the project's lifetime to the unit of electricity generated over the entire lifetime of the project (Chen et al. 2021). It is an effective metric that is used in comparing different energy options. It can be calculated using Eq. (8) (You and Kim 2020; Khodabandehloo et al. 2020).

$$\mathrm{COE} = \frac{\sum_{n=0}^{N} \mathbf{C_n}(\mathbf{1}+\mathbf{r})^{-\mathbf{n}}}{\sum_{\mathbf{n=0}}^{\mathbf{N}} \mathbf{E}_n(\mathbf{1}+\mathbf{r})^{-\mathbf{n}}} \tag{8}$$

where, C_n is the entire cost in year$n$, E_n represents the entire electricity consumption in year n measured in kWh, and r

Table 4 Technical parameters for the wind turbine

Parameter	Rated capacity (kW)	Rotor diameter (m)	Hub height (m)	Name
Description	25	12.6	30	Recycle EO25 Class IIA.

denotes the interest rate. The ROI is defined as the profitability ratio, which assesses the performance of an investment or project. The ROI can be calculated using Eq. (9).

$$\mathrm{ROI} = \frac{\mathrm{R}_{ev} - \mathrm{CI}}{\mathrm{CI}} \tag{9}$$

where, R_{ev} represents the revenue from the investment ($), and CI denotes the initial cost of the asset ($) (Liu et al. 2021). At the time of conducting this research, the inflation rate in Ghana was 8.20% (Timmerberg and Kaltschmitt 2019), and that is what was used (Fagbohungbe et al. 2019). The research also used a discount rate of 10% for the analysis (García et al. 2021).

$$H_2O \rightarrow H_2 + \frac{1}{2} O_2 \tag{10}$$

Water electrolysis having an efficiency of 65 to 85%, use electricity from renewable energy generated from wind, and it has a more significant potential between various technologies that create hydrogen,

$$\mathrm{V_{TH}} = \frac{\Delta \mathrm{H}}{2\mathrm{F}} \tag{11}$$

where V_{TH} indicates the produced hydrogen quantity. The equation shows the input of wind electricity to the electrolysis to produce hydrogen, F is the molar charge, ηel is the efficiency of the electrolysis process, and LHVH2 is the value of lower hydrogen heating (Kakoulaki et al. 2021).

$$\eta_{el} \approx \frac{1.48\mathrm{n}}{\mathrm{V_{el}}} \tag{12}$$

The electrolyzed elements in the system are denoted, although Mt is the hours measured in the electrolyzed system. Using this method, oxygen is formed for breathing and hydrogen for fuel. Both the electrodes are of metal (e.g., platinum) and are connected to electricity in the water. We have considered it as a base case study for cost evaluation. Similar methodologies have been used in various applications (Ikram et al. 2019c; Ikram et al. 2019a; Sun et al. 2020a, b, c, d, e, f; Ikram et al. 2019b; Rehman et al. 2021).

Results and discussions

Because of the deployment of this system in Ghana's energy industry, ECG, the country's only electricity distributor in the southern and middle zones, has seen an increase in revenue. It demonstrates how expanding the prepaid metering system to more consumers can improve the quality of energy distribution while also increasing revenue (Kumi 2017). This section presents the results obtained from the simulation using the above technical and financial parameters for the various components. The technical and financial evaluation is intended to help compare the integrity of the modeled power plants to a base case scenario. Hours between 7 am and 5 pm also have high load demand because most people work and require electricity. The least load demand occurs when most people are asleep and businesses are closed.

Technical analysis

Ghana's coastline region, according to a study, offers the most significant wind power potential. Wind speeds near the shore ranged from 3.33 to 6.08 m/s. It is also projected that the nation has approximately 20,674 km^2 of accessible land for wind farm construction, which is about 8.45% of the total land area (Park et al. 2009). As a result, the ministry in charge of energy has developed a renewable energy master plan to serve as a roadmap for attaining the specified renewable energy penetration goals. The proposal calls for a $5.8 billion investment, with at least 80% coming from private investors. To earn investor trust, the business and regulatory environment must encourage development in the industry.

The investor gains extra benefit from the ability to time their investments. It also lowers the risk of losses that may occur if an investment is made without sufficient understanding of the market's degree of uncertainty. While postponing investment may offer additional value to the investor, it is essential to remember that delaying investment has hazards such as rival entrance and missed cash inflows. As a result, in a world full of uncertainty, determining the best investment moment is critical. As a result, renewable energy investors must carefully examine variables other than the cost of investment when valuing their assets. Advanced DCF techniques utilize scenarios and decision tree options to account for strategic flexibility. On the other hand, these approaches do not consider the investment's intrinsic flexibility when valuing it.

Furthermore, DCF models are ineffective for valuing long-term assets in which the determination of future cash flows is subject to more significant uncertainty. The qualitative advantages that characterize strategic investments are often ignored by DCF analysis, undervaluing the investment's potential. Real options provide the bearer the power to select whether or not to invest in a real asset. It proposes a method for incorporating flexibility into assessing and planning real-estate investments, such as renewable energy technology. The physical value generated by the assets in place and the intangible value created by the flexibility inherent in taking advantage of future possibilities make up the worth of such an investment. As a result, it offers a method for correctly estimating an investment's intrinsic value. Various versions of real options methods have been used to energy investments in a significant quantity of research.

Table 5 shows the wind power potential of Ghana. Ghana has an enormous wind resource that might be used to create a significant amount of energy. The Solar and Wind Energy Resource Assessment (SWERA) project, which was carried out in collaboration with the US National Renewable Energy Laboratory (NREL), the United Nations Environment Programme (UNEP), and the Global Environment Facility in 2004 identified specific locations along Ghana's coastline that could support wind power generation. Wind speeds of 9 to 9.9 m/s are typical along Ghana's coastline, which might be used to create roughly 2000 MW of energy. Accessible wind for electricity generation may theoretically produce 500–600 GWh per year with present technology (Essandoh et al. 2014). Excellent wind power production opportunities have also been discovered and plotted along the country's coastlines.

Solar PV Ghana

In all areas of Ghana, solar resources are plentiful, with enormous power production. It is projected that the nation has 35 EJ of solar potential. This may supply approximately 100 times the nation's current power requirements, projected to be 53,000 MWh per yearly based (Zhou et al. 2017). Table 6 contains the monthly average solar variation.

Figure 2 shows the solar monthly data. According to the Ghanaian government, Ghana's foggy semi deciduous woodland zone, are 5.3 h, but they are 7.7 h in Wa, which is located in the dry Savannah zone.

Techno-economic analysis

The economic evaluation of the structure is presented in this section. From the simulation, a levelized cost of energy (LCOE) of 0.321 $/kWh was obtained for the system. There was excess electricity of 220 kWh/year, which is 0.309% of the total electricity produced; such excess is acceptable since the community is developing; hence, excess capacity is needed to take care of that situation. The renewable fraction for this system was 46.6%, with a maximum renewable penetration of 814%. According to the data, 3 h of daily production using extra energy would produce Nm3/year. of hydrogen at the cost of $0.303/kWh. Baloch et al. (2021) developed a new concept for producing methanol and hydrogen using wind energy (Zhou et al. 2017). A novel CO_2 collection system based on solar PV and wind energy also generate hydrogen, urea, and electricity. By containing CO_2, the hydrogen generated is turned into ammonia, which is then used to manufacture urea. The authors demonstrated that the proposed system could generate 518.4 k mol of hydrogen per day and 86.4 k mol of urea per day (Sun et al. 2020e; Baloch et al. 2020).

Robustness test

A robustness test analysis was conducted to evaluate the impact of certain variables on the techno-economic performance of the various systems. This is critical since it helps to know what to work on or pay attention to during the project's decision-making, implementation, and operation stages. Factors such as discount rate, cost of fuel, and wind speed were varied to ascertain their effect on the project's bankability. The robustness test reveals that fuel cost has a significant impact on the project's bankability and affordability. The price of gasoline is growing, which affects both NPC and LCOE. Two core factors affect facility cost and power output of wind turbines, i.e., hub height and rotor diameter, which further determine the LCOE of the power plant. Theoretically, wind speed increases with increasing hub height.

In the same way, a longer rotor diameter means the area for absorbing wind momentum increases which also increases the output power. The impact of surface roughness reduces with

Table 5 Wind power and potential of Ghana

Wind resource description	Wind class	Wind power density at 50 m (W/m^2)	Wind speed at 50 m (m/s)	Total area (km^2)	Windy land as a percentage of the total land of Ghana (%)	Potential installed capacity (MW)
Moderate	3	300–400	7.1–7.5	715	0.3	3575
Good	4	400–500	7.5–8.4	265	0.1	1340
Very Good	5	500–600	8.4–9.0	82	< 0.1	410
Excellent	6	600–800	9.0–9.9	63	< 0.1	315
Total				1128	0.5	5640

Table 6 Monthly averaged solar irradiation (kWh/m2/day)

Month	Northern zone			Middle zone				Southern zone		
	Wa	Bolga	Tamale	Sunyani	Kumasi	K'dua	Seko-T'adi	Cape Coast	Accra	Ho
Jan	5.73	5.72	5.7	5.49	5.38	5.41	5.65	5.19	5.24	5.51
Feb	6.02	5.96	5.98	5.67	5.57	5.62	6.09	5.3	5.4	5.7
Mar	6.15	6.11	6.1	5.63	5.56	5.63	5.75	5.37	5.41	5.7
Apr	6.1	6.06	5.92	5.45	5.46	5.51	5.54	5.22	5.36	5.56
May	5.96	5.82	5.68	5.14	5.17	5.18	4.97	4.82	4.97	5.16
Jun	5.46	5.32	5.11	4.49	4.58	4.63	4.33	4.17	4.43	4.59
Jul	4.92	4.88	4.73	3.97	4.22	4.41	4.97	4.13	4.58	4.48
Aug	4.67	4.61	4.41	3.69	3.92	4.26	4.97	4.04	4.44	4.36
Sep	5.01	4.95	4.79	3.83	4.03	4.38	4.92	4.09	4.48	4.51
Oct	5.6	5.58	5.57	4.4	4.71	4.96	5.48	4.67	4.95	5.03
Nov	5.59	5.56	5.41	4.82	5.08	5.09	5.68	4.91	5.01	5.15
Dec	5.63	5.59	5.63	5.08	5.05	5.16	5.41	4.91	5.03	5.24
Ave.	5.56	5.51	5.41	4.79	4.88	5.01	5.3	4.73	4.93	5.07

Source: (Sparks 2018)

height. Therefore, increment in wind speed arises in a mixed layer and lessens as the size reaches the boundary layer height. This suggests that increasing the turbine's hub height could positively affect the LCOE, which implies that the current capacity of 25 kW for the wind turbine will have to be increased since the smaller the capacity of the turbine, the shorter the hub height. Wind tracking could also be included to maximize the use of the wind.

Comparative analysis of the two systems

This section compares both systems and the current cost of electricity in Ghana to other literature in and outside Ghana. To compare the economics of the various modeled systems with existing scenarios, a base case was selected to enable that comparison. The diesel generator was selected as the base case because of the following: Ghana's electricity generation mix is mainly from thermal power plants that rely on fossil fuels for its generation; secondary, the people at the selected locality uses diesel-powered generators when there are power cuts. Table 7 contains the comparative analysis of the various systems.

Comparison with other literature

Several researchers have conducted such analysis for different hybrid systems in and around the globe. It is essential to run a

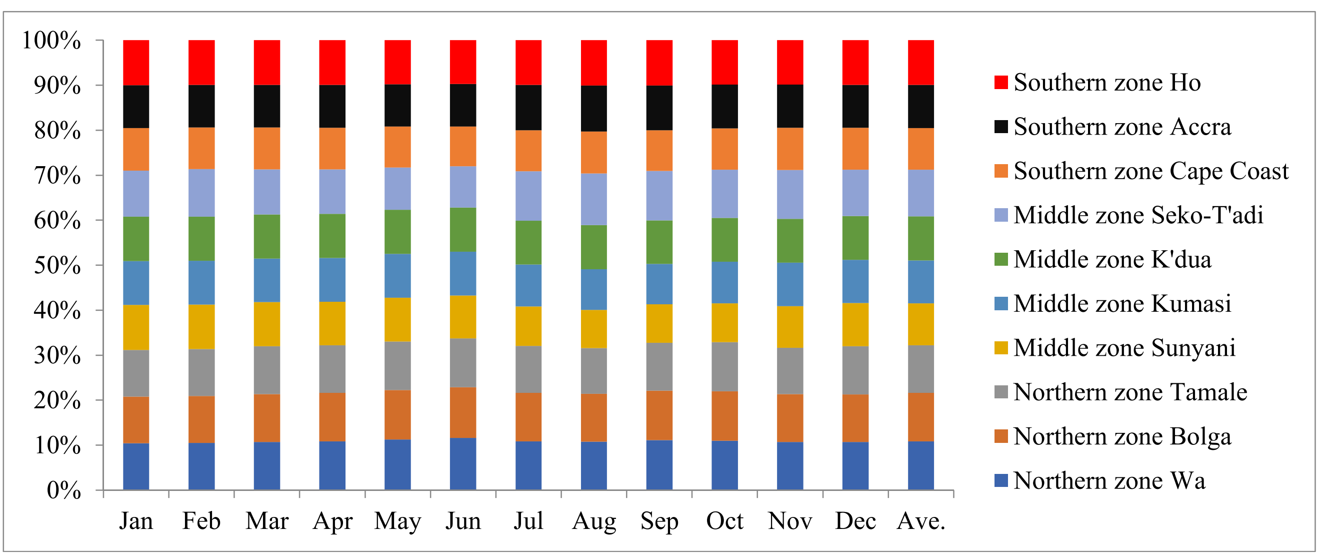

Fig. 2 Solar monthly wise data from different regions of Ghana

Table 7 Comparative analysis of the various systems

Indicator	PV/wind/DG/battery	PV/DG/battery
General comparison		
Present worth, ($)	775,105	761,772
Annual worth, ($/year)	30,265	29,744
Return on investment, (%)	27.9	43.2
Internal rate of return (%)	31.6	45.7
Simple payback, (year)	3.30	2.01
Discounted payback, (year)	3.29	2.00
Generator		
Fixed generation cost, ($/hour)	3.14	3.14
Marginal generation cost, ($/kWh)	0.291	0.291
Hours of operation, (hours/year)	1602	1,970
Fuel		
Total fuel consumed, (L)	10,054	11,854
Average fuel per day, (L/day)	27.5	32.5
Average fuel per hour (L/hour)	1.15	1.35
PV cell		
PV penetration, (%)	64.4	64.4
Hours of operation, (hours/year)	4380	4,380
LCOE, ($/kWh)	0.076	0.076
Wind turbine		
Wind penetration, (%)	9.62	-
Hours of operation (hours/year)	2386	-
LCOE, ($/kWh)	0.316	-

comparative analysis to ascertain the cogency of the current work. As indicated in Table 8, studying other literature shows that the present study perfectly aligns with other proposed projects elsewhere. A careful examination of that the area

Table 8 Techno-economic analysis of some hybrid systems

No	Location	Peak demand, kW	Hybrid system	LCOE, $/kWh	NPC, $	Initial capital, $
1	Ghana, Wa	1.3	PV/DG/battery/converter	0.760	412,104	243,000
2	Ghana, Amansie West district	19000	PV/DG/fuel cell/battery	0.242-0.300	345.10-426.67	-
3	Saudi Arabia, Yanbu, community load	68	PV/wind/battery	0.617	1,434,950	1,257,000
4	Turkey, Izmir	23.31	PV/wind/diesel/battery	0.280-0.500	253,000 -455,000	297,000-167,000
5	Ghana, Adafoah	83	PV/wind/DG/battery	0.281	3,905,581	1,163,800
6	Saudi Arabia	2400	PV/wind	0.037	3,080,182	-
7	Kenya	360	PV/diesel/battery	0.354	7,568,600.45	-
8	Egypt, New Borg El Arab City	18.41	PV/wind/diesel/battery	0.190	1,684,118	784,000
9	Malaysia	4	Wind/PV/diesel	1.877	288,194	-
10	Sudan, Dongola	476.31	PV/WT/DG/battery/converter	0.387	24,160,000	-
11	Bangladesh	51.52	PV/WT/DG/battery/converter	0.370	357,284	-
12	Nigeria		PV-wind-diesel-battery	0.110	1,010,000	796,000
13	Bangladesh	44.41	PV/Batt/biogas/diesel generator	0.280	612,280	-
14	Ghana, Mankwadze,	407.71	PV/wind/DG/battery	0.382	8,649,054	880,103
15	Ghana, Tamale	20.46	PV/wind/DG/battery	0.321	496,983.90	138,105
16	Ghana, Tamale	20.46	PV/DG/battery	0.338	510,316.30	98,711

Table 9 PEM electrolytes' parameters in the case studies (per electrolyze)

Maximum hydrogen production rate (Nm^3/h)	2
Number of stacks	4
Number of cells	20
Cell area (cm^2)	92
Stack current (A)	110
Maximum stack power (kW)	10.25
Hydrogen generation pressure (bar)	13.8
Stack efficiency	63.60%

has a relatively higher wind speed hence the contribution of electricity from the wind turbine was more elevated, i.e., 31.28% which is higher than the 9.45% recorded in this research. Therefore, a relatively more minor LCOE was obtained in that research than obtained in the current study. Generally, the recent research has been validated by other literature.

Production of renewable hydrogen using wind and solar power

Ghana, in general, is faced with the threat of an energy crisis mainly due to the growing population and limitation of resources. The ever-increasing population involves rising demand for energy and expanded infrastructure to match the growth (Gunawan et al. 2020). The country has created policies to deploy wind and solar energy for hydrogen production and supply electricity. There is a need to produce hydrogen from renewable energy because of the increased urgency to stop climate change. Reduced renewable energy costs, hydrogen, and fuel cell technologies have experienced significant technical progress in their efficiency, durability, reliability, and cost reduction (Yee Mah et al. 2021).

Figure 3 shows the hydrogen capacity per month. A few studies were conducted to address the production of hydrogen in Africa, including Ghana. With an electrolyzer converting excess electricity into chemical energy and a fuel cell using hydrogen to energize power, the hydrogen storage system could function as a carbon-free energy storage system as well. Therefore, a hybrid system such as a wind-solar system to produce hydrogen is considered environmentally essential and clean. Ghana is a West African country with a tropical atmosphere and a population of 27 million inhabitants. It has a gross land region of 238,500 km^2 with a tropical climate.

Table 9 shows that hybrid systems to produce hydrogen are also economically significant and can be very promising for a sustainable future. The use of wind and solar is abundant in producing energy that can generate hydrogen, which will then be stored and function, and the energy storage system (Zhang et al. 2020). Ghana has developing economies and is geographically located near the equatorial region. Besides, its primary source of domestic energy is generated from fossil fuels, mainly firewood, charcoal, and petroleum products. This resulted in many deaths because of poor ventilation and out-dated cooking methods. Moreover, Ghana faces economic instabilities that rely on importing petroleum products to cover its energy need. Therefore, there is a significant need to produce hydrogen from a solar-wind system that is considered cheap and safe.

Significant safety and the technological threat must also be understood and dealt with before Ghana can exploit all the

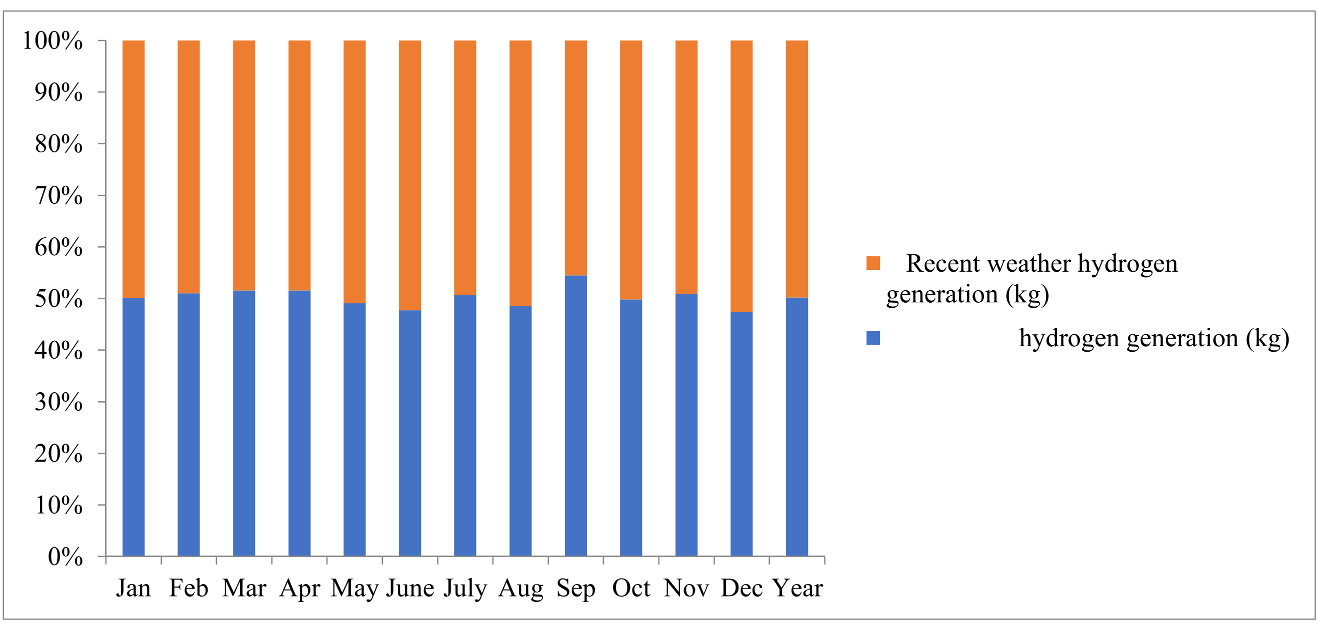

Fig. 3 Hydrogen generation results

possibilities provided by hydrogen. Hydrogen is a complex containing, holding, and transporting molecules. It has specific safety characteristics that can be difficult to fix, requiring technological sensitivity lacking in non-home hydrogen-producing countries. Also, in countries with some experience, it is essential to know how electrolyzes function, how fuel cell systems are preserved, and how the leak from high-pressure (or cryogenic) stocks is prevented. Additionally, hydrogen production using a solar-wind system faces challenges in production upscaling and supply logistics. This issue needs support from the government or other funded projects to ensure suitable equipment and other facilities comprehensively. The government should make an effort to initiate programs to create awareness and enlightenment on renewable energy resources, particularly in hydrogen production, which include developing policies, incentives, and a regulatory environment.

Conclusion and policy implications

This research aims to assess the techno-economic potential of wind and solar energy potential for Ghana's northern part. We employ the Weibull distribution function, levelized cost of energy (LCOE), and net present cost (NPC) metrics for the economic study. Also, the study measures the solar power potential in the country. The current paper evaluated the techno-economic potential of an integrated electricity generating system for Tamale in the Northern part of Ghana. Ghana's daily domestic cooking demand profile was calculated to be 2.5 kWh/day. These situations were fed into a machine model used to build and scale a solar hydrogen plant. Hydrogen output rates were measured using functional PV efficiency for each country's weather conditions, and 815 kg H_2 of hydrogen was used to fulfill Ghana's annual cooking needs.

Cooking is one of the most impacted by energy source volatility since it depends mainly on LPG. Analysis reveals that LPG is used by 86% of all Jamaican households for food preparation, with wood and charcoal coming in second. The robustness test conducted, however, suggests that both technologies could become economically effective and affordable if specific parameters such as discount rate and cost of fuel are varied in favor of the project. It, therefore, suggests that the involvement of decisions and policymakers in such projects is critical to its bankability or otherwise. Such programs could be in the form of fuel subsidies, tax waivers on equipment, among others.

Electricity is essential for economic development and poverty reduction. It promotes education, health, and livelihoods and aligns with broad human development indicators. The attainment of 125 of the 169 Sustainable Development Goals targets has been proven to be inextricably linked to access to electricity (Rahman et al. 2012). In the framework of international development initiatives, it is known as the "golden thread" that connects the economic, social, and environmental components of long-term growth. Unfortunately, over a billion people, or 13% of the world's population, still do not have access to electricity, robbing them of development prospects (Goverment of Pakistan 2016). The energy access problem has disproportionately impacted rural communities in general and low-income groups in particular. Rural areas, where centralized infrastructure electrification does not cost feasible, account for over 87% of the population without power today. Long distances from current grid networks, geographical inaccessibility, low energy consumption profiles, and rural residents' comparatively limited paying capacity are only a few of the reasons cited.

Availability of data and materials The data that support the findings of this study are openly available on request,.

Author contribution FengSheng Chien: conceptualization, data curation, methodology, and writing — original draft. Quang-Thanh, Ngo: data curation and visualization. Ching-Chi Hsu: review and editing. Ka Yin Chau: writing — review and editing and software. Muhammad Mohsin: visualization, supervision, and editing.

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Declarations

Ethical approval and consent to participate We declare that we have no human participants, human data, or human tissues.

Consent for publication We do not have any person's data in any form.

Competing interests The authors declare no competing interests.

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