Evaluation of Solar PV Microgrid Deployment Sustainability in Rural Areas: A fuzzy STEEP Approach

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***Abstract*- In recent times, the sustainability of renewable energy systems has been a concern to energy planners and decision-makers. This interest is because of system failures that are experienced in several communities. The current paper, therefore, uses a Criteria Importance Through Inter-criteria Correlation (CRITIC) - Preference Ranking Organization METHod for Enrichment of Evaluations (PROMETHEE) approach to select a suitable location for microgrid deployment in rural communities. STEEP (social-technical-economic-environmental-policy) criteria were used to select a suitable location for solar microgrid deployment. Three sub-criteria for each of the STEEP criteria were created to achieve this study objective. During the approach implementation, experts' judgments were used to generate relevant data for the proposed model testing. The case study for the model implementation was four rural locations in Nigeria. The model ranked the most and least preferred requirements for solar PV deployment as social and economic requirements, respectively. Also, the model was able to determine the solar PV microgrid sustainability values for the considered rural locations.**

Index Term—Renewable energy, STEEP requirements, CRITIC-PROMETHEE, rural community, sustainability

I. INTRODUCTION

In the nearest future, solar PV microgrid will play a pivotal role in the economic and environmental sustainability of rural communities. This will reflect in the productive use of clean energy systems. And economic sustainability will come from using the energy system to drive micro-businesses [1]– [3]. When solar PV microgrids are sustained in rural areas, dependence on fossil fuel for electricity generation will be reduced - a pathway to the mitigation of global warming and climate change.

Solar PV microgrid sustainability in rural areas is a major issue that needs research attention. This system's sustainability depends on several conflicting factors: effective planning, adequate and prompt maintenance, timely payment of electricity bills by consumers and regular energy audit [4]. Recently, efforts are directed at putting renewable energy-based microgrid system into productive use. This effort is necessary to create revenue that will be used to maintain and sustain the system. PV sustainability is usually determined based on the functional requirements of a community. Most studies on clean energy use in rural areas have focused on energy supply for lighting, household appliances, and healthcare facilities [1-3], [5-8]. Akinyele et al. advocated for the use of a more robust approach to clean energy sustainability compared to the traditional techno-economic model [8].

Techno-economic model is a widely used approach for developing clean energy systems. However, it does not present a comprehensive evaluation of the system from the sustainability point of view. The STEEP framework presents a detailed approach to solar PV microgrid, which can help understand the cause of the prevalent PV systems failure in several remote communities in Nigeria, and how to address the problem. The identified knowledge gap and the need to solve the sustainability problem motivates this present study. Therefore, a fuzzy Criteria Importance Through Inter-criteria Correlation (CRITIC) - Preference Ranking Organization METHod for Enrichment of Evaluations (PROMETHEE) approach are useful approaches in this regard. While CRITIC method is used to determine STEEP requirements importance, solar PV microgrid sustainability index for different rural areas was generated using a PROMETHEE method. This study aim is to determine a suitable location for PV microgrid deployment.

II. RURAL COMMUNITY AND CLEAN ENERGY

In advocating for access to clean electricity supply, researchers have focused on techno-economic viability, policy, smart systems, sustainability and integration of demand side management (DSM), for remote communities. For example, a study assessed the techno-economic and

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environmental viability of deploying hybrid renewable energy system (HRES) in low-income households [9]. A STEEP approach has been proposed for planning and managing renewable microgrids in Nigeria [8]. Techno-economic criteria have been used to identify suitable locations for hybrid energy location for a healthcare system [2]. The role of DSM in carbon footprint reduction in Modern energy services for a rural health care clinic has been presented [10]. Ajayi et al. [5] conducted a feasibility and economic viability assessment of using hybrid power generation at six rural settlements in North-West Nigeria. A study presented a comprehensive cost-effectiveness assessment of an off-grid PV system [7]. An optimum configuration of (PV)–diesel–battery hybrid energy system was proposed for a building at the University of Port Harcourt, Nigeria [11]. The viability of deploying a PV-grid tied energy system was discussed for a site in northern Nigeria [12]. A study also accessed the potential and economic viability of solar PV standalone systems for remote location [13]. The prospect of using hybrid renewable in rural and semi-urban areas in Northern Nigeria was examined [6]. The possibility of adopting solar array, wind turbine and diesel generator within the six geopolitical zones of Nigeria has also been investigated [14]. PV/battery/inverter capacity, yield and losses, battery state of charge, reliability and load growth analysis were evaluated for a typical rural healthcare centre in Nigeria [3]. Demand-side management was applied for sizing and modelling of a hybrid renewable system for a rural community [4]. Ayodele et al. considered the productive use of wind turbine for water provision in rural communities, using techno-economic criteria to select the best system [15]. This study takes a different position by using the STEEP framework and then ascertaining the location/community that is likely to sustain solar PV microgrid, as a way of mitigating the problem of systems failure.

III. PROPOSED FRAMEWORK

A. *ALGORITHM FOR SOLAR PV MICROGRID SITE SELECTION*

The proposed framework is a fuzzy-based system that uses linguistic values to implement a combined CRITIC-PROMETHEE method. The algorithm for the fuzzy-based system is presented in Fig 1. In this study, Eqs. (1) to (4) are used to aggregate experts' opinions as expressed in trapezoidal fuzzy numbers and Equ. (5) is used to convert the aggregated values into crisp values.

$$\alpha_{ij} = \min\left(\alpha_{ij}^{k}\right) \quad (1)$$

$$\beta_{ij} = \frac{\sum_{k=1}^{K} \beta_{ij}^{k}}{K} \quad (2)$$

$$\tau_{ij} = \frac{\sum_{k=1}^{K} \tau_{ij}^{k}}{K} \quad (3)$$

$$\delta_{ij} = \max\left(\delta_{ij}^{k}\right) \quad (4)$$

$$x_{ij} = \frac{\tau_{ij}\delta_{ij} + \frac{1}{3}\left(\tau_{ij} - \delta_{ij}\right)^{2} - \beta_{ij}\alpha_{ij} - \frac{1}{3}\left(\beta_{ij} - \alpha_{ij}\right)^{2}}{\tau_{ij} + \delta_{ij} - \beta_{ij} - \alpha_{ij}} \quad (5)$$

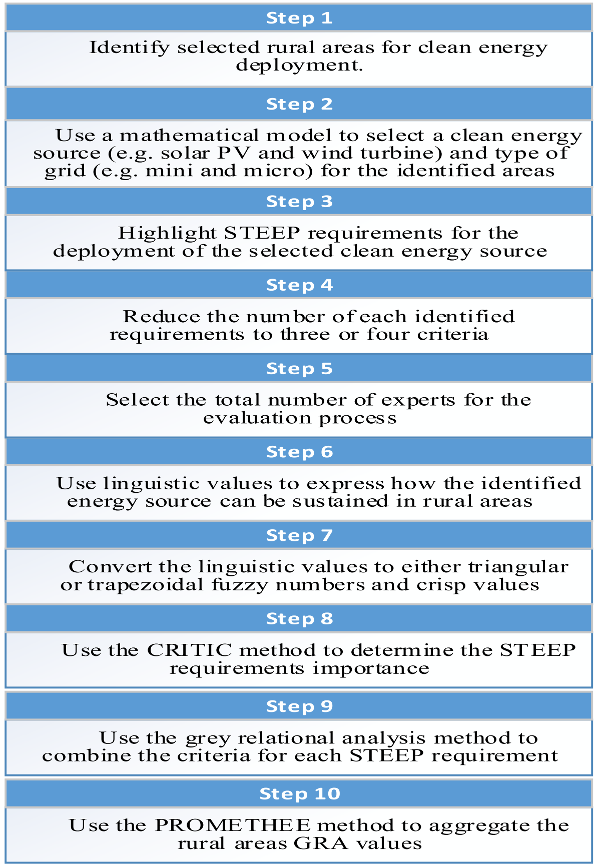

Fig 1. Solar PV microgrid site selection Algorithm

B. *Criteria Importance Through Inter-criteria Correlation (CRITIC) METHOD*

Most multi-criteria decision-making (MCDM) tool uses separate data sets to determine criteria importance [16]. Multi-criteria usually increase the complexity of a framework during the decision-making process. The complexity is due to the need for a special MCDM tool to determine criteria importance. For example, a framework that uses an analytical hierarchy process (AHP) to determine criteria importance required more data than a framework that uses entropy weighting method [16]. The need for the collection of more data can be by-passed using CRITIC method. This method uses criteria values for alternatives to determine their importance [16].

$$x_{ij} = \frac{r_{ij}}{\sqrt{\sum_{j=1}^{n} r_{ij}^{2}}} \quad (6)$$

CRITIC method implementation involves the determination of criteria standard deviation (Eq. 7) and the correlation among the criteria (Eq. 8). Based on the criteria's standard deviation and correlation, their information contents are determined (Eq. 9). This process is preceded by the criteria importance determination (Eq. 10).

$$\sigma_j = \sqrt{\frac{\sum_{i=1}^{m}\left(x_{ij} - \overline{x}_j\right)^2}{m}} \quad (7)$$

$$r_{jk} = \frac{\sum_{i=1}^{m}\left(x_{ij} - \overline{x}_j\right)\left(x_{ik} - \overline{x}_k\right)}{\sqrt{\sum_{i=1}^{m}\left(x_{ij} - \overline{x}_j\right)^2 \sum_{i=1}^{m}\left(x_{ik} - \overline{x}_k\right)^2}} \quad (8)$$

$$H_j = \sigma_j \sum_{k=1}^{K}\left(1 - r_{jk}\right) \quad (9)$$

$$w_j = \frac{H_j}{\sum_{j=1}^{n} H_j} \quad (10)$$

C. *GREY RELATIONAL ANALYSIS (GRA) METHOD*

GRA application has enjoyed a lot of recognition among researchers in machining processes, and this tool application is currently being investigated in other research areas, such as renewable energy and maintenance engineering [17]. This tool uses a three-step approach to generate grey relation grades for a decision-making problem. The first step deals with the normalization of data that are presented in a matrix form - this step considers criteria as either the higher-the-better or the lower-the-better (criteria orientation). Alternatively, an approach that by-pass criteria orientation is used to normalize the data with (Eq. 6). The second step uses a distinguishing coefficient to generate grey relational coefficient for the normalized data (Eq. 11).

$$\zeta_i(k) = \frac{\Delta\min + \zeta\Delta\max}{\Delta_{o,i}(k) + \zeta\Delta\max} \quad (11)$$

$$\Delta\min = \min_{\forall j \in i}\min_{\forall k}\left\|x_o^*(k) - x_i^*(k)\right\| \quad (12)$$

$$\Delta\max = \max_{\forall j \in i}\max_{\forall k}\left\|x_o^*(k) - x_i^*(k)\right\| \quad (13)$$

Where, $x_o^*(k)$ and $x_i^*(k)$ are the reference sequence and comparative sequence, ζ is called distinguishing coefficient and its values lie between (0,1). In the third step, the grey relational coefficients are combined with the criteria importance to generate grey relational grades (Eq. 14). The most suitable alternative for a decision-making problem is the alternative with the highest grade [17].

$$\gamma_i = \frac{1}{n}\sum_{k=1}^{n}\zeta_i(k)\, w_k \quad (14)$$

D. *PROMETHEE METHOD*

This method uses a preference approach to select the best alternative for an MCDM problem. Partial (PROMETHEE I) and complete (PROMETHEE II) ranks are created for alternatives based on alternatives' preference values. This method implementation is initiated by first defining a preference function for the data sets in a decision matrix. This study uses a linear preference function to illustrate the PROMETHEE method (Eq. 15) for simplicity.

$$p = \begin{cases} 0 & |d| \le q \\ \dfrac{d-q}{p-q} & q \le |d| \le p \\ 1 & |d| \ge p \end{cases} \quad (15)$$

Based on the preference function values, the degree to which an alternative is preferred to another alternative is determined (Eqs. 15 and 16).

$$\pi(a,x) = \sum_{x=a}^{K} P_x(a,x) w_x \quad (16)$$

$$\pi(x,a) = \sum_{x=a}^{K} \pi(x,a) w_x \quad (17)$$

PROMETHEE I method is used to interpret the positive and negative flows of alternatives. The higher the positive flow of an alternative, the more it is preferred to other alternatives with a lower positive flow value (Eq. 18). On the other hand, lower the negative flow value of the alternative, the more preferred it becomes when compared with other negative flow values that are higher (Eq. 19).

$$\phi^+(a) = \sum_{x=a}^{K} \pi(a,x) \quad (18)$$

$$\phi^-(a) = \sum_{x=a}^{K} \pi(x,a) \quad (19)$$

PROMETHEE II method uses the difference between an alternative's positive and negative flows to determine the alternative's net flow (Eq. 20). The most suitable alternative is one which has the highest net flow value among a set of alternatives.

$$\phi = \phi^+ + \phi^- \quad (20)$$

IV. FRAMEWORK APPLICATION

CASE STUDY DESCRIPTION

This paper uses four local communities that experience electricity shortage in Ogun State Nigeria as case studies. Several households in these communities are not connected to the grid because of the poor grid supply. In addition, on-grid and off-grid houses run petrol generators to meet a portion of their daily electricity demand. Also, the micro-businesses/small-scale enterprises in the selected communities use generators to meet their electricity needs.

Based on preliminary information on the study areas, PV microgrid has been identified as the most suitable clean energy for the selected communities [18].

The proposed model deployment is based on 15 criteria (TABLE I). Data for these criteria were obtained using the linguistic terms in TABLE II. While consulting stakeholders in the study areas - through a survey questionnaire, the following solar PV deployment sustainability criteria were considered:

i. Social criteria

Stakeholders' awareness and support/participation (C11): The first point of call is the awareness and participation of the host communities. The involvement of the intended communities and their full support/co-operation are one of the factors that can help achieve a sustainable microgrid system.

Training of users (C12): One thing is to create energy solutions (deploy energy systems) and another issue is to be able to properly handle (operate and maintain) the solutions. It is reasonable to train some of the intended users, as a way to get them involved in the process to ensure the long-term viability of the microgrid system and social sustainability.

The users/social acceptance (C13): This aspect has to do with the set of people a microgrid system is designed for. Who are they? What is their financial status? Will they be willing to pay if a microgrid system is deployed in their community? What's their opinion about the system?

ii. Technical criteria

Users' energy demand profiles (C21): This aspect has to do with the load demand profile of the users that a microgrid design is based upon. Different people have different energy consumption profile and time of operation of appliances. There is a tendency for users to climb the "energy ladder", which can affect technical sustainability.

Types of load/appliance operated (C22): This aspect is important because the use of inefficient appliances during post-installation stage can jeopardize the technical sustainability of the system. The appliances that a microgrid system caters for should be established ab initio and this must be understood and maintained.

Ease of system operation and maintenance (C23): Deploying microgrid systems with complex operation and maintenance will have issues during the systems' useful life. The community may not be able to help the situation with a complex system. This criterion is an important factor, and it is reasonable to deploy systems that are not complex but easy to maintain.

iii. Economic criteria

Economic/productive use of energy (C31): A localized energy system needs to go beyond a household level. The system should be built around a productive use that has an economic value. This approach will aid the economic sustainability of the microgrid system.

Revenue for a system's operation and maintenance (C32): This criterion is a critical factor because funds are needed for long-term operation and maintenance of the microgrid system. Will the users be willing to pay for the energy services?

Funding mechanism for the deployment/ROI (C33): Renewable energy systems, for instance, are associated with high initial capital cost. Who will be responsible for this? Is it the community? Or the community having part-funding and then getting support from the government? Or an independent energy producer?

iv. Environmental criteria

Environmental impact of a system (C41): Achieving environmental sustainability is an important part of the Sustainable Development Goals (SDGs). The kind of energy solutions is determined by the situation of the community. It may be 100% clean energy in a community, while it may be a hybrid of clean energy and conventional fossil fuel-based systems in another community.

Availability of resources (C42): The microgrid solutions are determined by the environmental factors and the availability of resources in a community. It will be absurd to develop an energy system for a community, where there is no assurance of continuous or sustainable resources.

End-of-life management (C43): This criterion is important as it considers how to handle the components of the microgrid system, such as batteries and solar PV modules after they are commissioned (lifespan). It is necessary to consider this aspect because of the toxic materials that batteries contain and mercury in the FLs (compact fluorescent tubes). This criterion is an important environmental sustainability factor.

v. Policy criteria

Favourable government policy/support (C51): A localized energy system is supposed to thrive under a favourable government support/policy. This aspect affects the other perspectives (S-T-E-E). Is there any government programme that supports the deployment of the system?

Financial incentive (C52): The presence of financial incentives for developing/deploying localized energy system is one of the factors that could ensure the long-term viability of the system. Is there any incentive for deploying the proposed system?

Institutional framework to drive the system (C53): This framework is important because it harmonizes the communities/users, government, the energy provider, and other relevant stakeholders in a manner that can help achieve sustainable energy supply.

TABLE I: Linguistic terms and fuzzy numbers for solar PV deployment sustainability

Linguistic terms for criteria evaluation	Linguistic terms for criteria importance	Fuzzy numbers
Very low (VL)	Very unimportant	(0.0, 0.1, 0.2, 0.3)
Low (L)	Unimportant	(0.2, 0.3, 0.4, 0.5)
Moderate (M)	Indecisive	(0.4, 0.5, 0.6, 0.7)
High (H)	Important	(0.6, 0.7, 0.8, 0.9)
Very high (VH)	Very important	(0.8, 0.9, 1.0, 1.0)

TABLE II: Aggregated fuzzy numbers for the STEEP factors

	S1	S2	S3	S4
C11	0.6,0.7,0.8,0.9	0.6,0.8,0.9,1	0.4,0.7,0.8,1	0.6,0.7,0.8,0.9
C12	0.8,0.9,1,1	0.6,0.8,0.9,1	0.4,0.7,0.8,1	0.8,0.9,1,1
C13	0.8,0.9,1,1	0.6,0.8,0.9,1	0.6,0.8,0.9,1	0.4,0.6,0.7,0.9
C21	0.4,0.5,0.6,0.7	0.4,0.8,0.9,1	0.2,0.6,0.7,1	0.4,0.7,0.8,1
C22	0.8,0.9,1,1	0.6,0.8,0.9,1	0.4,0.7,0.8,1	0.2,0.5,0.6,0.9
C23	0.2,0.3,0.4,0.5	0.6,0.8,0.9,1	0.2,0.7,0.8,1	0.4,0.7,0.8,1
C31	0.8,0.9,1,1	0.4,0.7,0.8,1	0.6,0.9,1,1	0.2,0.5,0.6,0.9
C32	0,0.1,0.2,0.3	0.4,0.6,0.7,0.9	0.4,0.7,0.8,1	0.4,0.7,0.8,1
C33	0,0.1,0.2,0.3	0.6,0.8,0.9,1	0.2,0.6,0.7,1	0.4,0.6,0.7,0.9
C41	0.4,0.5,0.6,0.6	0.4,0.6,0.7,0.9	0.4,0.7,0.8,1	0,0.5,0.6,1
C42	0.8,0.9,1,1	0.6,0.8,0.9,1	0.2,0.7,0.8,1	0.2,0.5,0.6,0.9
C43	0.2,0.3,0.4,0.5	0.4,0.7,0.8,1	0.2,0.6,0.7,1	0.6,0.8,0.9,1
C51	0,0.1,0.2,0.3	0.6,0.8,0.9,1	0.4,0.7,0.8,1	0.4,0.6,0.7,0.9
C52	0,0.1,0.2,0.3	0.6,0.8,0.9,1	0.2,0.6,0.7,1	0.4,0.7,0.8,1
C53	0.2,0.3,0.4,0.5	0.6,0.8,0.9,1	0.4,0.7,0.8,1	0.6,0.8,0.9,1

N.B: S1, S2, S3 and S4 are considered communities

TABLE III: Aggregated crisp values for STEEP factors

		Weight	S1	S2	S3	S4
S	C11	0.168	0.75	0.83	0.72	0.75
	C12	0.392	0.92	0.81	0.72	0.92
	C13	0.440	0.92	0.83	0.82	0.65
T	C21	0.152	0.55	0.74	0.62	0.72
	C22	0.509	0.92	0.81	0.72	0.55
	C23	0.339	0.35	0.81	0.66	0.72
E	C31	0.356	0.92	0.72	0.86	0.55
	C32	0.315	0.15	0.66	0.72	0.72
	C33	0.329	0.15	0.83	0.62	0.65
E	C41	0.161	0.52	0.66	0.72	0.52
	C42	0.399	0.92	0.83	0.66	0.55
	C43	0.440	0.35	0.72	0.62	0.82
P	C51	0.511	0.15	0.83	0.72	0.65
	C52	0.228	0.15	0.81	0.62	0.72
	C53	0.261	0.35	0.83	0.72	0.82

TABLE IV: Aggregated fuzzy numbers for the STEEP criteria importance

	S1	S2	S3	S4
S	0.6,0.7,0.8, 0.9	0.8,0.9,1,1	0.0,0.6,0.7,1	0.4,0.7,0.8,1
T	0.8,0.9,1,1	0.8,0.9,1,1	0.6,0.8,0.9,1	0.8,0.9,1,1
E	0.8,0.9,1,1	0.8,0.9,1,1	0.6,0.9,1,1	0.6,0.8,0.9,1
E	0.8,0.9,1,1	0.6,0.8,0.9,1	0.6,0.9,1,1	0.8,0.9,1,1
P	0.8,0.9,1,1	0.6,0.8,0.9,1	0.2,0.6,0.7,0.9	0.6,0.8,0.9,1

TABLE V: STEEP criteria importance using CRITIC method

	S	T	E	E	P
STD	0.151	0.251	0.249	0.250	0.180
H_j	0.143	0.068	0.061	0.099	0.075
Wj	0.321	0.152	0.137	0.222	0.168

TABLE VI: GRA values and ranks for solar PV deployment sustainability

	S1	S2	S3	S4
S	0.702 (4)	0.856 (3)	0.973 (1)	0.932(2)
T	0.759(4)	0.956(1)	0.940(2)	0.923(3)
E	0.801(4)	0.938(1)	0.906(3)	0.918(2)
E	0.807(4)	0.924(2)	0.970 (1)	0.879(3)
P	0.901(4)	0.984(1)	0.928(3)	0.950 (2)

Eq. 6 was used to normalize the data in TABLE III. After the normalization process, Eqs. 6 to 10 were used to determine STEEP requirement importance (TABLE VII).

TABLE VII: Normalized GRA values for solar PV deployment sustainability

	S1	S2	S3	S4
S	0.402	0.491	0.558	0.535
T	0.423	0.532	0.523	0.514
E	0.449	0.525	0.508	0.514
E	0.450	0.515	0.541	0.490
P	0.479	0.523	0.493	0.505

PROMETHEE method was used to combine the factors weights and their normalized values - TABLE VIII contains the generated results.

TABLE VIII: $\pi(a_i, a_j)$ values for the site selection problem

	S1	S2	S3	S4
S1	--	0	0	0
S2	0.309	--	0.035	0.052
S3	0.384	0.110	--	0.081
S4	0.070	0.056	0.012	--

TABLE IX: PROMETHEE outputs and ranks for the site selection problem

	S1	S2	S3	S4
ϕ^{+}	0.000 (4)	0.396 (2)	0.575 (1)	0.138 (3)
ϕ^{-}	0.763 (4)	0.166 (3)	0.047 (1)	0.133 (2)
ϕ	-0.763 (4)	0.230 (2)	0.528 (1)	0.005 (3)

V. DISCUSSION OF RESULTS

In terms of the social criterion, the most important factor is C13, while C11 is the least important social factor (TABLE III). On the other hand, the most important technical factor is C22, while C21 is the least important technical factor. In addition, TABLE III results show that C31 and C32 are the most and least important economic factor is C32, respectively. Furthermore, the results in TABLE III showed that the most important environmental factor is C43, while the least important factor is C41. Finally, the most important policy factor is C51, while the least important policy factor is C52 (TABLE III).

From Table IX, the PROMETHEE I and II methods generated the same ranking order for the solar PV microgrid sites: S3 → S2→S4 → S1. The results in TABLE IX shows that S1 is the least suitable site for the project. Based on the generated results, S2 is the most preferred site in terms of technical, economic and policy criteria, while S3 is the most suitable site in terms of social and economic criteria. And S4 site is ranked as the second most suitable site in terms of social, economic and policy criteria.

VI. CONCLUSIONS

This study has used a fuzzy CRITIC-PROMETHEE approach to evaluate solar PV microgrid deployment sustainability in rural areas. While the study used CRITIC method to determine STEEP requirements, PROMETHEE was used to generate sustainability indices for potential solar PV microgrid deployment in the considered rural areas. On the other hand, the latter method was able to generate sustainability indices for the four local communities. The most suitable site for the microgrid deployment from the two methods was the same. This paper posits that certain criteria need to be met for PV sustainability to be achieved in local communities. A natural extension of the proposed approach is to rank productive energy use centres in the identified site for microgrid deployment. In addition to this suggestion, the optimal allocation of solar PV microgrid output for residential and productive use can be determined using non-linear mathematical and simulation models.

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REFERENCES

[1] L. Olatomiwa, "Optimal configuration assessments of hybrid renewable power supply for rural healthcare facilities," *Energy Reports*, vol. 2, pp. 141–146, 2016.

[2] D. E. Ighravwe, B. OM, O. S. Adedoja, and T. E. Okharedia, "Evaluation and Selection of Hybrid Renewable Energy Systems for Healthcare Centres In Rural Areas: A Techno-economic Approach," in *2018 IEEE 7th International Conference on Adaptive Science & Technology (ICAST)*, 2018, pp. 1–7.

[3] O. Babatunde, D. Akinyele, T. Akinbulire, and P. Oluseyi, "Evaluation of a grid-independent solar photovoltaic system for primary health centres (PHCs) in developing countries," *Renew. Energy Focus*, vol. 24, pp. 16–27, 2018.

[4] T. O. Akinbulire, P. O. Oluseyi, and O. M. Babatunde, "Techno-economic and environmental evaluation of demand side management techniques for rural electrification in Ibadan, Nigeria," *Int. J. Energy Environ. Eng.*, vol. 5, no. 4, 2014.

[5] O. O. Ajayi, O. D. Ohijeagbon, M. C. Agarana, A. Attabo, and M. Ogbonaya, "Feasibility and Econometrics Assessment of Standalone and Hybrid RE Facilities for Rural Community Utilization and Embedded Generation in North-West, Nigeria," 2017.

[6] M. S. Adaramola, S. S. Paul, and O. M. Oyewola, "Assessment of decentralized hybrid PV solar-diesel power system for applications in Northern part of Nigeria," *Energy Sustain. Dev.*, vol. 19, pp. 72–82, 2014.

[7] C. O. Okoye and B. C. Oranekwu-Okoye, "Economic feasibility of solar PV system for rural electrification in Sub-Sahara Africa," *Renew. Sustain. Energy Rev.*, 2017.

[8] D. Akinyele, J. Belikov, and Y. Levron, "Challenges of Microgrids in Remote Communities: A STEEP Model Application," *Energies*, vol. 11, no. 2, p. 432, 2018.

[9] O. M. Babatunde, J. L. Munda, and Y. Hamam, "Hybrid energy system for low-income households," in *AFRICON, 2017 IEEE*, 2017, pp. 1038–1042.

[10] O. M. Babatunde, P. O. Oluseyi, T. O. Akinbulire, H. I. Denwigwe, and T. J. Akin-Adeniyi, "The Role of Demand-Side Management in Carbon Footprint Reduction in Modern Energy Services for Rural Health Clinics," in *Environmental Carbon Footprints*, Elsevier, 2018, pp. 317–363.

[11] E. O. Diemuodeke and C. O. C. Oko, "Optimum configuration and design of a photovoltaic--diesel--battery hybrid energy system for a facility in University of Port Harcourt, Nigeria," *Int. J. Ambient Energy*, vol. 37, no. 1, pp. 2–9, 2016.

[12] M. S. Adaramola, "Viability of grid-connected solar PV energy system in Jos, Nigeria," *Int. J. Electr. Power Energy Syst.*, vol. 61, pp. 64–69, 2014.

[13] O. D. Ohijeagbon and O. O. Ajayi, "Solar regime and LVOE of PV embedded generation systems in Nigeria," *Renew. Energy*, vol. 78, pp. 226–235, 2015.

[14] L. Olatomiwa, S. Mekhilef, A. S. N. Huda, and O. S. Ohunakin, "Economic evaluation of hybrid energy systems for rural electrification in six geo-political zones of Nigeria," *Renew. Energy*, vol. 83, pp. 435–446, 2015.

[15] T. R. Ayodele, A. S. O. Ogunjuyigbe, and T. O. Amusan, "Techno-economic analysis of utilizing wind energy for water pumping in some selected communities of Oyo State, Nigeria," *Renew. Sustain. Energy Rev.*, vol. 91, pp. 335–343, 2018.

[16] D. E. Ighravwe and D. E. Babatunde, "Development of a framework for the selection of a project site for a landfill gas plant using techno-economic parameters," *Environ. Heal. Eng. Manag. Journal,* vol. in press, 2019.

[17] Y. Kuo, T. Yang, and G.W. Huang, "The use of a grey-based Taguchi method for optimizing multi-response simulation problems", *Engineering Optimization,* vol. 40, no.6, pp. 517-28, 2008.

[18] D. O. Akinyele *et al.*, "Possibility of solar thermal power generation technologies in Nigeria: Challenges and policy directions," *Renew. Energy Focus*, vol. In press, 2019.