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Optimizing Site Selection for Interconnected Mini-Grids: Expert-Driven Procedure for Criteria Weight Determination

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Abstract

Multiple operational criteria are involved in the selection process of a viable site for an interconnected mini-grid (IMG) project. A challenge at the heart of the process revolves around determining the relative importance or weight or significance of these criteria in the decision-making process. The solution lies in leveraging expert judgment mining, a method that harnesses the knowledge and insights of experts in the field to establish a systematic and robust procedure for assigning relative weights to these criteria. This study aimed to develop an appropriate procedure for determining the relative weights of identified criteria for site selection using experts' judgment mining. These criteria were carefully chosen to characterize potential sites for IMG projects based on both the characteristics of the proposed sites and the lifetime value of the on-grid customers associated with these sites. The criteria pairwise comparison questionnaire was developed for stakeholders in the electricity supply industry, and experts in renewable energy projects to express their opinions on the relativeness of the criteria. Analytic Hierarchy Process (AHP), integrated with the interval type-2 fuzzy method was used to transform experts' opinions into criteria and sub-criteria weights, while the reliability of the experts' opinions was determined using the AHP Consistency Ratio (ACR) test. The ACR reliability threshold infers that the experts' opinions were consistent and the criteria weights obtained will be suitable in the context of multi-criteria decision-making for renewable energy projects.

Keywords: Interconnected Mini-Grid, Site Selection Criteria, Lifetime Value, Criteria Pairwise Comparison, Analytic Hierarchy Process

Introduction

There is an apparent need for continuous improvement in power generation and distribution to bridge the electricity supply gap in underdeveloped and developing countries. The unreliable and epileptic electricity supply from the national grid is one of the main reasons for the prevalent cases of service outages and poor customer experiences (Aliyu *et al.,* 2013). The inadequate generation of electricity created a clear supply gap amidst frequent outages. This gap necessitated the need to augment supply via Mini-grid. Sambo (2008) suggested the utilization of all energy resources in Nigeria as well as participation from private and foreign investors to close the gap in supply. Arowolo *et al.,* (2019) suggested using a mini-grid, similar to what other developing countries like Mozambique and India with difficulties similar to Nigeria have done (Katre *et al.,* 2019; Uamusse *et al.,* 2019).

The diversification and adoption of new technologies, such as mini-grid, to generate electricity is required to combat the threat of global warming and achieve sustainable development through energy security. However, one of the key issues facing mini-grid investors is a quest for a working tool for identifying and selecting an optimal location with a quick return on investment. Other offshoot challenges from this include (i) lack of a scientific-based decision support system for IMG site selection (ii) non-availability of verifiable criteria weights for known selection criteria and sub-criteria for decision-making (iii) unavailability of customer and site historical data for decision-making. The sustainability of the mini-grid system depends on the careful management of these issues. To ensure sustainability, the deployment and operation of mini-grids would need to adopt a decision framework, use a tested business model, be inclusive of the community, and engage with other stakeholders (Graber, 2019).

In recent years, mini-grid deployment in Nigeria has started moving away from grant funding to commercial investment (NESP, 2017). This shift requires investors to make sound techno-economic decisions in a way that provides value for all stakeholders including the customers. One such decision revolves around the selection of a site that will optimize both the economic and technical performances of a mini-grid system (Akinlabi and Oladokun, 2020b). This is central to the sustainability of mini-grid adoption in Nigeria and other developing countries. An interconnected mini-grid (IMG) is an autonomous electricity production and distribution network that is set up inside a prevailing grid and then linked to the grid as a portion of the approved distribution network. (Akinlabi and Oladokun, 2020a). IMG is a viable option for bridging the electricity supply gap in many developing countries.

Selecting the best project location is a crucial phase that will have a big impact on investment choices across the whole life cycle of mini-grid projects (Yunna et al. 2018). However, a challenge arises when selecting an appropriate site for an interconnected mini-grid (IMG) project. This challenge stems from the necessity to evaluate potential sites based on various operational criteria, which are derived from site characteristics and the lifetime value of customers associated with the sites. To address this issue, this study focuses on establishing a systematic procedure for determining the relative importance of these criteria in the site selection process, leveraging expert judgment mining.

CRITERIA FOR IMG SITE SELECTION

The selection of criteria for interconnected mini-grid cannot be done without the consideration of influencing factors that speak to the lifetime of the customers on the existing grid utilization and location of the site. Some of the existing literature, Herrera-Seara *et al.,* (2010); Gastli, and Charabi, (2011); Khan and Rathi, (2014); Ayodele *et al.,* (2018) and Ohunakin and Saracoglu, (2018) adopted Geographical Information System (GIS) with various multi-criteria decision-making methods, mostly AHP in making site selection decision (Saracoglu *et al.,* 2015). However, very few have considered the influence of physical site characteristics and customer lifetime value on the mini grid's site selection. This study proposes Revenue and Cost of generating revenue as the components of customer lifetime. Also, it breaks down the site characteristics into Customer classifications, Commercial potential, Energy demand, Aggregate Technical, Commercial and Collection Losses (ATC&C). The site characteristics criteria have been further broken down into sub-criteria like customer population, customer type (residential, commercial, public sector) revenue billed, cash collection, collection efficiency, and infrastructural investment required. Other sub-criteria are average daily consumption, metering rate, supply availability hours, technical commercial and collection losses. The criteria relationship and definitions are in Table 1.

METHODOLOGY FOR CRITERIA WEIGHT DETERMINATION

The criteria weight determination for this study adopted the Analytic Hierarchy Process (AHP) technique (Akinlabi and Oladokun, 2020b). AHP is the most frequently used, robust multi-criteria decision-making technique for determining criteria weights. This study's conceptual framework is based on AHP's structured technique for organizing and analyzing complex decisions such as the selection of an optimal site for an interconnected mini-grid, by ranking the alternative sites ($k_1, k_2, k_3, \ldots, k_q$) with consideration of criteria and sub-criteria weights. The Interval Type-2 Fuzzy set (IT2FS) is integrated with AHP to obtain criteria weights through pairwise comparisons of criteria by experts (Saaty, 2008; Hofer *et al.,*2016). The judgments of the experts are associated with uncertainties and risks, and this is controlled by IT2FS because of its capability to handle many uncertainties and produce robust and accurate results (Celik *et al.,* 2015). Several investigations have used Saaty's crisp values (1, 3, 5, 7, 9) to represent linguistic judgments for criteria weights calculation. The fuzzy set is integrated with the AHP to characterize linguistic judgments in calculating the criteria weight. If the consistency ratio is <10%, the criteria weights obtained are good. The flowchart in Figure 1 is implemented in the computer interface using Python software programming to generate criteria weights.

TABLE 1: CRITERIA RELATIONSHIP AND DEFINITIONS

MAIN CRITERIA	SUB-CRITERIA	SUB-SUB-CRITERIA	DEFINITIONS
CUSTOMER LIFETIME VALUE	Revenue	Revenue	Income earned from customers in period 't'
	Cost of generating revenue	Cost of generating revenue	Costs associated with obtaining consumer revenue
SITE CHARACTERISTICS VALUE	Customer Classification	Customer Population	Total number of buildings/structures connected to the grid supply
		Residential Customer	The customer that uses grid supply for residential purposes only
		Commercial Customer	The customer that uses grid supply for commercial activities only
		Public Sector Customer	Government or public customers connected to the grid supply for their establishment
	Commercial Potential	Revenue Billed	The total amount billed and invoiced to the customer in a period
		Cash Collection	Amount of cash collected/energy vended by the customer in a period
		Collection Efficiency	Percentage cash collection against the revenue billed

		Infrastructural Investment Required	The amount required for infrastructural investment before Mini-grid take-off
	Energy Demand	Peak Power Demand	Total energy demand by customers in kilowatt (kW)
		Average Daily Consumption	Total energy consumed by the customer in kilowatt-hour (kWh) per day
		Metering Rate	The percentage of metered customers in a given site
		Supply Availability Hours	Number of hours of supply per day (hrs./day)
	Average Technical, Commercial, and Collection Losses	Technical loss	Loss due to technical network infrastructural deficiencies from transmission through distribution, down to the customers.
		Commercial loss	Loss due to commercial inefficiencies such as energy theft, non-capturing of the customer for billing, under-billing, and poor energy accounting.

		Collection loss	Loss due to inability to collect total revenue billed from the customer as and when due leading to customer outstanding debt

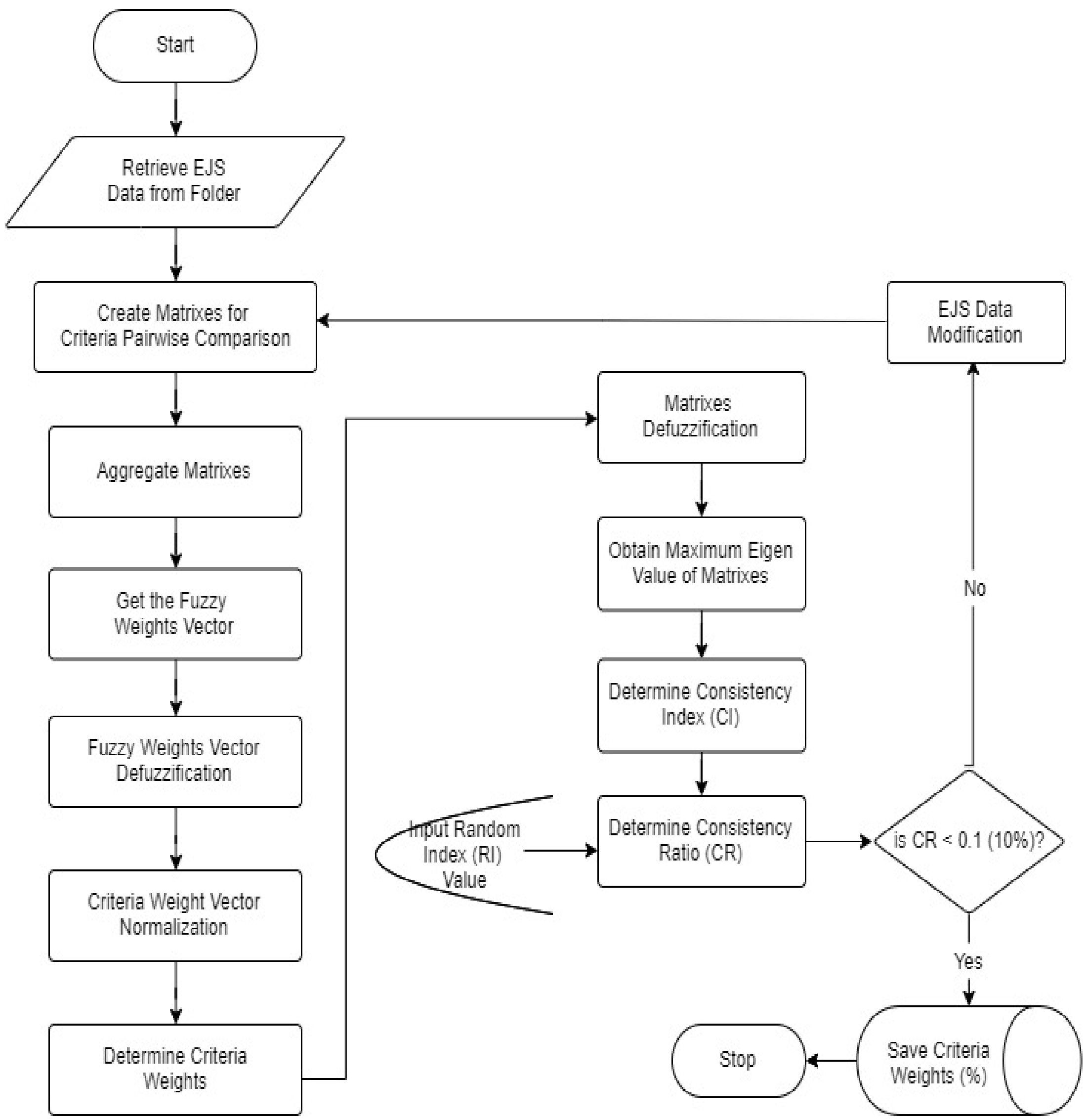

FIGURE 1: CRITERIA WEIGHTS GENERATION Source: Ayodele *et al.,* (2018).

EXPERTS SELECTION

This study adapted Jamal *et al.,* (2018) method of determining the correct sample size by utilizing qualtrics.com online sample size calculator. In other to get a robust opinion, the population size of 25 experts selected comprises mini-grid developers and investors, academics researchers, policymakers, industry experts, and consultants. The sample confidence level is 95%, an error margin of 5%, and an ideal sample size of 24. Table 2 shows detailed information about the experts' decision-makers for this study and their areas of specialty. The experts were contacted via phone calls, emails, and chats to inform them about the aim of the study. The electronic questionnaire was deployed with Google Forms and the survey link was sent to experts' email addresses. The responses for the survey were downloaded in an Excel .csv document. The responses were converted from words into linguistic short codes and then uploaded as inputs for the Python-coded programming model interval type-2 fuzzy developed for the model of the study.

SOLUTION PROCEDURE FOR OBTAINING CRITERIA WEIGHTS

The steps taken to obtain relative weights for the criteria, sub-criteria and sub-sub-criteria are as follows:

STEP 1: Get the Expert Judgment folders from the Expert Judgments Directory
STEP 2: Aggregate Experts' Judgments using Geometric Mean Method
STEP 3: Test for Consistency of Aggregated Comparison Matrices
STEP 3.1: Difuzzification of Aggregated Comparison Matrices
STEP 3.2: Normalization of Diffuzzified Aggregated Comparison Matrices
STEP 3.3: Calculate Geometric Mean
STEP 3.4: Normalizing the Geometric Mean Vector
STEP 3.5: Getting the maximum Eigen Value
STEP 3.6: Calculate the consistency ratio
STEP 4: Calculate the fuzzy weights of the criteria comparison matrices
STEP 5: Calculate Fuzzy Weights of Criteria
STEP 5.1: Addition of geometric mean rows
STEP 5.2: Inverse of the sum of the geometric mean rows
STEP 5.3: Multiplication of the geometric mean vector and the inverse of the sum of the geometric mean rows

STEP 6: Diffuzification of the fuzzy weights

STEP 7: Normalization of Crisps' Weights of Criteria

STEP 8: List all Criteria Weights

STEP 9: Stop

TABLE 2: EXPERTS' DECISION-MAKERS

S/N	Industry	Educational Qualification	Years of Experience	Career Details	Area of Specialties
Expert 1	Mini-grid Investors / Developers	PhD	22	top executive of a mini-grid company	Off-grid minigrid developer and operators
Expert 2		MSc	24	operator of mini-grid company	Mini-grid business operations, solar energy expert
Expert 3		PhD	18	solar minigrid investor and developer	solar mini-grid investment and project developer
Expert 4		MSc	15	top manager in solar energy solution	renewable energy equipment sales, installation and support
Expert 5		MBA	18	founder of renewable energy company	solar energy deployment, minigrid developer
Expert 6		MSc, PGD	25	investor in renewable energy company	Smart grid and micro-grid developer
Expert 7		MBA	19	top manager in renewable energy company	mini-grid operations and maintenance
Expert 8	Academics /University Lecturers / Researchers	Prof.	25	Professor of Electrical and Electronics Engr.	Alternative power generation, renewable energy research
Expert 9		Prof.	23	Professor of Mechanical Engineering	Renewable energy, energy and environment research
Expert 10		Prof.	26	Professor of Economics, Law and Management	Energy economics, market design and energy policy
Expert 11		Ass. Prof.	23	Ass. Prof. of Electrical Engineering	Power, energy, machine and drive research
Expert 12		PhD	18	Senior lecturer in Mechanical Engineering	Energy conservation and renewable options
Expert 13		PhD	20	Senior lecturer in Electrical and Electronics Engr.	Electrical power distribution, alternative power generation
Expert 14		PhD	17	Senior lecturer in Electrical Engineering	New technologies for power generation and storage system
Expert 15	Policy Makers	MSc	25	top manager with NERC	energy market rules and regulations
Expert 16		PhD	21	Deputy General Manager with NERC	technical services, legal and enforcement
Expert 17	Electricity Distributors	MSc	19	manager in electricity distribution company	Embeded generation and franchisement
Expert 18		MSc, MBA	24	top manager in electricity distribution company	Energy scorecard and performance management
Expert 19		MSc, PGD	20	manager in distribution substation operations	Energy dispatch, management and operations
Expert 20		MSc	27	business manager in distribution company	Energy sales, technical support and customer service
Expert 21	Consultants	PhD	24	senior advisor in a consultancy firm	advisor to NESI market operators (DISCOs, GENCOs etc)
Expert 22		PhD	19	senior advisor in a consultancy firm	advisor to NESI market operators (DISCOs, GENCOs etc)
Expert 23		PhD	15	consultant in energy management	energy investment advisor
Expert 24		MSc, PGD	17	senior consultant in energy market	energy market and rates advisor

DESCRIPTIVE AND MATHEMATICAL MODEL

The study aims to develop a model for determining appropriate procedures for generating the relative weights of identified criteria as a decision support system for site selection. A conceptual model where the two main criteria, customer lifetime value and site characteristics value are denoted by X and Y. Some sets of sub-criteria further characterize the two main criteria as listed and defined in Table 1. The two criteria are defined such that for a given period i, the customer lifetime value (X) is a composite of two sub-criteria, namely revenue (R_t) and cost of generating revenue (C_t). The site characteristics value (Y) is a composite of four sub-criteria, namely customer classification, commercial potential, energy demand, average technical, commercial, and collection losses (ATC&C). The Analytic Hierarchy Process Framework in Figure 2 describe the hierarchical relation and flow of data for the sub-sub criteria and sub-criteria concerning alternative sites, customer lifetime value and site characteristics value. The model's basic indexes, notations and definitions are listed in Table 3.

Table 3: INDEXES, NOTATIONS AND DEFINITIONS

Indexes	
i	Index identifying customer, with i = 1, 2, …, N; where N is the number of customers in site k under consideration.
k	Index identifying site, with k = 1, 2, …, K; where K is the number of sites under consideration.
q	Index identifying criteria, with q = 1, 2, …, Q; where Q is the number of criteria under consideration.
t	Index identifying period, with t = 1, 2,…, T; where T is the number of periods in the planning horizon of customer transactions cash flow.
v	Index identifying criteria value, with v = 1, 2, …, V; where V is the number of criteria values under consideration.

Notations and their definitions

Notations		**Unit**
d	Assumed discount	%
r	Interest rate to finance assets (WACC)	%
w	Weighted value of criteria	
wC_t	Weighted cost of generating revenue in period t	₦
wC_{tk}	Weighted cost of generating revenue in period t for site k	₦
wR_{it}	Weighted revenue obtained from customer i in period t	₦
wR_{itk}	Weighted revenue obtained from the customer i in period t for site k	₦
wX	Weighted customer lifetime value	
wX_k	Weighted customer lifetime value of site k	
wX_{itk}	Weighted customer lifetime value for customer i in period t for site k	
wY	Weighted site characteristics value	
wY_k	Weighted site characteristics value of site k	

A_v	Actual value of criteria
A_{vq}	Actual value of criteria q

Notations and their definitions

Notations		Unit
C_t	Cost of generating revenue in period t	₦
F^S	Feeder's score in model ranking	%
$F^S{}_Z$	Feeder's score in site suitability ranking	%
$F^S{}_{NPV}$	Feeder's score in NPV ranking	%
$F^S{}_{IBSS}$	Feeder's score in IBSS ranking	%
N_v	Normalised value of criteria	
N_{vq}	Normalised value of criteria q	
R_d	Debt cost (yield to maturity on existing debt)	%
R_e	Equity cost (requires rate of return)	%
R_{it}	Revenue from the customer i in period t	₦
R_{itk}	Revenue obtained from the customer i in period t for site k	₦
S_{max}	Maximum score in IBSS ranking	
S_{min}	Minimum score in IBSS ranking	
w_{q}	Weighted value of criteria q	
Z_k	Site suitability value for site k	
Z_{max}	Maximum site suitability value	
Z_{min}	Minimum site suitability value	
D	Market value of debt	₦
E	Market value of equity (market cap)	₦
V	Total value of capital (equity plus debt)	₦
X	Customer lifetime value	
Y	Site characteristics value	
Z	Site suitability value	
Tr	Tax rate	%
NPV	Net present value	₦
D/V	Percentage debt (in capital)	%
E/V	Percentage equity (in capital)	%

CUSTOMER LIFETIME VALUE MODEL

As a theoretical basis for the proposed customer lifetime value, the study adapts Sohrabi and Khanlari (2007) basic customer lifetime value model, where X is defined as the total profit earned from the customer over the transactions lifetime, after the removal of the total cost of generating the profit, considering time value of money. Using notations in Table 3, Customer Lifetime Value X is written as

$$X = \sum_{t=1}^{T} \frac{(R_t - C_t)}{(1+d)^{t-0.5}} \qquad 3.1$$

(Sohrabi and Khanlari, 2007)

WEIGHTED CUSTOMER LIFETIME VALUE

This study adapts equation 3.1 by introducing the weighted value of revenue wR_t and cost of generating revenue wC_t. The model sums up all customers' lifetime value to derive the weighted customer lifetime value wX. Hence, equation 3.1 is modified to obtain expression 3.2. where N and T are the number of customers and planning periods respectively.

$$wX = \sum_{i=1}^{N} \sum_{t=1}^{T} \frac{(wR_{it} - wC_t)}{(1+d)^{t-0.5}} \qquad 3.2$$

The weighted customer lifetime value wX_k for all customers with respect to a specific site/feeder k can be deduced from equation 3.2 as:

$$w\mathrm{X}_k = \sum_{i=1}^{N} \sum_{t=1}^{T} \frac{(wR_{itk} - wC_{tk})}{(1+d)^{t-0.5}} \qquad 3.3$$

The weighted customer lifetime value of site k, expression 3.4, is the sum of revenue for all customers in site k, less the cost of generating the revenue.

SITE CHARACTERISTICS VALUE MODEL

In developing the function for Site characteristics value, there are 4 sub-criteria and 15 sub-sub criteria listed for each site with individual values and different unit of measurement. For each candidate site, an actual value A_v for each criterion, sub-criteria and sub-sub-criteria is obtained. The values are added over all Q criteria to obtain the total actual value of criteria as shown in equation 3.4.

$$\sum A_{vq} = A_{v\,q^1} + A_{v\,q^2} + A_{v\,q^3} + A_{v\,q^4} + \ldots . A_{v\,q^Q} \qquad 3.4$$

However, since there are different units of measurement of the site characteristics criteria into a compatible unit, there is need for value standardization and normalization (Tercan *et al.,* 2020). The study employed Chakraborty and Yeh's (2007) Linear Scale transformation (sum method) for the normalization of the different criteria values for dimensional consistency. The normalized value N_{vq} of criterion q is expressed as:

$$N_{vq} = \frac{A_{vq}}{\sum_{k=1}^{K} A_{vq}} \qquad 3.5$$

where k represents individual site.

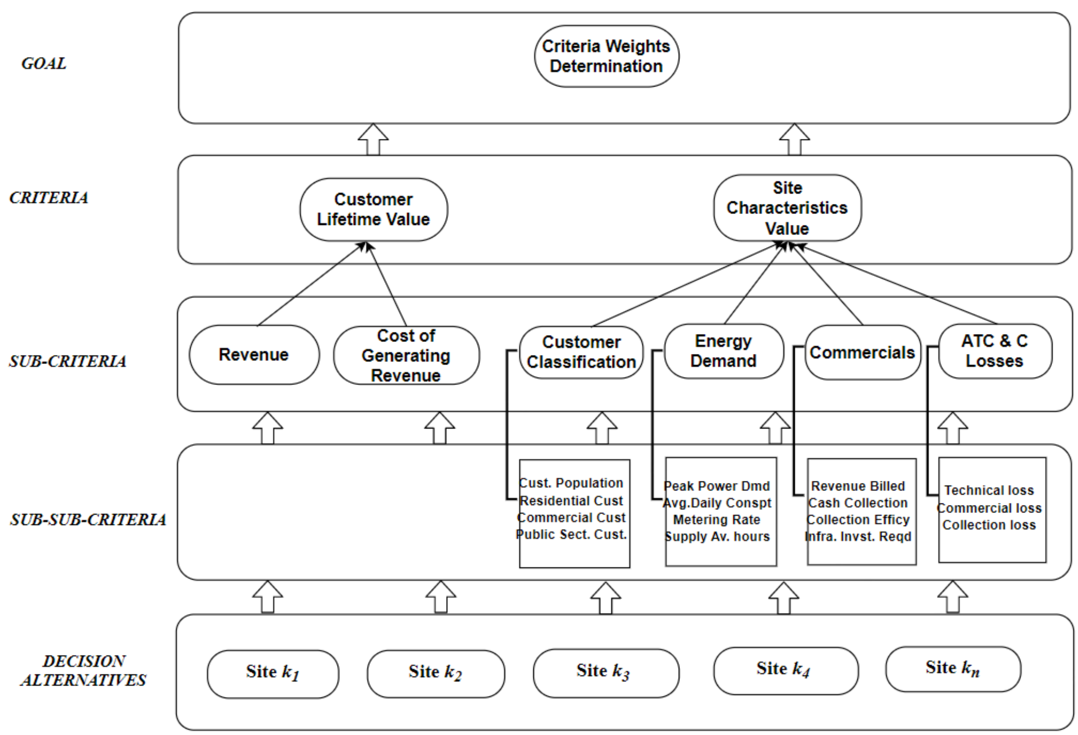

FIGURE 2: ANALYTIC HIERARCHY PROCESS FRAMEWOR

Therefore, using the simple additive weighting (SAW) method a normalized version of equation 3.4 is defined as site characteristics value Y of criteria q as:

$$Y = N_{v\,q^1} + N_{v\,q^2} + N_{v\,q^3} + N_{v\,q^4} + \ldots . N_{v\,q^Q} \qquad 3.6$$

Summing up all normalized value over all Q criteria, the expression becomes:

$$Y = \sum_{q=1}^{Q} N_{v\,q} \qquad 3.7$$

The function enhances the site characteristics value Y by integrating the criteria weights value of each criterion. These weights can be derived from expert judgment using appropriate method. The Interval Type 2-Fuzzy (IT2-F) AHP is adopted for obtaining these weights. This would give us the resulting function of the product of criteria weights value and the normalized value of criteria.

$$wY = w_{q^1} N_{v\,q^1} + w_{q^2} N_{v\,q^2} + w_{q^3} N_{v\,q^3} + w_{q^4} N_{v\,q^4} + \ldots . w_{q^Q} N_{v\,q^Q} \qquad 3.8$$

Summing up all the product of criteria weights value and the normalized value of criteria, the expression becomes:

$$w\mathrm{Y} = \sum_{q=1}^{Q} w_q N_{vq} \qquad 3.9$$

Thus, the weighted site characteristics value for all criteria of site k (wY_k) will be

$$wY_k = \sum_{q=1}^{Q} \left(w_q N_{vqk} \right) \qquad 3.10$$

DISCUSSION OF RESULTS

Experts' Opinion Results of Criteria Pairwise Comparison

The criteria pairwise comparison results allocate specific weight to each criterion and the sub-criteria. The criteria are grouped into six categories and the weight assigned for each criteria group is in Table 3 while the weights for the criteria and their sub-criteria are in Table 4.

BASELINE DATA COLLECTION

The customer and site characteristic data used for this study was obtained from a Southwest Nigeria-based electricity distribution company with a customer population of over two million. The 4-year data spanning 2017 to 2020 comprises customer population, customer classification (residential, commercial, public), peak power demand, average daily consumption, metering rate, supply availability hours, revenue billed, cash collection, cost of generating revenue, collection efficiency, infrastructural investment, technical commercial and collection losses.

TABLE 4: CRITERIA GROUP WEIGHTS

SN	Criteria group	Total weight	% weight
1	Site Characteristics	2.88	28.34
2	Customer Classification	2.49	24.51
3	Energy Demand	2.19	21.56
4	Commercial Potential	1.35	13.29
5	ATCC	0.9	8.86
6	Customer Lifetime Value	0.35	3.44

From Table 4, the criteria were categorized into six groups based on their relationship with their total weight and corresponding percentage weights. The breakdown of the criteria weights to the sub-criteria and sub-sub-criteria levels is shown in Table 4. The calculated criteria weights, the normalized weight and their approximate weight (%) are shown in Table 4. The observations made are (i) The customer lifetime value has the lowest percentage (3.4%) in the criteria group weight analysis (ii) From the criteria weights ranking results presented in Table 4, the Top 3 sub-criteria with the highest influence are customer population, peak power demand, and commercial potential with total weights of 37.1% while the least 3 criteria were collection efficiency, public sector customer, and cost of generating revenue with total weights of 1.2% and (iii) It is obvious that customer population, peak power demand, and commercial potential are the most influencer criteria with their weights values.

Similarly, from the Normalized Site Characteristics criteria weights presented in Table 5, the experts' opinions agreed that the criteria weights ranking by calculated and normalized weights identified Customer Population and Peak Power Demand as the two sub-criteria that mostly influence site selection while Collection Efficiency, Cost of Generating Revenue and Public Sector Customer have the least influence on site selection.

TABLE 5: CRITERIA AND SUB-CRITERIA WEIGHTS

SN	Criteria/ Sub-criteria	Sub-Sub-criteria	Calculated weight	Normalized weight	Approximate weight (%)
1	Customer Classification	Customer population	1.37	0.55	10.5
2	Energy Demand	Peak power	1.2	0.55	10.5
3	Commercial Potential	Revenue billed	0.68	0.5	9.5
4	Site Characteristics	Energy demand	0.19	0.42	8
5	Avg. Technical, Commercial and Collection losses	Commercial losses	0.42	0.42	8
6		Technical losses	0.39	0.39	7.4
7	Site Characteristics	Customer classification	1.08	0.38	7.2
8	Customer Classification	Commercial customer	0.88	0.35	6.7
9	Customer Lifetime Value	Revenue	0.33	0.33	6.3
10	Commercial Potential	Cash Collection	0.42	0.31	5.9
11	Energy Demand	Metering rate	0.56	0.26	4.9
12	Site Characteristics	Avg. Technical, Commercial and Collection losses	0.41	0.14	2.7
13	Commercial Potential	Infrastructural Investment	0.17	0.13	2.5
14	Energy Demand	Average daily consumption	0.25	0.11	2.1
15	Customer Classification	Residential customer	0.22	0.09	1.7
16	Avg. Technical, Commercial and Collection losses	Collection losses	0.09	0.09	1.7
17	Energy Demand	Supply availability hours	0.18	0.08	1.5
18	Site Characteristics	Commercial Potential	1.2	0.07	1.3
19	Commercial Potential	Collection Efficiency	0.08	0.06	1.1
20	Customer Lifetime Value	Cost of generating revenue	0.02	0.02	0.4

21	Customer Classification	Public sector customer	0.02	0.01	0.2
TOTAL			**10**	**5**	**100**

CONCLUSION

The criteria and sub-criteria for selecting an interconnected mini-grid site were identified and defined. A carefully chosen set of experts conducted a Criteria Pairwise Comparison (CPC) using an expert judgment survey. A framework for transforming experts' judgment survey responses captured by pairwise comparison matrices, from linguistic variable short-codes to Excel and matrices and criteria weights generated in a multi-criteria decision-making scenario.

The criteria weight generated in this study is recommended for the stakeholders in the electricity supply industry, international development agencies, mini-grid investors and other utility industry participants. The criteria weights determined by this study can be applied for subsequent research work by other researchers without bothering to go through the route of defining each criteria value process again. The derived consistency ratio further strengthened the correctness of these criteria values.

DECLARATIONS

Ethical Approval

Not applicable.

Competing interests

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Authors' contributions

The author, Akinlabi K.A. carried out the conceptualization and drafting of the research work. Oladokun V.O. provided the supervision and guidance for the study and also the editing of the final article. Both authors approved the submitted version.

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Availability of data and materials

The datasets generated and/or analyzed during the current study are not publicly available due to Non-disclosure Agreement with the experts (respondents to criteria pairwise comparison survey) but are available from the corresponding author on reasonable request.

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