Selection of an Electricity Tariff Plan for Mini-Grid Business Models: an Intuitionistic Fuzzy Axiomatic Design Approach

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Abstract

This article proposes a conceptual framework that used mini-grid business models (MBMs) to rank electricity tariff plans. The framework combines intuitionistic fuzzy set (IFS), Criteria Importance Through Inter-criteria Correlation (CRITIC), fuzzy axiomatic design (FAD) and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS). It considered when decision-makers specify or did not specify for MBM's requirements. Also, this article considered uncertainty in decision-makers information. The framework applicability was showed using information obtained from Sub-Sahara Africa. Five decision-makers provided information for the model implementation based on a well-structured questionnaire. The CRITIC method results showed that least and most important MBM are community-based and private MBMs, respectively. The IFS-FAD method identified time-based electricity tariff plan as the best suitable for the case study, while the IFS-TOPSIS method identified flexible best electricity tariff plans for the case study, respectively. However, both methods identified flat-rate as the least suitable plan. The proposed framework will provide mini-grid business owners with relevant information for energy tariff selection.

Keywords Business model · CRITIC · Energy tariff · IFS-FAD · IFS-TOPSIS

Introduction

Mini-grid systems deployment help to improve the standard of living in remote communities without access to electricity. These systems transmit a positive social impact on energy-poverty areas. Besides, they encourage and harmonise local content when adopting renewable energy technologies for a community. Also, these systems improve the viability of a remote community's electrification project. [1]. Based on structures and design, there are different kinds of mini-grid system. The mini-grid structure usually depends on resource availability in a particular environment, site topology, demography of customers, and the existing resident policy framework. Hence, diverse electricity tariff plans are being tested and implemented in mini-grids worldwide.

To be economically viable, A mini-grid project is expected to secure funding for its initial investment, generates revenue for operation and maintenance cost over its lifespan, and generates an appreciable rate of returns on investment. It can achieve this if the scheduled operational plan of the project is flexible enough to accommodate uncertainty - such as governmental changes, ownership changes, and economic variations. Hence, without adequate evaluation of its financial attributes, it will be difficult to evaluate the long-term economic viability of a mini-grid project.

Projected electricity sale is among the key parameters used for mini-grid business investment analysis. Decision-makers often base this investment standing on other economic metrics such as project return, loan return targets and payback period. For a mini-grid business to be financially viable, selected tariff plans should be able to off-set the business's debt and other operational expenses [14]. However, business owners should try as much as possible to balance tariff with their customers' standard of living - neglecting this balance will make customers seek other cheaper means of getting electricity [13]. For example, in Zambia, the Energy Service Company (ESCOs) installed a solar PV system for 400 energy consumers. This project failed because of the high electricity cost. Most entrepreneurs and farmers withdrew because civil

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servants cannot maintain a payment scheme with a regular income [24, 26].

Hence, the design and selection of an electricity tariff plan should be diverse. It will enable business owners to capture the unique characteristic of a mini-grid. Also, the design should fit the economic structure and the financial cash flow of targeted consumers - it will aid mini-grid project sustainability. A mini-grid business financial sustenance depends on the tariff plan used by the operators of the grid to collect revenues. A cost-recovering tariff is often higher in a mini-grid as compared to the central grid tariffs and is likely to scare away customers. Hence, mini-grid operators should place a priority on the tariff plan that will make the electricity price affordable for consumers while ensuring that the business generates adequate revenue to break-even. This consideration will reduce the number of electricity debtors in a community.

Apart from this suggestion, other authors have documented useful insights on micro-grid management [4–9, 20]. For instance, Chauhan et al. [8] developed a novel demand-side management framework. They considered DC micro-grid for building under an autonomous condition. On the other hand, Chauhan et al. [9] analysed similar system using a real-time price-based approach. Ighravwe and Babatunde [20] used a risk-based approach to select renewable energy system for remote communities. Chauhan and Chauhan [6] in another study proposed a procedure coordinated control of a mini-grid system. The proposed algorithm was tested in a grid-connected and islanded mode. The mini-grid was composed of photovoltaic, hybrid vehicle, battery, and utility. The adoption of the photovoltaic, hybrid vehicle and battery is dependent on their feed-in-tariff [6]. Based on our knowledge, no research work has been directed towards the selection of electricity tariff plan for mini-grid business models (MBMs).

This article aims to select suitable electricity tariff plan for MBMs in developing countries. It proposes a combined intuitionistic fuzzy set (IFS), Criteria Importance Through Inter-criteria Correlation (CRITIC), fuzzy axiomatic design (FAD) and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) as a solution method for electricity tariff plan evaluation. Some of the contributions of this article:

- It uses intuitionistic fuzzy sets to capture vagueness and certainty in energy business model data sets;
- It uses intuitionistic fuzzy sets to aggregate experts' judgments for energy tariff plans evaluation under a multi-criteria scenario;
- IF-TOPSIS, which is a variant of standard TOPSIS method, is used to select a suitable energy tariff plan for developing countries;
- It uses a fuzzy axiomatic method to select a suitable tariff plan for different MBMs; and
- It uses a CRITIC method to determine the importance of MBM.

Business Models for Mini-Grid Implementation

From the foregoing, mini-grid facilities have exhibited a satisfactory track record in the electrification of remote communities. However, mini-grid systems are different from centralised grid systems in terms of asset ownership, operation, planning, and customer relations. Consequently, the type of MBMs that mini-grid systems determine their success. MBM depends on factors such as metrological, socio-political structure, economic policies and regulatory standards. Based on financing institutions have identified four main operator's business models: utilities, private companies, community-based organisations, and public-private business model [29–31].

Utility Model (C_1)

Under a utility model business scheme, a state utility company-owned and managed medium or large size mini-grid. They install and operate mini-grid systems. In this model, governments subsidise electricity using public funds and its operation is like that of the centralized grid system. It is designed mainly for rural electrification in developing countries. Tsumkwe mini-grid in Namibia and Nuon RAPS utility in northern KwaZulu-Natal, South Africa are examples of this model [2, 17, 22].

Private Business Model (C_2)

This model is driven and owned by private investors. Under this model, private investors own, operate, and maintain this model. Unlike the utility business model, this business model is small or medium in size and operates on centralized grids. Some of the financing sources for this type of model are equity and commercial loans. Sometimes, governments provide grants to business owners to make the electricity tariff affordable for their customers. Business owners spend these grants on distribution network equipment and the project development costs. Power-hive in Kisii and Nyamira, Kenya and Mesh Power in Rwanda are examples of this model [18, 19, 27].

Community-Based Model (C_3)

Communities own, operate, and maintain this model. They regulate and collect tariffs from electricity consumers while designing and installing a mini-grid to a third party. Grants often serve as the initial investment capital for this model implementation. In several developing countries, communities own and operate this mini-grid, but governments subsidise the project through the provision of technical and safety specifications [31]. Examples of such projects include hydropower

mini-grids in Kenya at Thima, Kathamba, Tungu Kabiri and Kipin [25]. In Sri Lanka, community-based cooperative groups owned and operated micro-hydro mini-grid systems [31].

Hybrid Model (C₄)

Multiple sectors are in charge of this type of mini-grid project investment, operation, and maintenance. For example, utility companies provide finance, private companies implement the project, and community-based cooperative societies operate the project. The effectiveness and efficiency of this model depend on the proper management of its activities. Also, the political atmosphere affects its success. For example, the government of Senegal owns over 18 mini-grids operated and maintained by a private company for a 15-year concession period. These mini-grids can meet the electricity demands of over 38,000 homes, 88 schools and 88 clinics as well as business and public buildings [25].

Methodology

This article methodology presents a framework for selecting a mini-grid electricity tariff plan (Table 1) using different MBM (Fig. 1). The conceptual framework considered different MBMs as evaluation criteria for electricity tariff plan ranking (Fig. 1). It considered when decision-makers specify or did not specify for MBMs' requirements. This article addresses the first and second situations IFAD method and a CRITIC-TOPSIS, respectively.

IT2FSs

A type-2 fuzzy set is a fuzzy logic concept that caters for the uncertainty during a decision-making process [23]. These fuzzy sets require complex mathematical evaluations [23]. However, incorporating IT2FSs into a type-2 framework reduces the mathematical processes for a type-2 fuzzy set [10–12, 16]. We now have IT2FSs for triangular and trapezoidal membership functions. Fig. 2 shows the structure of a trapezoidal membership for IT2FSs [16].

Table 1 Electricity tariff plan for mini-grid business models

Tariff plans	Symbols
1 Flat-rate	T ₁
2 Time-based	T ₂
3 Flexible	T ₃
4 Customer class	T ₄
5 Progressive	T ₅
6 Regressive	T ₆

Equations (1) and (2) show the mathematical expressions for trapezoidal memberships. These equations show that we can carry standard fuzzy operations out on IT2FSs membership functions [16, 23].

$$\tilde{A}_1 = \left(a_{11}^U, a_{12}^U, a_{13}^U, a_{14}^U; H_1(\tilde{A}_1^U), H_2(\tilde{A}_1^U) \right), a_{11}^L, a_{12}^L, a_{13}^L, a_{14}^L; H_1(\tilde{A}_1^L), H_2(\tilde{A}_1^L) \quad (1)$$

$$\tilde{A}_2 = \left(a_{21}^U, a_{22}^U, a_{23}^U, a_{24}^U; H_1(\tilde{A}_2^U), H_2(\tilde{A}_2^U) \right), a_{21}^L, a_{22}^L, a_{23}^L, a_{24}^L; H_1(\tilde{A}_2^L), H_2(\tilde{A}_2^L) \quad (2)$$

Based on literature knowledge, Eqs. (3) to (5) gives the expressions for the sum, product and difference of two IT2FSs, respectively [15].

$$\begin{aligned} \tilde{A}_1 + \tilde{A}_2 = & \left((a_{11}^U + a_{21}^U, a_{12}^U + a_{22}^U, a_{13}^U + a_{23}^U, a_{14}^U + a_{24}^U); \right. \\ & \min(H_1(A_1^U); H_1(A_2^U)), \min(H_2(A_1^U); H_2(A_2^U))) \\ & \left((a_{11}^L + a_{21}^L, a_{12}^L + a_{22}^L, a_{13}^L + a_{23}^L, a_{14}^L + a_{24}^L); \right. \\ & \left. \min(H_1(A_1^L); H_1(A_2^L)), \min(H_2(A_1^L); H_2(A_2^L))) \right) \end{aligned} \quad (3)$$

$$\begin{aligned} \tilde{A}_1 * \tilde{A}_2 = & \left((a_{11}^U * a_{21}^U, a_{12}^U * a_{22}^U, a_{13}^U * a_{23}^U, a_{14}^U * a_{24}^U); \right. \\ & \min(H_1(A_1^U); H_1(A_2^U)), \min(H_2(A_1^U); H_2(A_2^U))) \\ & \left((a_{11}^L * a_{21}^L, a_{12}^L * a_{22}^L, a_{13}^L * a_{23}^L, a_{14}^L * a_{24}^L); \right. \\ & \left. \min(H_1(A_1^L); H_1(A_2^L)), \min(H_2(A_1^L); H_2(A_2^L))) \right) \end{aligned} \quad (4)$$

$$\begin{aligned} \tilde{A}_1 - \tilde{A}_2 = & \left((a_{11}^U - a_{21}^U, a_{12}^U - a_{22}^U, a_{13}^U - a_{23}^U, a_{14}^U - a_{24}^U); \right. \\ & \min(H_1(A_1^U); H_1(A_2^U)), \min(H_2(A_1^U); H_2(A_2^U))) \\ & \left((a_{11}^L - a_{21}^L, a_{12}^L - a_{22}^L, a_{13}^L - a_{23}^L, a_{14}^L - a_{24}^L); \right. \\ & \left. \min(H_1(A_1^L); H_1(A_2^L)), \min(H_2(A_1^L); H_2(A_2^L))) \right) \end{aligned} \quad (5)$$

A crisp value of IT2FSs is calculated using Eq. (6) [15].

$$k(M) = \frac{1}{2} \left(\sum_{f \in \{U, L\}} \frac{a}{b} \right) \quad (6)$$

Fig. 1 The hierarchy of electricity tariff selection problem

$$a = a'_{11}, a'_{21} + \left(1 + H_1(\tilde{A}^f)\right)(a'_{12}, a'_{22}) + \left(1 + H_2(\tilde{A}^f)\right)(a'_{13}, a'_{23}) + a'_{14}, a'_{24} \quad (7)$$

$$b = 4 + H_1(\tilde{A}^f) + H_2(\tilde{A}^f) \quad (8)$$

$$\tilde{A}^f = \min\left(H_{x \in 1,2}(A_1^f); H_{x \in 1,2}(A_2^f)\right) \quad (9)$$

where v_{ij} denotes the normalised value of criterion i with respect to response j , denotes maximum values of response j , and $x_{\min, j}$ represents minimum values of response j ,

The evaluation of the criteria standard values (Eq. 12) and the construction of the Pearson correlation coefficient matrix (Eq. 13) comes after the normalisation step.

$$\sigma_j = \sqrt{\frac{\sum_{i=1}^n (x_{ij} - \bar{x}_j)^2}{n}} \quad (12)$$

CRITIC Method

Critic method relieves decision-makers of the burden of using complex weighting method to determine criteria importance. It uses the actual values of alternative values for criteria to determine criteria importance. This method initial step consists of criteria normalisation. During the normalisation, the desired directions of the criteria, as either cost or benefit-based, are considered. Eq. (10) and Eq. (11) give the normalised values for cost-based and benefit-based criteria, respectively.

$$v_{ij} = \frac{x_{\max, j} - x_{ij}}{x_{\max, j} - x_{\min, j}} \quad (10)$$

$$v_{ij} = \frac{x_{ij} - x_{\min, j}}{x_{\max, j} - x_{\min, j}} \quad (11)$$

Fig. 2 A trapezoidal interval type-2 fuzzy sets [16]

$$R = [r_{jk}]_{m \times m} \quad (13)$$

$$r_{jk} = \frac{\sum_{i=1}^m (x_{ij} - \bar{x}_j)(x_{ik} - \bar{x}_k)}{\sqrt{\sum_{i=1}^m (x_{ij} - \bar{x}_j)^2 \sum_{i=1}^m (x_{ik} - \bar{x}_k)^2}} \quad (14)$$

where $\bar{x}_j$ denotes the mean value of criterion j .

The relationship between Eqs. (12) and (13) give a criterion information measure (Eq. 15). When the measure is processed further, it generates a criteria weight or importance (Eq. 16).

$$H_j = \sigma_j \sum_{k=1}^K (1 - r_{jk}) \quad (15)$$

$$w_j = \frac{H_j}{\sum_{k=1}^K H_k} \quad (16)$$

Intuitionistic Fuzzy Axiomatic Method

An IFA method as a decision support tool as two main benefits - it considers decision-makers specifications in ranking alternatives, and it considers uncertainty during the alternatives' evaluation. It uses membership and non-membership

Table 2 Linguistic terms and interval type-2 fuzzy sets

Linguistic terms	Interval type-2 fuzzy sets
Very low (VL)	(0.05, 0.15, 0.25; 0.35, 0.25)
Low (L)	(0.20, 0.35, 0.50; 0.30, 0.35)
Moderate (M)	(0.25, 0.40, 0.55; 0.40, 0.30)
High (H)	(0.40, 0.55, 0.65; 0.55, 0.25)
Very high (V)	(0.55, 0.65, 0.80; 0.65, 0.20)
Extremely high (E)	(0.65, 0.80, 1.00; 0.70, 0.20)

functions - an alternative has two information contents - to evaluate alternatives. Membership functions' requirements are used to determine the first information content, while the second information content is based on the functional requirement of the non-membership functions [15]. Eqs. (17) and (18) give the expression for the first and second information contents for criteria [15].

$$I_{ij}^{\bar{m}} = \log_2 \left(\frac{S_{ij}^{\bar{m}}}{A_{ij}^{\bar{m}}} \right) \quad (17)$$

$$I_{ij}^{\bar{n}} = \log_2 \left(\frac{S_{ij}^{\bar{n}}}{A_{ij}^{\bar{n}}} \right) \quad (18)$$

where $I_{ij}^{\bar{m}}$, $S_{ij}^{\bar{m}}$ and $A_{ij}^{\bar{m}}$ denote the information content, system design and common areas of an electricity tariff plan i value for criterion j membership values, respectively, and $I_{ij}^{\bar{n}}$, $S_{ij}^{\bar{n}}$ and $A_{ij}^{\bar{n}}$ represent the information content, system design and common areas of an electricity tariff plan i value for criterion j non-membership values, respectively.

The total weighted information content for an electricity tariff plan using membership information content is expressed as Eq. (19a), while Eq. (19b) represents the total weighted information content for an electricity tariff plan using non-membership information content. The most and least suitable

Table 3 Design requirements for the business models

Business models	Interval type-2 fuzzy sets
M ₁	(0.20, 0.35, 0.50; 0.30, 0.35)
M ₂	(0.20, 0.35, 0.50; 0.30, 0.35)
M ₃	(0.20, 0.35, 0.50; 0.30, 0.35)
M ₄	(0.20, 0.35, 0.50; 0.30, 0.35)

Table 4 Importance of the mini-grid business model

Business models	D ₁	D ₂	D ₃	D ₄	D ₅
M ₁	H	M	V	H	M
M ₂	H	V	V	V	M
M ₃	M	H	V	M	H
M ₄	V	M	V	VL	M

alternatives are the alternatives with the highest and lowest information contents [21].

$$I_i = \sum_{j=1}^n w_j \left(\log_2 \left(\frac{S_{ij}^{\bar{m}}}{A_{ij}^{\bar{m}}} \right) \right) \quad (19a)$$

$$I_i = \sum_{j=1}^n w_j \left(\log_2 \left(\frac{S_{ij}^{\bar{n}}}{A_{ij}^{\bar{n}}} \right) \right) \quad (19b)$$

where I_i denotes the total weighted information content of alternative i .

IFS-TOPSIS Method

IFS-TOPSIS method incorporates uncertainties during the evaluation of alternatives' ranks [3]. It is similar to a standard TOPSIS method but uses a different method to generate positive and negative ideal solutions [28]. The initial step of an IFS-TOPSIS method is aggregation of the criteria values (Eqs. 20 and 22).

$$\bar{x}_{ij1} = 1 - \left(1 - \prod_{k=1}^K x_{ijk1} \right) \quad (20)$$

$$\bar{x}_{ij2} = \prod_{k=1}^K x_{ijk2} \quad (21)$$

$$\bar{x}_{ij3} = 1 - \left(1 - \prod_{k=1}^K x_{ijk1} \right) - \prod_{k=1}^K x_{ijk2} \quad (22)$$

Table 5 Importance of the mini-grid business model

Models	σ_j	h_j	w_j
M ₁	0.0733	0.2743	0.2920
M ₂	0.0639	0.1570	0.1672
M ₃	0.0737	0.2269	0.2416
M ₄	0.0975	0.2810	0.2992

This method uses normalised values to determine alternative distances from the positive and negative ideal solutions. Eq. (24) represents the expression for positive ideal solutions, and Eq. (25) represents the expression for negative ideal solutions [3, 28].

$$x_{j1}^s, x_{j2}^s, x_{j3}^s = (1, 0, 0) \quad (23)$$

$$x_{j1}^s, x_{j2}^s, x_{j3}^s = (0, 1, 0) \quad (24)$$

Equations (25) and (26) are used to the positive ideal and negative-ideal solutions for the alternatives, respectively. To generate an alternative closeness coefficient, Eq. (27) is used to combine Eqs. (25) and (26) outputs. The alternative with the highest closeness coefficient is ranked as the best alternative [28].

$$d_i^+ = \sqrt{\sum_{j=1}^n w_j \left(|\bar{x}_{ij1} - 1|^2 + |\bar{x}_{ij2} - 0|^2 + |\bar{x}_{ij3} - 0|^2 \right)} \quad (25)$$

$$d_i^- = \sqrt{\sum_{j=1}^n w_j \left(|\bar{x}_{ij1} - 0|^2 + |\bar{x}_{ij2} - 1|^2 + |\bar{x}_{ij3} - 0|^2 \right)} \quad (26)$$

Table 6 Linguistic ratings of the electricity tariff plans

	Business model	T ₁	T ₂	T ₃	T ₄	T ₅	T ₆
D ₁	M ₁	VL	H	M	H	V	VL
	M ₂	L	M	H	H	M	L
	M ₃	M	H	H	H	H	V
	M ₄	VL	E	E	V	V	V
D ₂	M1	E	E	V	V	V	H
	M2	M	M	E	V	L	E
	M3	H	H	V	M	V	E
	M4	M	H	E	M	E	E
D ₃	M1	M	H	E	L	H	VL
	M2	M	H	V	M	H	L
	M3	M	H	V	M	V	L
	M4	M	H	V	V	V	L
D ₄	M1	H	M	H	H	H	L
	M2	M	M	L	M	M	M
	M3	L	L	M	M	H	L
	M4	L	L	M	L	L	H
D ₅	M1	VL	VL	VL	M	M	M
	M2	VL	L	L	M	H	H
	M3	L	L	L	M	H	V
	M4	L	L	M	H	M	M

Table 8 System areas of the electricity tariff plans

	M ₁	M ₂	M ₃	M ₄
Memberships				
T ₁	0.0644	0.0555	0.0566	0.0525
T ₂	0.0675	0.0595	0.0689	0.0696
T ₃	0.0702	0.0725	0.0624	0.0884
T ₄	0.0662	0.0672	0.0624	0.0689
T ₅	0.0728	0.0616	0.0738	0.0440
T ₆	0.0566	0.0675	0.0754	0.0754
Non-memberships				
T ₁	0.0350	0.0450	0.0450	0.0465
T ₂	0.0338	0.0435	0.0392	0.0406
T ₃	0.0324	0.0392	0.0351	0.0372
T ₄	0.0365	0.0378	0.0421	0.0351
1T ₅	0.0312	0.0406	0.0288	0.0231
T ₆	0.0406	0.0435	0.0377	0.0377

$$d_i = \frac{d_i^-}{d_i^+ + d_i^-} \quad (27)$$

Numerical Example

This article applied the proposed framework in a remote community in Lagos, Nigeria. Using a well-structured questionnaire, five decision-makers provided information for the model implementation. The questionnaire contained information about different tariff plan assessment for MBM. This article considered four MBM during the conceptual framework application (Fig. 1). These business models are private (M1), community-based (M2), utility-based (M3) and hybrid (M4) models. Table 2 shows the design requirements for the mini-grid tariff plan and Table 3 shows the design requirements for the MBMs.

Table 4 shows the five experts' rating of the MBMs' importance. The information in this table shows that the experts' rating varies from one model to another, else the third expert who rated all the models as very high.

Equation (4) was used to aggregate the experts' responses in Table 4. Eq. (6) was used to convert the aggregated values to crisp values. Based on the crisp values, Eqs. (10) to (17) were used to determine the MBMs' importance (Table 5). The results in Table 5 show that the least and most important MBM for the case study are M2 and M1, respectively.

Table 6 shows the results of experts' rating of the plan ratings. Apart from the third expert who rated assigned the same ratings to T₁, as well as T₂, with respect to the MBM,

Table 7 Aggregated fuzzy numbers of the electricity tariff plans

	T ₁	T ₂	T ₃
M ₁	(0.26,0.42,0.54; 0.46,0.25)	(0.33,0.48,0.60; 0.50,0.25)	(0.36,0.50,0.63; 0.52,0.24)
M ₂	(0.20,0.36,0.50; 0.37,0.30)	(0.27,0.42,0.56; 0.41,0.30)	(0.40,0.54,0.69; 0.50,0.27)
M ₃	(0.26,0.41,0.55; 0.39,0.31)	(0.32,0.47,0.59; 0.45,0.29)	(0.39,0.52,0.66; 0.51,0.26)
M ₄	(0.19,0.35,0.49; 0.35,0.31)	(0.37,0.52,0.66; 0.48,0.28)	(0.47,0.61,0.78; 0.57,0.24)
	T ₄	T ₅	T ₆
M ₁	(0.36,0.50,0.63; 0.49,0.27)	(0.43,0.56,0.69; 0.56,0.24)	(0.19,0.36,0.48; 0.39,0.28)
M ₂	(0.34,0.48,0.62; 0.48,0.27)	(0.30,0.45,0.58; 0.44,0.29)	(0.34,0.49,0.64; 0.45,0.29)
M ₃	(0.28,0.43,0.57; 0.43,0.29)	(0.46,0.59,0.71; 0.59,0.23)	(0.43,0.56,0.72; 0.52,0.26)
M ₄	(0.39,0.52,0.66; 0.51,0.26)	(0.31,0.41,0.53; 0.40,0.21)	(0.41,0.55,0.70; 0.52,0.26)

the other experts did not assign the same ratings to the models under the same plan (Table 6).

Based on the information in Table 2, this article converted Table 5 information into interval type-2 fuzzy sets. Equation (4) was used to aggregate the interval type-2 fuzzy sets (Table 6).

Using the tariff plans information in Table 3, the tariff plans' system areas were determined - Table 8 shows the results obtained. The tariff plans' common areas were determined based on the relationship between the information in Tables 3, 7, 8 and 9 shows the results obtained.

The tariff information in Tables 8 and 9 were used to generate their information contents were generated. Table 10 shows the results obtained.

The membership and non-membership results show that the best-ranked electricity tariff plans for the case study were the different (i.e., T₆), see Fig. 3.

In terms of the membership information contents, the most and least suitable plans are T₁ and T₂, respectively. On the

other hand, T₄ and T₆ are the most and least suitable plans in terms of the non-membership information contents.

Using the information in Table 7, a decision matrix for an IF-TOPSIS for the selection problem (Table 11). Equations (20) to (22) were used to determine the tariff plans aggregate values. Based on the aggregated values in Table 12, Eqs. (26) was used to calculate the tariff planning problem positive ideal solutions. On the other hand, Eq. (27) is used to calculate the tariff planning problem negative ideal solutions. Table 13 shows these solutions results. Table 13 shows that T₃ is the most suitable tariff plan, while T₁ is the least suitable tariff plan. The IF-TOPSIS ranking order is $T_3 > T_5 > T_4 > T_6 > T_2 > T_1$.

Conclusions

This article proposes a conceptual framework that used MBM to rank electricity tariff plans. This framework integrated IFS, CRITIC, FAD and TOPSIS. It considered when decision-

Table 9 Common areas of the electricity tariff plans

	M ₁	M ₂	M ₃	M ₄
Memberships				
T ₁	0.0162	0.0000	0.0180	0.0005
T ₂	0.0238	0.0621	0.0396	0.0221
T ₃	0.0288	0.0160	0.0165	0.0300
T ₄	0.0238	0.0320	0.0000	0.0165
T ₅	0.0700	0.0460	0.0036	0.0475
T ₆	0.0364	0.0304	0.0035	0.0099
Non-memberships				
T ₁	0.0020	0.0000	0.0060	0.0006
T ₂	0.0187	0.0253	0.0171	0.0098
T ₃	0.0112	0.0055	0.0060	0.1200
T ₄	0.0091	0.0120	0.0253	0.0253
T ₅	0.0210	0.0190	0.0023	0.0023
T ₆	0.0003	0.0120	0.0021	0.0041

Table 10 Information contents of the electricity tariff plans

	M ₁	M ₂	M ₃	M ₄
Memberships				
T ₁	1.9911	Infinite	1.6528	6.7142
T ₂	1.5039	-0.0617	0.7990	1.6550
T ₃	1.2854	2.1799	1.9191	1.5591
T ₄	1.4759	1.0704	1.4975	2.0620
T ₅	0.0566	0.4213	4.3576	-0.1104
T ₆	0.6369	1.1508	4.4291	2.9291
Non-memberships				
T ₁	4.1293	Infinite	2.9069	6.4017
T ₂	0.8540	0.7819	1.1969	2.0580
T ₃	1.5325	2.8334	2.5484	-1.6897
T ₄	2.0040	1.6554	0.7347	0.4723
T ₅	0.5712	1.0955	3.6781	3.3599
T ₆	7.3434	1.8580	4.1661	3.2186

Fig. 3 Ranks of electricity tariff plan using the IFAD metho **Table 11** The decision-makers' IFS values for the IFS-TOPSIS method

		T ₁		T ₂		T ₃		T ₄		T ₅		T ₆	
D ₁	M ₁	0.35	0.25	0.55	0.25	0.40	0.30	0.55	0.25	0.65	0.20	0.35	0.25
	M ₂	0.30	0.35	0.40	0.30	0.55	0.25	0.55	0.25	0.40	0.30	0.30	0.35
	M ₃	0.40	0.30	0.55	0.25	0.55	0.25	0.55	0.25	0.55	0.25	0.65	0.20
	M ₄	0.35	0.25	0.70	0.20	0.70	0.20	0.65	0.20	0.65	0.20	0.65	0.20
D ₂	M ₁	0.65	0.20	0.65	0.20	0.65	0.20	0.65	0.20	0.65	0.20	0.55	0.25
	M ₂	0.40	0.30	0.40	0.30	0.70	0.20	0.65	0.20	0.30	0.35	0.70	0.20
	M ₃	0.55	0.25	0.55	0.25	0.65	0.20	0.40	0.30	0.65	0.20	0.70	0.20
	M ₄	0.40	0.30	0.55	0.25	0.70	0.20	0.40	0.30	0.70	0.20	0.70	0.20
D ₃	M ₁	0.40	0.30	0.55	0.25	0.65	0.20	0.30	0.35	0.55	0.25	0.35	0.25
	M ₂	0.40	0.30	0.55	0.25	0.65	0.20	0.40	0.30	0.55	0.25	0.30	0.35
	M ₃	0.40	0.30	0.55	0.25	0.65	0.20	0.40	0.30	0.65	0.20	0.30	0.35
	M ₄	0.40	0.30	0.55	0.25	0.65	0.20	0.65	0.20	0.65	0.20	0.30	0.35
D ₄	M ₁	0.55	0.25	0.40	0.30	0.55	0.25	0.55	0.25	0.55	0.25	0.30	0.35
	M ₂	0.40	0.30	0.40	0.30	0.30	0.35	0.40	0.30	0.40	0.30	0.40	0.30
	M ₃	0.30	0.35	0.30	0.35	0.40	0.30	0.40	0.30	0.55	0.25	0.30	0.35
	M ₄	0.30	0.35	0.30	0.35	0.40	0.30	0.30	0.35	0.30	0.35	0.55	0.25
D ₅	M ₁	0.35	0.25	0.35	0.25	0.35	0.25	0.40	0.30	0.40	0.30	0.40	0.30
	M ₂	0.35	0.25	0.30	0.35	0.30	0.35	0.40	0.30	0.55	0.25	0.55	0.25
	M ₃	0.30	0.35	0.30	0.35	0.30	0.35	0.40	0.30	0.55	0.25	0.65	0.20
	M ₄	0.30	0.35	0.30	0.35	0.40	0.30	0.55	0.25	0.40	0.30	0.40	0.30

Table 12 Aggregated tariff plans intuitionistic fuzzy number

	T ₁	T ₂	T ₃	T ₄	T ₅	T ₆
$\bar{x}_{ij1}$						
M ₁	0.9846	0.9846	0.9893	0.9702	0.9851	0.9201
M ₂	0.9017	0.9320	0.9768	0.9660	0.9490	0.9603
M ₃	0.9206	0.9553	0.9768	0.9417	0.9888	0.9820
M ₄	0.8853	0.9702	0.9887	0.9768	0.9846	0.9802
$\bar{x}_{ij2}$						
M ₁	0.0009	0.0009	0.0008	0.0013	0.0008	0.0016
M ₂	0.0024	0.0024	0.0012	0.0014	0.0020	0.0018
M ₃	0.0028	0.0019	0.0011	0.0020	0.0006	0.0010
M ₄	0.0028	0.0015	0.0007	0.0011	0.0008	0.0011
$\bar{x}_{ij3}$						
M ₁	0.9837	0.9837	0.9885	0.9689	0.9844	0.9185
M ₂	0.8994	0.9296	0.9756	0.9646	0.9470	0.9585
M ₃	0.9179	0.9534	0.9758	0.9397	0.9882	0.9810
M ₄	0.8826	0.9687	0.9879	0.9758	0.9837	0.9791

Table 13 The IFS-TOPSIS results

Tariff	D_i^+	D_i^-	CC_i
T ₁	1.8434	1.7050	0.4805
T ₂	1.9181	1.8412	0.4898
T ₃	1.9640	1.9287	0.4955
T ₄	1.9247	1.8530	0.4905
T ₅	1.9519	1.9061	0.4941
T ₆	1.9192	1.8442	0.4900

makers specify or did not specify for MBMs' requirements. Also, this article considered uncertainty in decision-makers' information. We showed the framework applicability using information obtained from Sub-Sahara Africa. Using a structured questionnaire, five experts provided information for the framework testing. The CRITIC method results showed that the least and most important MBM as community-based and private models, respectively. Also, the IFS-FAD method identified a regressive electricity tariff plan as the most suitable for the case study, while the IFS-TOPSIS method identified flat-rate and flexible tariff plans as the least and best electricity tariff plans. Thus, the framework can give guideline mini-grid business owners investors to expand mini-grid in remote areas.

With minor modifications, researchers and practitioners can transform the proposed model to a renewable energy source case-specific model from the current generalised form. Since electricity tariff plan alone could not guarantee MBM success, integrating energy generation and storage technology into the proposed model will make it more robust. Finally, system dynamics modelling approach can model the complex interrelationships among mini-grid parameters for MBM selection.

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