

Article

Business Model Selection for Community Energy Storage: A Multi Criteria Decision Making Approach

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Abstract: This paper explores business models for community energy storage (CES) and examines their potential and feasibility at the local level. By leveraging Multi Criteria Decision Making (MCDM) approaches and real-world case studies in Europe and India, it presents insights into CES deployment opportunities, challenges, and best practices. Different business models, including community energy cooperatives, utility–community partnerships, demand response, energy services, and market mechanisms, are analyzed. The proposed method combines the MCDM method PROMETHEE II with the fuzzy set theory to obtain a complete CES business model ranking, addressing project uncertainties. The analysis emphasizes CES's role in balancing local renewable energy supply and demand, facilitating energy sharing, and achieving energy independence. Findings prioritize models like Community Cooperative, Energy Arbitrage, and Energy Arbitrage Peak Shaving for CES with renewables. Environmental benefits include reduced diesel use and greenhouse gas emissions. Efficient cooperatives are advocated to recover costs and enable competitive energy prices. The paper highlights the need for novel value propositions to boost the energy transition in local communities. This research contributes to the discourse on CES business models, fostering knowledge exchange and promoting effective strategies for sustainable energy systems.

Keywords: community; storage; business models; MCDM; energy; Europe; India



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1. Introduction

The rapid growth of renewable energy sources has presented both opportunities and challenges for the modern power grid. While renewable generation technologies, such as solar photovoltaics (PV) and wind turbines, contribute to decarbonization efforts, their intermittent nature poses a significant integration challenge. To ensure a reliable and sustainable energy future, it is crucial to address the variability and intermittency of renewable energy sources while maximizing their benefits.

Community Energy Storage (CES) emerges as a smart and innovative solution that holds great potential in facilitating the integration of local renewable generation, managing demand loads, and decarbonizing the residential sector. CES involves the deployment of energy storage systems within communities, enabling them to store excess renewable energy and utilize it during periods of high demand or when the renewable generation is low [1].

1.1. Background and Motivation for the Study

In recent years, there has been a growing interest in understanding the techno-economic benefits of CES systems and identifying the optimal storage technologies, deployment sizes, and operational strategies for community-scale applications [2]. The business models and market mechanisms associated with CES play a pivotal role in realizing its potential and ensuring its widespread adoption.

This paper aims to explore business models for community energy storage, examining their potential and assessing their feasibility at a local level. This paper delves into the multifaceted aspects of CES, including economic viability, environmental impact, grid integration, and community engagement, to shed light on the transformative role it can play in transitioning towards a more sustainable and resilient energy system. The need for this assessment stems from the ongoing research performed in the H2020 project RE-EMPOWERED [3,4], which develops and demonstrates novel tools for local energy systems in Europe and India.

By leveraging Multi Criteria Decision Making (MCDM) [5,6] approaches and drawing insights from real-world case studies, a comprehensive understanding of the opportunities, challenges, and best practices associated with CES deployment is presented. Furthermore, the potential revenue streams, cost-effectiveness, and policy implications that underpin the successful implementation of CES projects are explored.

Through a systematic analysis of different business models, including community energy cooperatives, utility–community partnerships, demand response operators, energy services providers, and market mechanism facilitators, the paper aims to offer valuable insights and recommendations to stakeholders, policymakers, and industry practitioners seeking to harness the full potential of CES.

Ultimately, this research endeavors to contribute to the ongoing discourse on community energy storage business models, foster knowledge exchange, and promote the adoption of effective strategies that enable communities to actively participate in the energy transition while unlocking the benefits of local renewable generation and energy storage integration.

1.2. Research Questions and Objectives

The concept of CES holds immense promise, but its successful implementation relies on the selection of suitable business models that align with the unique characteristics and objectives of each community. Choosing the most appropriate business model for CES involves evaluating multiple criteria and considering the preferences and priorities of stakeholders, which can be a complex and multi-dimensional decision-making process.

To address this challenge, Multi-Criteria Decision-Making (MCDM) can provide a systematic and robust framework for evaluating and selecting the most suitable business models for CES.

This study seeks to leverage MCDM techniques, specifically the Fuzzy PROMETHEE methodology [7], to assess and compare different business models for CES. By considering criteria such as economic viability, environmental impact, social acceptance, technical feasibility, and regulatory compliance, this paper aims to provide a comprehensive evaluation of the potential business models and their suitability for specific community contexts.

Furthermore, motivation stems from the need to identify business models that not only maximize economic benefits but also align with community values, sustainability goals, and local regulatory frameworks. By employing MCDM techniques, one can incorporate the diverse perspectives and preferences of stakeholders, ensuring a participatory and inclusive decision-making process [8].

Overall, this study's background and motivation originate from the recognition that CES represents a smart and sustainable choice for local communities and the broader smart grid ecosystem. By integrating renewable energy sources, managing demand loads, and leveraging MCDM techniques to select the appropriate business models, CES has the potential to reshape energy consumption patterns, enhance grid resilience, and contribute to a cleaner and more decentralized energy future. Through the application of the Fuzzy PROMETHEE methodology, this work aims to support stakeholders in selecting the most suitable business models for CES, fostering its successful implementation and widespread adoption.

1.3. Contributions

This paper makes significant contributions by proposing a novel approach for business model selection, utilizing Multi Criteria Decision Making (MCDM) techniques, combined with fuzzy methods, to assess and classify business models for Community Energy Storage (CES). The methodology is applied to two real-life case studies in Europe and India, providing practical insights and guidance for the development of local energy systems. The primary contribution lies in the innovative approach that integrates MCDM and fuzzy methods, allowing for a comprehensive evaluation and classification of CES business models, which, to the best of the authors' knowledge, has not been performed before. By considering multiple criteria and addressing uncertainties, the proposed approach provides a robust framework for decision-making and model selection. Furthermore, the application of the methodology to two distinct geographical contexts enhances the practical relevance and applicability of the research. By analyzing the specific needs and characteristics of each case study, the paper identifies the most suitable and feasible business models for CES deployment, thereby supporting the development of local energy systems. Overall, this research contributes to the advancement of CES by offering a systematic and effective approach to evaluate and classify business models, providing valuable insights for policymakers, industry practitioners, and stakeholders involved in the transition towards sustainable and resilient energy systems.

1.4. Organization

The rest of the paper continues with a literature review on business models for CES, and the different approaches for assessing their suitability. Section 3 provides an overview of the legal framework for the case studies, relevant to the business models that are selected for assessment. Section 4 discusses the methodology employed for the evaluation of the business models, while Section 5 deals with the deployment of the methodology in the two different case studies, one in Europe and one in India. The document concludes with a discussion of the results and the key takeaways from the analysis.

2. Literature Review

2.1. Overview of Community Energy Storage and Business Models

The successful implementation of community energy storage relies on effective business models that can ensure economic viability, maximize benefits for stakeholders, and foster long-term sustainability. Understanding these models is essential for policymakers, entrepreneurs, and community leaders as they navigate the complexities of deploying and operating community energy storage systems. There is still limited research on the topic of business models for community energy storage, yet there are a few authors who try to tackle the issue.

Terlouw et al. [9] explored the use of Community Energy Storage (CES) as a solution to enhance flexibility in power systems with a large-scale integration of renewable energy sources. They present two business models: Energy Arbitrage (EA) and Energy Arbitrage-Peak Shaving (EA-PS). In [2], the authors addressed the challenge of balancing greenhouse gas emissions reduction and associated costs in the operation of a CES system in a neighborhood with high photovoltaic (PV) electricity generation capacity. Others [10] investigated the influence of energy storage on the community's carbon emissions, revealing that storage operations yield minimal additional emissions reduction when considering grid average emissions factors. The authors proposed a multi-objective optimization framework to determine the trade-off between emissions and costs when operating the CES system on the day-ahead spot market.

Parra et al. [11] examined the performance and economic benefits of CES systems, focusing on the suitability of different energy storage technologies and the optimal size of the CES. The study provides insights into the techno-economic considerations for CES implementation, highlighting the optimal capacities of different battery technologies and the financial implications for various community sizes and retail tariff structures. The paper

in [12] presented a strategy for optimally allocating multiple CES units in a distribution system with photovoltaic (PV) generation. The strategy considered various scenarios, including energy arbitrage, peaking power generation, energy loss reduction, system upgrade deferral, emission reduction, and VAR support. A cost–benefit analysis was conducted to determine the optimal Net Present Value (NPV), Discounted Payback Period (DPP), and Benefit–Cost ratio (BCR). The importance of system upgrade deferral due to storage was also stressed in [13–16], and significant benefits from upgrade deferrals in distribution, transmission systems, and feeders were observed, depending on several factors such as the capital and operational cost of battery storage, rate of yearly load increase, etc. The authors in [1] investigated the deployment level of energy storage for integrating local renewable generation, focusing on the comparison between individual households and community-level adoption. They emphasized the importance of developing market mechanisms and energy policies that facilitate the deployment of community storage, considering the increasing rates of residential battery adoption.

Different multi-objective optimization approaches and state-of-the-art techniques are used for the selection of CES technologies [17–21], conversely, with numerous conflicting aspects. Stakeholders find it challenging to directly select a suitable CES strategic location for energy loss minimization in a local distribution system. Hence, an MCDM problem may be formulated in a fuzzy environment due to uncertain and vague information to consider all-inclusive CES requirements, which is otherwise difficult to define precisely during the initial stages of planning and adoption.

Although different authors tackle business models for CES from different perspectives, it seems that the most prominent business models that are considered in this paper can be summarized by the following categories:

Energy Arbitrage (EA) model

An aggregator can operate the CES system by buying low-cost electricity during off-peak periods and storing it in batteries. Then, during peak demand periods when electricity prices are higher, the stored energy can be discharged to the grid, thus reducing electricity costs and minimizing CO₂ emissions.

Energy Arbitrage Peak Shaving (EA-PS)

This model involves collaboration between a Distribution System Operator (DSO) and an aggregator. The CES system is utilized not only for energy arbitrage but also for peak shaving. The DSO and aggregator jointly manage the CES system to minimize operation costs and CO₂ emissions while ensuring grid stability. The CES system helps to smooth out peak electricity demand by storing excess energy during low-demand periods or periods with high Renewable Energy Source (RES) production and supplying it to the grid during high-demand periods, reducing strain on the distribution transformer.

Emission Reduction and VAR Support

CES units can contribute to emission reduction efforts by integrating renewable energy generation and providing voltage and reactive power support (VAR). By optimizing the operation of CES units and coordinating them with PV generation, utilities can reduce their carbon footprint and improve the stability of the distribution system. This business model can involve offering emission reduction and VAR support services to utilities or partnering with them to achieve their sustainability goals.

Cost Optimization and energy loss reduction model

This model focuses on optimizing the operation of a CES system in a neighborhood with high shares of photovoltaics (PVs). The CES system is used to balance the intermittency of PV generation and reduce associated costs and greenhouse gas emissions. By employing optimization frameworks, the trade-off between reducing emissions and minimizing costs can be determined. CES systems can be utilized to reduce energy costs for residential communities by optimizing energy consumption and performing demand response and renewable energy integration. By strategically locating CES units and optimizing their

operation energy losses in the distribution system, the need for system upgrades can be deferred. This business model can involve providing energy loss reduction and system optimization services to utilities or partnering with them to improve the efficiency of their distribution systems.

Aggregated Energy Services model

The CES system can be utilized to provide various energy services to the grid and the community. This may include demand response, frequency regulation, voltage support, or grid stability services. By aggregating multiple CES systems, an aggregator or service provider can offer these services to grid operators or utilities, generating revenue based on the value of the provided services.

- *Demand Load Shifting Service*: By storing excess energy during low-demand periods and supplying it during peak hours, CES can help manage electricity demand and reduce reliance on the grid (wherever applicable). This business model can be based on a time-of-use tariff or real-time pricing tariff, where the CES system optimizes energy usage based on wholesale electricity prices.
- *CES as a Service (CaaS)*: Adopting a service-oriented business model, CES providers can offer CES as a service to communities and utilities. They can own, operate, and maintain the CES systems on behalf of the community or utility, charging a subscription or usage-based fee. This model allows communities to benefit from CES without the upfront capital investment or operational responsibilities.
- *Digitally Enabled Flexibility Services*: This is developed to respond to extremely low levels of demand on the network, especially in severe weather conditions where both supply and demand are low. In principle, this service could be delivered by both community-scale wind and solar farms. Key components of these services may include monitoring and control systems, energy storage, RES, smart grid technologies, demand response via IoT, and smart appliances.

Vehicle-to-(micro)grid (VTMG) model

The wide deployment of Electric Vehicles (EVs) in the future may pose challenges to the local grid (or microgrid, depending on the case), due to supply and demand constraints, but can also offer the possibility for internal balancing and/or (micro)grid support. For efficient operation, EV charging must be regulated. However, during emergencies, the EVs can be utilized to support local energy systems for flexibility. The model investigates internal EV optimization, improving self-consumption or carrying out price arbitrage, as well as external optimization aiming for market revenues. Internal EV optimization can be performed as part of an energy community depending on the availability of charging opportunities. The internal EV optimization process in the VTMG model involves managing the charging and discharging of electric vehicles within a microgrid or local energy community. This can be performed by utilizing Demand Forecasting, where the system uses predictive algorithms and real-time data to forecast energy demand within the microgrid. This includes not only household or community electricity needs but also the expected charging requirements of connected electric vehicles. Also, Smart charging algorithms take into account various factors, such as energy pricing, grid conditions, and individual vehicle preferences. They optimize the timing and rate of EV charging to minimize costs and reduce stress on the grid. For example, EVs may be scheduled to charge during periods of low electricity demand or when renewable energy generation is at its peak. Lastly, in a VTMG setup, EVs equipped with bidirectional charging capability can not only draw energy from the grid but also feed excess energy back into the microgrid when needed. This bidirectional flow is coordinated to maintain grid stability and optimize energy use. In the case of smart charging (demand response), the EVs adapt their load-shifting charging pattern based on real-time or time-of-use price signals, which allows EVs to interact bi-directionally with the grid by adjusting their charging and discharging pattern from the energy system/ local grid, creating a significant monetization opportunity. VTMG charging comprises bidirectional charging activities in which power from an EV can be fed

back to the microgrid. Application of the VTMG concept to EVs facilitates participation in congestion and ancillary markets.

Community Cooperative Model

CES providers can facilitate the establishment of community cooperatives, where community members collectively own and operate the CES systems. The CES provider can assist in setting up the cooperative structure and providing technical expertise, financing options, and ongoing support. This model promotes community engagement, local resilience, and shared benefits from CES deployment.

2.2. Existing Approaches to Business Model Selection

The process of selecting appropriate business models depends on various factors, including local market conditions, the policy landscape, technology maturity, and specific project goals. Therefore, a tailored approach combining multiple methods and considering the local context is often necessary for making informed decisions. Several methods are traditionally used, aimed at quantifying the tangible economic benefits while assessing possible risks and barriers. The works analyzed in the previous section showcase examples of different ways of assessing the suitability of business models. Some typical approaches are listed below:

- **Market Analysis:** Conducting a comprehensive analysis of the relevant market to identify potential opportunities, gaps, and challenges for energy storage. This includes assessing regulatory frameworks, market structures, pricing mechanisms, and competitive landscape.
- **Cost–Benefit Analysis:** Evaluating the costs and benefits associated with different business models. This analysis considers factors such as capital investment, operational costs, revenue streams, savings from grid services, and potential revenue stacking opportunities.
- **Techno-Economic Analysis:** Assessing the technical feasibility and economic viability of various technologies and their compatibility with specific business models. For energy storage, this analysis may consider factors such as energy storage capacity, efficiency, lifespan, scalability, and integration with renewable energy sources.
- **Risk Assessment:** Identifying and evaluating risks associated with different business models, including market risks, regulatory risks, technological risks, financial risks, and operational risks. Understanding these risks helps in selecting business models that mitigate or manage them effectively.
- **Stakeholder Engagement:** Engaging with relevant stakeholders, including energy providers, consumers, policymakers, and industry experts, to gather insights and perspectives on potential business models. This involvement ensures alignment with market needs and regulatory requirements.
- **Pilots and Demonstrations:** Implementing pilot projects or demonstrations to test and validate the feasibility and effectiveness of specific business models. This approach provides real-world data and feedback to refine and optimize the chosen business model.
- **Collaboration and Partnerships:** Exploring collaborations and partnerships with other entities in the energy ecosystem, such as utilities, renewable energy developers, technology providers, and financing institutions. Collaborative approaches can leverage synergies, share risks and rewards, and create innovative business models.

Traditional decision-making methods often focus on a single criterion, leading to suboptimal outcomes when complex decisions involve multiple conflicting objectives. Multi-criteria decision-making (MCDM) is a decision-making approach that aims to consider multiple criteria or objectives simultaneously when evaluating and selecting the best alternative among a set of options. MCDM provides a systematic framework to address such complexities by integrating and analyzing multiple criteria, enabling decision-makers to make more informed and balanced decisions. Various MCDM techniques have been

developed over the years, each with its own strengths and applicability. These techniques include the analytic hierarchy process (AHP) [5,22,23], the technique for order preference by similarity to ideal solution (TOPSIS) [15,22–26], and modified fuzzy TOPSIS [27–29], as well as many others like ANP [24], PROMETHEE [15,25], DEMATEL [24,30], and VIKOR [31]. These methods employ mathematical models, algorithms, and decision rules to calculate overall rankings or scores for each alternative and provide insights into the best decision option.

3. Methodology

3.1. Overview of the Proposed MCDM Strategy

The existing literature combines MCDM and other methods for ranking alternatives and selecting the best-ranking energy storage technologies. The authors in [32] introduce a multicriteria decision-making (MCDM) framework for selecting an appropriate energy storage technology based on specific storage requirements. The research acknowledges the importance of considering storage requirements rather than solely focusing on ranking and selecting the best technologies. The MCDM framework incorporates nine criteria organized into four aspects: Technological, economic, environmental, and social. The proposed method transforms and fuses interval numbers, crisp numbers, and linguistic terms into probabilistic dual hesitant fuzzy sets (PDHFS), enabling the selection of suitable technology through distance measurement.

Among various MCDM methods, PROMETHEE is widely used in energy projects [33], while applied fuzzy PROMETHEE II has been used for solar power plant site selection [34]. It is a significant method, which employs the outranking principles using a preference function to rank the alternatives [35] by obtaining a complete ranking of the solution set [34]. The paper in [36] presents a multistage framework for selecting an appropriate renewable energy source (RES) by integrating picture linguistic fuzzy numbers (PLFNs), preference-ranking organization method for enrichment evaluations II (PROMETHEE II), and prospect theory (PT). The framework addresses the complex nature of RES selection, considering economic, environmental, technological, and societal factors.

In this study, the PROMETHEE II method, extended into a fuzzy environment, is used to obtain a complete CES business model ranking, utilizing existing studies that introduced the fuzzy set theory to the PROMETHEE method [37,38], which can avoid detailed uncertain information loss. The assessment of performance evaluation problems is limited to experts' subjective judgement, which is difficult to directly calculate or rank. PROMETHEE I may lead to some information loss as experts' opinions are subjective in nature with partial information on the ranking, whereas PROMETHEE II is more complete and eliminates incomparability. In addition to this, Fuzzy is used to address MCDM problems, which are uncertain and vague, thus rendering it difficult to prioritize the alternatives in some cases.

In this paper, the fuzzy PROMETHEE II method is employed by integrating the trapezoidal fuzzy number (TFN). The methodology offers significant advantages, primarily stemming from its user-friendly nature, driven by linguistic evaluations, and its ability to account for the inherent vagueness and fuzziness often present in decision-making environments. Consequently, this method emerges as a highly efficient and effective approach, well-suited for decision-makers.

3.2. Description of Criteria Used for Evaluating Business Models

Energy-storage technologies require realizing multiple objectives and consider many aspects, including economic, technological, social, and environmental [39]. Among technological indicators, energy efficiency (C1) was selected as a representative criterion to measure the degree of energy utilization [40,41]. Economic factors include costs related to capital investment and operation, power and energy costs, and economic benefits. Investment and operational costs (C2) were selected as the criteria [33,40–46]. Environmental impact was comprehensively considered as a reduction in CO₂ emissions (C3) [40,41,43,46]

to evaluate CES business models. Social factors embrace a wide variety of criteria like job creation, social acceptance, government incentives, and health and safety. After consideration, social acceptance (C4) [29,43–47] was selected to express social characteristics in the assessment procedure.

3.3. Data Collection and Analysis Methods

Eight in total, four for each case experts were selected as decision makers (DM1, DM2, DM3, DM4, DM5, DM6, DM7, and DM8) for each of the case studies (Gaidouromantra Microgrid and Ghoramara island), respectively, with industrial and academic experience of more than 20 years. The selection of a small number of experts (typically 3–5) for each case study is standard practice in many studies involving (MCDM) methods [48–52]. While it is true that individual biases can exist, the collective wisdom of a diverse panel tends to mitigate the influence of any single biased decision. Having a small panel of experts allows for more focused and efficient decision-making processes and is often easier to manage and obtain clear, actionable insights. The selected experts are designated as chief engineer for implementing solar energy projects, chief technical officer in a battery manufacturing organization, professor in energy management and technology, and finance head of a private organization involved in assessing financing, risk analysis, and project management of government projects in the energy sector. As the experts have similar levels of experience, they were selected as respondents to provide pair-wise responses based on a linguistic scale for the identified alternatives, i.e., seven potential business models for the CES system and four criteria. Thus, the weights of decision makers were considered uniform as $w = (0.25, 0.25, 0.25, 0.25)$ for both case studies. By using the linguistic rating variables, all DMs evaluated the criteria weight with the performance of each alternative under the criterion for the estimation of aggregated fuzzy weight [53] (Table 1). An estimated fuzzy matrix was normalized, and the decision matrix was defined. Further, to compute the preference index, the intuitionistic fuzzy distance was measured through the Hamming distance [54] to solve the pair-wise comparison of TFNs for each criterion. Finally, positive (entering) flow, negative (leaving) flow, and net flow (difference) were estimated. Upon applying the defuzzification of net flow, a ranking of the alternatives was achieved. The higher the value of net flow, the better the performance of the alternative.

Table 1. Linguistic variables for criterion weights and performance ratings.

For Importance Weights of Criteria		For Performance Ratings	
Linguistic Variables	Fuzzy Numbers	Linguistic Variables	Fuzzy Numbers
Very Low (VL)	(0, 0, 0.1, 0.2)	Very Poor (VP)	(0, 0, 1, 2)
Low (L)	(0.1, 0.2, 0.2, 0.3)	Poor (P)	(1, 2, 2, 3)
Medium Low (ML)	(0.2, 0.3, 0.4, 0.5)	Medium Poor (MP)	(2, 3, 4, 5)
Medium (M)	(0.4, 0.5, 0.5, 0.6)	Fair (F)	(4, 5, 5, 6)
Medium High (MH)	(0.5, 0.6, 0.7, 0.8)	Medium Good (MG)	(5, 6, 7, 8)
High (H)	(0.7, 0.8, 0.8, 0.9)	Good (G)	(7, 8, 8, 9)
Very High (VH)	(0.8, 0.9, 1, 1)	Very Good (VG)	(8, 9, 10, 10)

Steps for the Fuzzy PROMETHEE Method

Step 1:

The selection of decision makers with K decision makers DM_k ($k = 1, 2, \dots, K$). The fuzzy rating of each decision maker is represented as a trapezoidal fuzzy number $\tilde{R}_k$ ($k = 1, 2, \dots, K$).

Step 2:

Evaluation criteria are determined, and feasible alternatives are generated. Let there be m alternatives (A_m) and n criteria (C_n).

Step 3:

The next step is choosing linguistic variables and their corresponding trapezoidal fuzzy numbers (Figure 1). They are used for evaluating the relative importance of criteria weights and ratings of the alternatives under each criterion.

$$\mu_{\tilde{A}}(X) = \begin{cases} 0, & x < a_1, \\ \frac{(x-a_1)}{(a_2-a_1)}, & a_1 \leq x \leq a_2, \\ 1 & a_2 \leq x \leq a_3, \\ \frac{(x-a_4)}{(a_3-a_4)} & a_3 \leq x \leq a_4, \\ 0, & x > a_4, \end{cases}$$

Hamming distance: Given any two positive trapezoidal fuzzy numbers, $\tilde{A}$ is:

$$x_{\tilde{A}} = \frac{a_1 + a_2 + a_3 + a_4}{4}$$

$$d_H(A, B) = \sum_{j=1}^n |a_j - b_j|$$

The defuzzified value of $\tilde{A}$ is: $x_{\tilde{A}} = \frac{a_1 + a_2 + a_3 + a_4}{4}$.

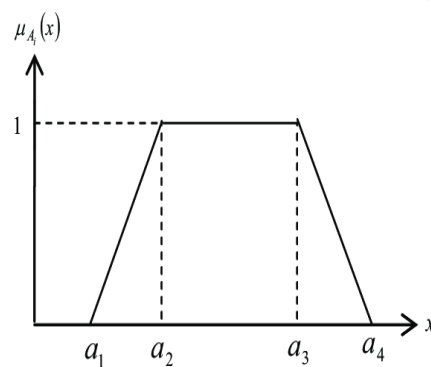


Figure 1. Trapezoidal fuzzy numbers.

Step 4:

Fuzzy ratings ($\tilde{X}_{ij}$) of alternatives under each criterion are aggregated as:

$$(\tilde{X}_{ij}) = (a_{ij}, b_{ij}, c_{ij}, d_{ij})$$

$$a_{ij} = \min_k \{a_{ijk}\}, b_{ij} = \frac{1}{K} \sum_{k=1}^K b_{ijk}, c_{ij} = \frac{1}{K} \sum_{k=1}^K c_{ijk}, d_{ij} = \max_k \{d_{ijk}\}$$

Then the fuzzy weights ($\tilde{w}_{ij}$) are aggregated as:

$$\tilde{w}_j = (w_j^i, w_j^p, w_j^q, w_j^r)$$

$$w_j^i = \min_k \{w_{jk}^i\}, w_j^p = \frac{1}{K} \sum_{k=1}^K w_{jk}^p, w_j^q = \frac{1}{K} \sum_{k=1}^K w_{jk}^q, w_j^r = \max \{w_{jk}^r\}$$

Step 5:

The fuzzy decision matrix is calculated as:

$$\tilde{D} = \begin{bmatrix} \tilde{X}_{11} & \cdots & \tilde{X}_{1n} \\ \vdots & \ddots & \vdots \\ \tilde{X}_{m1} & \cdots & \tilde{X}_{mn} \end{bmatrix}$$

$$\tilde{W} = [\tilde{w}_1, \tilde{w}_2, \dots, \tilde{w}_k]$$

where $\tilde{X}_{ij} = (a_{ij}, b_{ij}, c_{ij}, d_{ij})$ and $\tilde{w}_j = (w_j^i, w_j^p, w_j^q, w_j^r)$, $i = 1, 2, \dots, M$, $j = 1, 2, \dots, n$ can be approximated by positive trapezoidal fuzzy numbers.

Step 6:

The Fuzzy decision matrix is normalized with the linear normalization formulae as follows:

$$\tilde{R} = [\tilde{r}_{ij}]_{m \times n} \quad i = 1, 2, \dots, m, j = 1, 2, \dots, N$$

$$\tilde{r}_{ij} = [\frac{a_{ij}}{d_j^-}, \frac{b_{ij}}{d_j^-}, \frac{c_{ij}}{d_j^-}, \frac{d_{ij}}{d_j^-}]$$

where $d_j^- = \max_i d_{ij}$ if it belongs to the benefit criterion, $j \in \Omega_B$

$$\tilde{r}_{ij} = [\frac{a_j^-}{d_{ij}}, \frac{a_j^-}{c_{ij}}, \frac{a_j^-}{b_{ij}}, \frac{a_j^-}{a_{ij}}]$$

where $a_j^- = \min_i a_{ij}$ if it belongs to the cost criterion, $j \in \Omega_C$.

Step 7:

The weighted Normalized Fuzzy decision matrix $\tilde{V}$ is defined as:

$$\tilde{V} = \begin{bmatrix} \tilde{v}_{11} & \cdots & \tilde{v}_{1n} \\ \vdots & \ddots & \vdots \\ \tilde{v}_{m1} & \cdots & \tilde{v}_{mn} \end{bmatrix}$$

where $\tilde{V}_{ij} = \tilde{r}_{ij}(\cdot) \tilde{w}_j$ $i = 1, 2, \dots, m$ $j = 1, 2, \dots, n$ and here $\tilde{w}_j$ represents the importance weight of the criterion j .

Step 8:

The Hamming distance is used for comparing two alternatives g and f on each criterion. At first, the maximum between two fuzzy numbers is computed so their lowest upper bound is determined to find $\max(\tilde{V}_{gj}, \tilde{V}_{fj})$. Then the Hamming distances $d(\max(\tilde{V}_{gj}, \tilde{V}_{fj}), \tilde{V}_{gj})$ and $d(\max(\tilde{V}_{gj}, \tilde{V}_{fj}), \tilde{V}_{fj})$ are calculated. $\tilde{V}_{gj} \geq \tilde{V}_{fj}$, if and only if $d(\max(\tilde{V}_{gj}, \tilde{V}_{fj}), \tilde{V}_{fj}) \geq d(\max(\tilde{V}_{gj}, \tilde{V}_{fj}), \tilde{V}_{gj})$. Otherwise, $\tilde{V}_{gj} < \tilde{V}_{fj}$ if and only if $d(\max(\tilde{V}_{gj}, \tilde{V}_{fj}), \tilde{V}_{fj}) < d(\max(\tilde{V}_{gj}, \tilde{V}_{fj}), \tilde{V}_{gj})$.

Then the preference function is constructed as:

$$P_j(g, f) = \begin{cases} d(\max(v_{gj}, v_{fj}), v_{gj}) & \tilde{V}_{gj} < \tilde{V}_{fj} \\ d(\max(v_{gj}, v_{fj}), v_{fj}) & \tilde{V}_{gj} \geq \tilde{V}_{fj} \end{cases}$$

Step 9:

The fuzzy preference index is calculated to determine the value of the outranking relation ($j = 1, 2, \dots, n$):

$$\tilde{\pi}(g, f) = \frac{\sum_{j=1}^n \tilde{W}_j P_j(g, f)}{\sum_{j=1}^n \tilde{W}_j}$$

Step 10:

Calculation of Positive flows ($\tilde{\phi}^+(g)$) and Negative flows ($\tilde{\phi}^-(g)$) by using the following formulas:

$$\tilde{\phi}^+(g) = \sum_{\substack{f=1 \\ f \neq g}}^m \tilde{\Pi}[g, f]$$

$$\tilde{\phi}^-(g) = \sum_{\substack{f=1 \\ f \neq g}}^m \tilde{\Pi}[g, f]$$

Step 11:

Net flow is calculated as the difference between the values of Positive flows ($\tilde{\phi}^+(g)$) and Negative flows ($\tilde{\phi}^-(g)$).

Step 12:

Finally, the preference ranking of each alternative is performed based on the Net flow scores.

4. Case Studies*4.1. Description of the Local Energy System and Business Models in the Case Study**4.1.1. Case Study I: Gaidouromantra, Kythnos Island, Greece [55,56]*

Gaidouromantra is a small settlement of 14 vacation houses located in a small valley next to the coast in the southern part of Kythnos Island. It is isolated from the rest of the Kythnos grid; thus, the electricity supply is provided by a permanently islanded microgrid, with 100% renewables since 2001 when it was upgraded. Gaidouromantra was the first microgrid developed in Europe and has been the pilot test for advanced technologies based on renewable energies, batteries, and decentralized technologies for demand-side management (DSM).

The consumption profile is typical for holiday homes, i.e., consumption is very high in summer and very low in non-holiday periods. Several power converters were installed to improve the operation and to test different control strategies (intelligent) to monitor the house power line, as well as the voltage, current, and frequency. The existing electric infrastructure of the Gaidouromantra microgrid includes the following components and topology:

- 11.145 kW of solar PV panels: 6 solar PV plants (rooftop and ground-mounted).
- System house: 1.920 kWp connected to 3 inverters is the center of the microgrid for housing the energy storage battery, the diesel generator, grid inverters, and communication equipment for monitoring.
- A Lead-Acid battery bank with a nominal capacity of 1000 Ah/11,900 Wh/48 V, connected through 3 single-phase battery inverters. During the daytime, the battery bank is connected to the AC, while at night, it is disconnected, and a secondary system covers the control and monitoring equipment needs.
- One new battery system with a capacity storage of 96 kWh Valve Regulated Tubular Plate GEL Batteries (only when there is no solar PV production, and the batteries are deeply discharged).
- 3-phase microgrid composed of overhead power lines and a communication cable running parallel.
- A 3-phase diesel generator of 22 kVA.

The total electricity production of solar PV panels and the diesel generator is around 4.7 MWh/year. Agent-based software/hardware for centralized and distributed control provides protection against overloading or extreme battery discharge in each house. Battery inverters play the role of energy management, regulating frequency either for load

shedding or for solar PV derating. Furthermore, they manage the diesel generator start-up. Consumption on the island is limited to some electric appliances only (e.g., lamps, refrigerators, and dwelling pumps). Most of this consumption can be shifted to moments when the solar PV generation is higher, for example, water pumping. All the houses of the microgrid are connected using 3-phase voltage overhead AC power lines, operating at 230 V, and a communication cable runs parallel to the power lines. The low-voltage system is formed by the battery inverters. There is no necessity for heating since the houses are only used in the summer holidays. A major problem is the overloading of the batteries when many houses reach their maximum demand at the same time. Thus, users of the microgrid have a grid-oriented energy culture, instead of a culture of autonomous energy supply. For this reason, it is important to reach a combination of technical and behavioral demand responses to ensure that energy management is optimized.

As for the electricity price in Gaidouromantra, the local consumers have to pay a low price based on their consumption comprising only the fuel cost and the operation and maintenance cost of the microgrid. However, as the microgrid is not connected to the rest of Greece's power system, the tariff does not include the power term. This means that there are neither balancing services nor is the security of supply guaranteed. The microgrid is not operated by any specialized entity or private or public body. In the past, CRES (Centre for Renewable Energy Sources and Saving), a public company, oversaw the operation and maintenance of the Gaidouromantra microgrid. However, after the funding from EU research projects stopped, this maintenance was neglected, and electricity bills were no longer issued. In 2019, the project Kythnos Smart Island [57], by DAFNI and ICCS-NTUA, gave the opportunity to renovate the microgrid and create a new business model to guarantee the long-term sustainability of the microgrid. The investment cost is not covered by the users or "owners" of the local community but has been paid by different European projects. This reduces the need for future income. Likely, if the cost of the project was not covered by these European projects, the project would not be economically feasible.

4.1.2. Case Study II: Ghoramara Island, West Bengal, India [55,56]

Ghoramara Island has no grid connectivity, and the only mode of transportation is a ferry, which highly constrains mobility, creating logistic issues. It is characterized by severe weather conditions and the region is severely affected every 5–10 years due to cyclonic storms. Approximately 3000 inhabitants (1100 households) are residents, and the island area is approximately 5 km². There is a local village council, i.e., elected gram panchayat, for implementing various government welfare schemes and programs. The island has a gram panchayat office, two primary schools, one higher secondary school (approximately 420 students enrolled), a primary healthcare center, a relief center, a kiosk, and some shops located in the central area of the island. The nearest mainland is Kakdwip, which is approximately 5 km away and takes around an hour via diesel-operated boats.

The proposed 250 kW solar wind microgrid local energy system (230 kW conventional technology + 20 kW from the H2020 RE-EMPOWERED project) and assets will be deployed and demonstrated on the island. The area is isolated from the main utility grid, inhabitants rely on kerosene lamps, and a few households have PV panels installed on their rooftops. Two rice-cum-hauler mills are run by a diesel engine. The residents have no access to electricity and no normal access to the Internet.

- The utility grid is not available on the island with no future scope.
- A 3 kW wind turbine was installed near the school, but the system was damaged during a cyclone and is inoperative.
- Discrete solar panels are installed on the rooftops of individual houses and shops used for mobile charging and glowing LED lamps (one/two in number).
- Around 100 streetlights with solar panels were also found inoperative.
- Six e-rickshaws are currently running on the island, and charging is performed through a diesel generator.
- The following components are planned for the proposed solar wind microgrid:

- AC microgrid #1: 150 kW capacity (240 kW PV + 5 kW Wind turbine (02)).
- AC microgrid #2 for testing of eco-toolsets 20 kW capacity (17.5 kW PV + 2.5 kW Wind turbine).
- Load flow controller, power conditioner, converters, battery energy storage system, load limiter, charging facility (12.5 kW approximately, with 5 ports and one advanced charger).
- Electric three-wheelers (02) and one electric boat with the capacity to carry 15 passengers.
- Dimmable streetlights (05), stand-alone high-mast, distribution infrastructure.
- Cyclone-resilient structure for solar and wind turbine.
- Remote monitoring system.

The fixed tariff is planned to be charged to households for residential purposes provided during the evening for four to six hours, with commercial rates for operating pumps for agricultural purposes, mills, charging of e-vehicles, shops, etc.

4.2. Regulatory Background

It is important to note that specific business models and revenue streams may vary depending on local regulations, market conditions, and the specific characteristics of the CES system and its integration into the energy ecosystem. Regarding the local regulations, the regulatory framework governing energy storage and renewable energy differs across regions and countries. It is crucial to understand the specific regulations and policies in place that may impact the operation, deployment, and revenue generation of CES systems. These regulations may include interconnection standards, tariff structures, grid codes, and incentives provided by the government. Adhering to and leveraging these regulations can help shape the business model and revenue generation strategies for CES operators.

Moreover, the market dynamics and conditions play a significant role in shaping business models for CES. Factors such as electricity demand patterns, energy market structures, pricing mechanisms, and competition from conventional energy sources impact the revenue potential of CES systems. Market assessments should be conducted to determine the optimal business model, considering factors such as the size of the target market, the level of demand for energy storage services, and the competitive landscape. Understanding the market conditions helps to identify the most viable revenue streams and pricing models.

4.2.1. Europe

Europe has made significant strides in promoting renewable energy and advancing the transition to a sustainable energy system. Key policies and regulations have been established to drive the deployment of renewable energy sources, encourage energy storage technologies, foster competitive energy markets, and empower energy communities.

At the core of Europe's renewable energy efforts is the Renewable Energy Directive (RED), which sets binding targets for EU member states to increase the share of renewable energy in their energy consumption. The current target is to achieve a 32% share of renewable energy by 2030. To incentivize renewable energy generation, countries have implemented mechanisms such as Feed-in Tariffs (FiTs). FiTs guarantee a fixed payment rate for renewable energy producers for a specific period, encouraging investment in renewable energy projects. However, there is a growing trend towards competitive auction mechanisms, where renewable energy projects compete for contracts based on their cost-effectiveness, fostering market competition and driving down costs.

Recognizing the importance of energy storage in facilitating the integration of renewable energy into the grid, Europe has been actively addressing the regulatory aspects of energy storage technologies. The European Battery Regulation proposes sustainability, performance, and safety requirements for batteries placed on the market, aiming to support the growth of battery storage systems. Additionally, network codes and market rules are being developed to enable the participation of energy storage systems in the electricity grid, ensuring fair access and allowing storage to provide valuable grid services.

Europe has been working on modernizing its energy markets to accommodate the evolving energy landscape. The Clean Energy Package, comprising several legislative acts, aims to transform the European electricity market and facilitate the integration of renewable energy. Market coupling and intraday trading mechanisms are being introduced to enhance market efficiency, while demand response and flexibility services are being promoted to optimize grid management. Transparency and fair competition are also prioritized through regulations such as the Wholesale Energy Market Integrity and Transparency (REMIT), which requires market participants to disclose inside information and report wholesale energy market transactions.

Furthermore, Europe recognizes the power of empowering energy communities and encouraging active consumer participation. The Clean Energy Package acknowledges the concept of energy communities, granting individuals and communities the right to self-consume, produce, store, and sell renewable energy locally. This recognition facilitates the formation and operation of energy communities, allowing consumers to actively contribute to the energy transition. Some countries have implemented specific regulations tailored to energy communities, defining their rights, responsibilities, and regulatory frameworks, further supporting local energy initiatives.

It is important to note that while European Union policies provide a framework, individual member states have the flexibility to adapt and implement measures that align with their specific circumstances. Consequently, policies and regulations may vary across countries. Additionally, the renewable energy, energy storage, energy markets, and energy communities landscape continue to evolve as policy developments and technological advancements shape the future of Europe's sustainable energy sector.

Greece:

In Greece, the regulatory framework for renewable energy, energy communities, and energy storage has undergone several developments and amendments over the years. One significant aspect is the implementation of ten-year renewable energy contracts between independent producers and the System Operator.

The feed-in tariff structure plays a crucial role in the regulatory framework. The tariff, paid, consists of an energy charge and a capacity charge, except for non-interconnected islands where only the energy charge is applicable.

Law 3851/2010 set ambitious targets for renewable energy, including a 20% share in gross final energy consumption, a 40% share in gross electricity consumption, a 20% share in heating and cooling, and a 10% share in transport by 2020. The law also created the Special Renewable Energy Investment Service to facilitate investments and manage funding allocation. Additionally, it introduced a credit-sharing mechanism to allocate a portion of taxes paid by renewable energy producers to local households as credits on their electricity bills.

Several programs were launched to promote energy efficiency and renewable energy projects. These include the EXOIKONOMO programs, which incentivized citizens and municipalities to undertake energy-saving measures, and the "Building the future" program, which focused on reducing energy consumption in buildings through financial instruments and energy performance contracts.

Net metering and virtual net metering systems were introduced in 2014 and 2016, respectively, allowing autonomous producers and diverse entities to develop solar PV and wind energy projects. The regulatory framework also witnessed a shift from feed-in tariffs to feed-in premiums in 2016. Producers now receive additional remuneration in the wholesale electricity markets, requiring participation and balancing responsibilities.

The targets set for the integration of renewable energy, initially established in the National Renewable Energy Action Plan and Law 3851/2010 back in 2010, have been revisited and revised within the framework of the National Energy and Climate Plan starting from 2020. These objectives encompass the following key points:

- By the year 2030, the proportion of renewable energy in the overall final energy consumption is targeted to be no less than 35%.
- The share of renewable electricity in the total gross final electricity consumption is aimed to reach a minimum of 60% by 2030.
- To fulfill the energy needs for heating and cooling, it is intended that renewable energy's contribution exceeds 40% of the final energy consumption by 2030.
- In the domain of transportation, the aspiration is for renewable energy to constitute more than 14% of the total energy consumption within the transportation sector by 2030.
- A significant reduction of greenhouse gas emissions by either 40% in comparison to 1990 levels or 55% relative to the levels recorded in 2005 is sought to be achieved by 2030.

To accomplish these targets, competitive bidding processes will be periodically initiated to promote commercially mature renewable energy technologies. Additionally, these technologies will be mandated to actively participate in the market. Specific renewable energy ventures, particularly those of high domestic value, can be granted financial assistance. Moreover, the streamlining and optimizing of licensing procedures are envisioned.

Notably, the provisions of Law 4685/2020 encompass the issuance of producer's certificates by the Regulatory Authority for Energy. This initiative is aimed at simplifying the licensing process for power-plant establishment.

Overall, Greece's regulatory framework has evolved to encourage renewable energy development, streamline licensing procedures, and promote energy efficiency measures. The country has set ambitious targets and implemented various support mechanisms to accelerate the transition towards a sustainable and clean energy future. In this context, it seems that there are efforts to promote new business models, integrating more RES and storage.

4.2.2. India

West Bengal:

In West Bengal, the government has set ambitious targets for renewable energy capacity. The First Renewable Energy Policy, launched in 2012, aimed to reach 2706 MW of capacity from renewable energy sources, including cogeneration, by 2022. However, the Energy Policy was revised in 2016, increasing the target to 5336 MW for solar PV power plants, encompassing large-scale grid-connected projects and rooftop installations. Subsequently, the target was reviewed and scaled down to 4500 MW.

To fulfill its Renewable Energy Purchase Obligations, the West Bengal State Electricity Distribution Company Limited (WBSEDCL) procures renewable energy from other sources. As of 2018, West Bengal had already installed 80 MW of solar PV capacity, with expectations of reaching 200 MW within a year, largely driven by private stakeholders.

India is expected to become one of the most significant markets for renewable energy [58]. The revised renewable energy targets direct policy formulation and regulatory initiatives for promoting technologies towards the reduction in carbon emission and achieving net zero faster than the targeted timeline. Hence, CES business models will become essentially relevant for real-time deployment and demonstration, not only in rural communities but also in urban settlements.

The government has taken significant steps to promote renewable energy in the state. The West Bengal Renewable Energy Development Agency (WBREDA) and the West Bengal Green Energy Development Corporation Limited (WBGEDCL), a public-private partnership, have been established to encourage private sector investment and increase the penetration of renewable energies. WBSEDCL acts as the state agency on behalf of the state of West Bengal for procurement of renewable energy from organizations like Solar energy corporation of India limited (SECI) through power sale agreements. All the tariffs and other terms of purchase, as well as provisions of suitable laws such as the intra-state Availability Based Tariff (ABT), state grid code, etc., and compliances are performed by this agency. It is

one of the major stakeholders in renewable energy initiatives, thus any dedicated programs for CES may be designed to adopt environmentally friendly technology and models for enabling clean energy with zero emissions goal.

West Bengal has taken significant steps to promote renewable energy adoption, set renewable energy targets, and implement policies that encourage energy efficiency. These efforts are crucial for the sustainable development and future energy security of the respective states. Both WBREDA and WBGEDCL play instrumental roles in identifying untapped opportunities, which serve as potential avenues for renewable energy business models. Additionally, they are actively engaged in crafting comprehensive policy recommendations aimed at promoting the proliferation of financially viable renewable energy ventures. These recommendations not only facilitate the dissemination of successful renewable energy practices but also lay the groundwork for a supportive legal framework, grounded in established and tested laws.

4.3. Application of the Proposed Methodology

It is necessary to involve citizens in the use of advanced demand response tools to adapt their consumption to the availability of energy, promote a behavioral change from adapting consumption to avoid overloads and adapt it to the availability of electricity produced with the solar PV plant, and minimize the use of diesel generator. On the other hand, to create an energy community to promote CES systems, users should be aware of the benefits stemming from it in order to accept the probable cost–benefit understanding for electricity prices. It is critical to identify the group of stakeholders. Local people's participation with local authorities will be of the utmost importance for the successful implementation and functioning of CES business models. Moreover, CES providers can focus on developing and supplying CES technologies, including hardware, software, and control systems. They can offer turnkey solutions for communities and utilities, providing CES equipment, installation, and integration services. CES providers can act as developers and investors in CES projects, partnering with communities, utilities, or other stakeholders. They can identify suitable locations, secure financing, develop the CES infrastructure, and monetize the energy storage assets through long-term contracts, energy trading, or ancillary services. This requires expertise in project development, risk management, and financial analysis. Table 2 summarizes the relevant stakeholders and their key activities.

Table 2. Stakeholders' Engagement and Key Activities for CES system.

Stakeholder's	Key Activities
All residents, house owners and other consumers of the network, if any	Membership of the energy cooperative Equity ownership, energy storage developer or investor Respond to demand response requests and adapt tools
CES Aggregators	Developers and investors in CES projects with community / utilities Manages storage units and provide performance data Providers of the range of services and consultancy for CES system Developing and supplying CES technology and infrastructure Partnership with manufacturers, system integrators, software developers Energy trading and management, financial accounting
Manufacturers of equipment	Maintenance of energy storage devices and equipment Replacement of storage equipment
Local public authorities	To support residents in management of such energy community
R&D partners and Technical experts	Demonstration of new storage technologies and algorithms as pilot and test model
Other investors	Funding the CES development plans
Citizen organizations and fora	Identification of potential new members of the energy community Channelizing crowdfunding for CES projects for energy communities

It is important to note that the specific business models and revenue streams may vary depending on local regulations, market conditions, and specific requirements and objectives of the utility (Table 3).

Table 3. Potential Revenue Streams for the Proposed CES Business Models.

Proposed CES Business Model	Potential Revenue Streams
Community Cooperative (CC) Model	• Membership fees or revenue sharing in the community cooperative model. • Development fees, equity ownership, or project financing returns as an energy storage developer and investor.
Energy Arbitrage (EA) Model	• <u>Energy Trading</u>: Aggregator can participate in energy markets, buying electricity at low prices and selling it at higher prices during peak periods, thus generating revenue from price differentials. • <u>Grid Services</u>: CES system can provide ancillary services to the grid, like frequency regulation, voltage support, or grid stability. Aggregator can offer these services to grid operator and receive compensation.
Energy Arbitrage Peak Shaving (EA-PS) Model	• <u>Demand Response</u>: CES system can be utilized for demand response programs, where electricity consumption is adjusted based on grid conditions or price signals. Aggregator can participate and earn incentives for reducing or shifting electricity demand during peak periods. • <u>Capacity Markets</u>: Depending on local regulatory structure, CES system may be eligible to participate in capacity markets, receiving payments for providing reliable capacity to the grid.
Emission Reduction and Var Support (ER-VS)	• <u>Service fees</u>: CES providers can charge service fees for emission reduction and/or Var support • <u>Equipment sales or leasing</u>: CES providers can generate revenue by selling or leasing CES units and associated energy storage technologies to utilities. • <u>Performance-based contracts</u>: CES providers can enter into performance-based contracts with utilities, where they receive payments based on the achieved energy savings, emission reductions, or system improvements.
Cost-Emission Optimization and Energy Loss Reduction (CEO-ELR) Model	• <u>Service fees</u>: CES can charge fees for energy loss reduction, system upgrade deferral, emission reduction, grid services. • <u>Consulting and advisory services</u>: CES providers can offer consulting and advisory services to utilities on CES system optimization, financial evaluations, and regulatory compliance. • <u>Energy market participation</u>: CES systems can participate in energy markets, selling stored energy during high-demand periods or when electricity prices are favorable. • <u>Demand response programs</u>: CES systems can participate in demand response programs, reducing or shifting electricity consumption based on grid conditions or price signals, and earning incentives. • <u>Carbon offset or emission reduction credits</u>: CES systems can generate revenue by reducing greenhouse gas emissions, which can be monetized through carbon offset schemes or sold to entities seeking to offset their emissions.
Aggregated Energy Services (AES) Model	• <u>Service fees</u>: CES providers can charge service fees for demand load shifting services, energy cost optimization, grid decarbonization support, installation services, and ongoing maintenance contracts as a technology provider and integrator • <u>Equipment sales or leasing</u>: CES providers can generate revenue by selling or leasing CES systems, including the associated energy storage technologies, to residential communities. • <u>Performance testing and evaluation</u>: CES providers can charge fees for conducting battery technology evaluations and providing performance data and analysis to stakeholders in the energy industry. • <u>Consulting and advisory services</u>: CES providers can offer consulting and advisory services to homeowners, utilities, or government entities on CES system deployment, optimization strategies, and policy implications. • <u>Subscription</u>: or usage-based fees for providing CES as a service. Licensing or subscription fees for energy management and optimization software platforms.
Vehicle-to-Microgrid (VTMG) Model	• <u>Service fees</u>: CES system can offer price responsive charging, EV optimisation services to EV owners and balancing or support to microgrid on fee basis.

These business models can intensify access to community participation, through more space in the energy network to support electrification, e-mobility, carbon reduction, and create new energy services to enhance income for sustenance. CES providers can widen the range of local energy strategies that communities and individuals can use to meet their needs, based on their local situation, e.g., to use in conjunction with energy trading and energy efficiency initiatives [56].

4.4. Results of the Analysis

In this paper, the proposed business models for the CES system were selected as alternatives, using the identifier (A): CC (A1), EA (A2), EA-PS (A3), ER-VS (A4), CEO-ELR (A5), AES (A6), and VTMG (A7). Based on a previous study [29,41,46,47], the criteria were determined: Energy efficiency (C1), investment and operation cost (C2), reduction in CO₂ emissions (C3), and social acceptance (C4), where C2 is the cost criteria while others are the benefit criteria. Aggregated fuzzy weights of criteria were calculated and provided below (Table 4). Similarly, the results of the performance of each alternative under a certain criterion are evaluated by the four DMs, and the aggregated fuzzy weights are obtained (Tables 5 and 6).

Table 4. The weight of criteria and aggregated fuzzy weight.

Criteria	Gaidouromantra Microgrid					Ghoramara Island				
	DM ₁	DM ₂	DM ₃	DM ₄	Aggregated Fuzzy Weight	DM ₁	DM ₂	DM ₃	DM ₄	Aggregated Fuzzy Weight
C1	H	M	H	M	(0.4, 0.675, 0.7, 1)	H	H	VH	M	(0.4, 0.75, 0.775, 1)
C2	M	H	H	M	(0.4, 0.65, 0.65, 0.9)	M	M	MH	H	(0.4, 0.6, 0.625, 0.9)
C3	VH	H	VH	H	(0.7, 0.825, 0.85, 1)	MH	VH	H	H	(0.5, 0.775, 0.825, 1)
C4	M	M	H	M	(0.4, 0.575, 0.575, 0.9)	H	H	H	VH	(0.7, 0.825, 0.85, 1)

Table 5. Weighted normalized fuzzy matrix for Gaidouromantra microgrid.

Alternatives	C1	C2	C3	C4
A1	(0.28, 0.57, 0.63, 1)	(0.20, 0.46, 0.49, 0.81)	(0.35, 0.62, 0.66, 0.90)	(0.22, 0.48, 0.50, 0.90)
A2	(0.28, 0.59, 0.67, 1)	(0.20, 0.46, 0.49, 0.81)	(0.35, 0.56, 0.66, 1)	(0.22, 0.45, 0.48, 0.90)
A3	(0.20, 0.54, 0.61, 1)	(0.28, 0.54, 0.55, 0.90)	(0.28, 0.50, 0.53, 0.90)	(0.22, 0.48, 0.50, 0.90)
A4	(0.20, 0.49, 0.56, 1)	(0.28, 0.55, 0.59, 0.90)	(0.28, 0.56, 0.60, 0.90)	(0.18, 0.46, 0.46, 0.90)
A5	(0.20, 0.47, 0.53, 0.90)	(0.20, 0.47, 0.52, 0.90)	(0.35, 0.54, 0.62, 0.90)	(0.22, 0.45, 0.48, 0.90)
A6	(0.20, 0.51, 0.54, 0.90)	(0.20, 0.54, 0.60, 0.90)	(0.35, 0.56, 0.66, 1)	(0.22, 0.42, 0.46, 0.90)

Table 6. Weighted normalized fuzzy matrix for Ghoramara island.

Alternatives	C1	C2	C3	C4
A1	(0.28, 0.64, 0.70, 1)	(0.20, 0.44, 0.50, 0.90)	(0.25, 0.62, 0.72, 1)	(0.28, 0.56, 0.60, 0.90)
A2	(0.16, 0.53, 0.58, 1)	(0.20, 0.44, 0.50, 0.90)	(0.25, 0.50, 0.60, 0.90)	(0.35, 0.60, 0.68, 1)
A3	(0.16, 0.49, 0.56, 1)	(0.20, 0.45, 0.48, 0.81)	(0.20, 0.56, 0.66, 1)	(0.35, 0.60, 0.68, 1)
A4	(0.16, 0.53, 0.58, 1)	(0.16, 0.39, 0.45, 0.90)	(0.25, 0.52, 0.64, 1)	(0.35, 0.60, 0.68, 1)
A5	(0.16, 0.43, 0.45, 0.90)	(0.16, 0.39, 0.45, 0.90)	(0.25, 0.60, 0.68, 1)	(0.28, 0.56, 0.60, 0.90)
A6	(0.16, 0.60, 0.68, 1)	(0.20, 0.45, 0.48, 0.81)	(0.25, 0.58, 0.70, 1)	(0.35, 0.54, 0.62, 0.90)
A7	(0.16, 0.56, 0.60, 1)	(0.20, 0.39, 0.45, 0.81)	(0.20, 0.45, 0.54, 0.80)	(0.28, 0.58, 0.64, 1)

The preference index is derived (Tables 7 and 8), and the leaving or positive flow, entering or negative flow, net flow (difference between positive and negative flow), and overall ranking (Table 9) are finally estimated. In the Appendix, Tables A1–A3 show pairwise comparisons and preferences for each of the criteria.

From the values of positive flows ($\tilde{\phi}^+(g)$) and negative flows ($\tilde{\phi}^-(g)$), the net flow is calculated, which defines the ranking of the respective BMs. Here, $A1 > A2 > A3 > A6 > A5 > A4$ for the Gaidouromantra microgrid, which means that A1 is preferred over other BMs. Similarly, for Ghoramara island, $A1 > A2 > A3 > A4 > A5 > A6 > A7$ (Table 10). In both cases, the top three ranking BMs are the same, i.e., Community Cooperative, Energy Arbitrage, and Energy Arbitrage Peak Shaving (Figures 2 and 3).

Table 7. Preference index for Gaidouromantra microgrid.

Alternatives	A1	A2	A3
A1		(0.029, 0.052, 0.055, 0.103)	(0.106, 0.202, 0.209, 0.388)
A2	(0, 0, 0, 0)		(0.124, 0.235, 0.245, 0.458)
A3	(0, 0, 0, 0)	(0, 0, 0, 0)	
A4	(0, 0, 0, 0)	(0, 0, 0, 0)	(0, 0, 0, 0)
A5	(0, 0, 0, 0)	(0, 0, 0, 0)	(0, 0, 0, 0)
A6	(0, 0, 0, 0)	(0, 0, 0, 0)	(0, 0, 0, 0)
	A4	A5	A6
A1	(0.109, 0.220, 0.228, 0.443)	(0.083, 0.174, 0.181, 0.358)	(0.094, 0.198, 0.205, 0.409)
A2	(0.118, 0.237, 0.246, 0.475)	(0.091, 0.188, 0.197, 0.382)	(0.076, 0.171, 0.177, 0.361)
A3	(0.049, 0.093, 0.097, 0.187)	(0.087, 0.172, 0.179, 0.344)	(0.106, 0.195, 0.204, 0.378)
A4		(0.063, 0.130, 0.134, 0.264)	(0.071, 0.311, 0.136, 0.253)
A5	(0, 0, 0, 0)		(0.056, 0.105, 0.109, 0.205)
A6	(0, 0, 0, 0)	(0, 0, 0, 0)	

Table 8. Preference index for Ghoramara island.

Alternatives	A1	A2	A3	A4
A1		(0.132, 0.250, 0.272, 0.492)	(0.127, 0.242, 0.262, 0.483)	(0.125, 0.235, 0.255, 0.471)
A2	(0.097, 0.165, 0.180, 0.318)		(0.045, 0.090, 0.099, 0.186)	(0.034, 0.066, 0.073, 0.140)
A3	(0.086, 0.143, 0.155, 0.281)	(0.045, 0.090, 0.099, 0.186)		(0.027, 0.054, 0.059, 0.117)
A4	(0.125, 0.235, 0.255, 0.471)	(0.034, 0.066, 0.073, 0.140)	(0.027, 0.054, 0.059, 0.117)	
A5	(0.091, 0.207, 0.223, 0.429)	(0.136, 0.256, 0.278, 0.512)	(0.108, 0.199, 0.215, 0.398)	(0.102, 0.190, 0.205, 0.372)
A6	(0.053, 0.103, 0.112, 0.211)	(0.105, 0.194, 0.211, 0.387)	(0.078, 0.144, 0.156, 0.283)	(0.087, 0.158, 0.172, 0.318)
A7	(0.156, 0.304, 0.333, 0.614)	(0.083, 0.153, 0.167, 0.312)	(0.101, 0.192, 0.211, 0.384)	(0.094, 0.176, 0.193, 0.351)
	A5	A6	A7	
A1	(0.091, 0.207, 0.223, 0.398)	(0.053, 0.103, 0.112, 0.211)	(0.156, 0.304, 0.333, 0.614)	
A2	(0.136, 0.256, 0.278, 0.512)	(0.105, 0.194, 0.211, 0.387)	(0.083, 0.153, 0.167, 0.312)	
A3	(0.109, 0.199, 0.215, 0.398)	(0.078, 0.144, 0.156, 0.283)	(0.101, 0.192, 0.211, 0.384)	
A4	(0.102, 0.190, 0.205, 0.372)	(0.087, 0.158, 0.172, 0.318)	(0.094, 0.176, 0.193, 0.351)	
A5		(0.084, 0.178, 0.192, 0.366)	(0.148, 0.294, 0.321, 0.590)	
A6	(0.084, 0.178, 0.192, 0.366)		(0.121, 0.228, 0.251, 0.455)	
A7	(0.148, 0.294, 0.321, 0.590)	(0.092, 0.185, 0.204, 0.374)		

Table 9. Business models ranking for Gaidouromantra.

Gaidouromantra Microgrid			
	Positive Flow	Negative Flow	Net Flow
Energy Arbitrage (A1)	0.961	0.000	0.961
Energy Arbitrage Peak Shaving (A2)	0.945	0.060	0.886
Emission Reduction and VAr Support (A3)	0.523	0.492	0.031
Vehicle-to-Microgrid (A6)	0.295	0.625	−0.330
Aggregated Energy Services (A5)	0.119	0.756	−0.637
Cost Emission Optimization and Energy Loss Reduction (A4)	0.000	0.910	−0.910

Table 10. Business models ranking for Ghoramara.

Ghoramara Microgrid			
	Positive Flow	Negative Flow	Net Flow
Community Cooperative (A1)	1.5387	0.014	1.525
Energy Arbitrage (A2)	0.8815	0.294	0.588
Energy Arbitrage Peak Shaving (A3)	0.6893	0.427	0.263
Emission Reduction and VAr Support (A4)	0.6259	0.446	0.180
Cost Emission Optimization and Energy Loss Reduction (A5)	0.5646	1.016	−0.451
Aggregated Energy Services (A7)	0.3324	0.919	−0.587
Vehicle-to-Microgrid (A7)	0.0408	1.558	−1.517

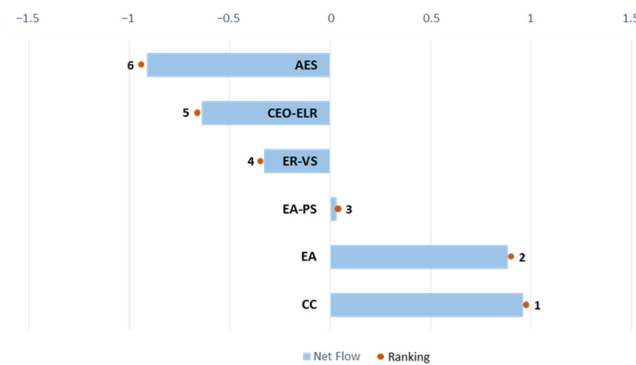


Figure 2. Net Flow and Ranking of CES Business Models for Gaidouromantra microgrid.

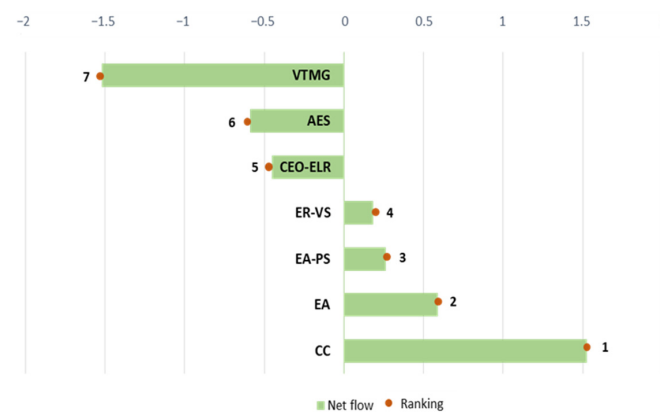


Figure 3. Net Flow and Ranking of CES Business Models for Ghoramara Island.

The Community Cooperative model is most suitable in both cases. This is critical as both of them lack an established energy community or cooperative for the monitoring and operation of the assets, while it is imperative to have a legal entity to run various proposed services.

The transformation of the energy system indicates the futuristic prominence of the CES system as demonstration projects play a pivotal role in showing the operation of CES systems in practice, with emerging business and regulatory models. CES reinforces the participation, duties, and control of cooperative communities because they can share energy storage in a localized manner depending on their use, in conjunction with the market and governance conditions. Technological, social, and behavioral alignment of the communities and CES lies in its design, implementation, and operation.

4.5. Sensitivity Analysis

A sensitivity analysis was conducted to evaluate the impact of the criteria weights on maintenance business models [59]. Therefore, 16 experiments were conducted by varying the criteria weights in the proposed model and observing the ranking of the alternatives. As detailed in Tables 11 and 12, the criteria weights were varied, ranging from (0,0,0.1,0.2), (0.1,0.2,0.2,0.3), (0.2,0.3,0.4,0.5), (0.4,0.5,0.5,0.6), (0.5,0.6,0.7,0.8), (0.7,0.8,0.8,0.9), and (0.8,0.9,1,1) by reversing the criteria from the proposed model with different permutations and combinations. The results indicate that among all of the experiments conducted, business model CC (A1) is the top-ranked model, followed by EA (A2), for both case studies. From experiments E1 to E16, the results (Figures 4 and 5) show that when the weightage of all the criteria was altered—energy efficiency, investment and operation cost, reduction in CO₂ emissions, and social acceptance—it does not affect the final ranking. Therefore, it can be concluded that regardless of the criteria weights, business models CC and EA consistently retain the leading position, thereby demonstrating that the proposed fuzzy PROMETHEE II approach is robust and stable to criterion weights with validation.

Table 11. Sensitivity analysis for Gaidouromantra.

Expt.	Definition	Net Flow						Ranking
		A1	A2	A3	A4	A5	A6	
E1	$W_{A1:A6}=(0.8,0.9,1,1)$	1.18801	1.10080	0.02157	−0.45179	−0.77337	−1.08521	A1 > A2 > A3 > A4 > A5 > A6
E2	$W_{A1:A6}=(0.7,0.8,0.8,0.9)$	0.89425	0.89312	0.06800	−0.33044	−0.64423	−0.88070	A1 > A2 > A3 > A4 > A5 > A6
E3	$W_{A1:A6}=(0.5,0.6,0.7,0.8)$	0.75674	0.57366	0.10599	−0.23080	−0.49731	−0.708282	A1 > A2 > A3 > A4 > A5 > A6
E4	$W_{A1:A6}((0.7,0.8,0.8,0.9)=(0.8,0.9,1,1))$	1.03011	0.94553	0.02277	−0.36185	−0.66975	−0.96681	A1 > A2 > A3 > A4 > A5 > A6
E5	$W_{A1:A6}((0.7,0.8,0.8,0.9)=(0.5,0.6,0.7,0.8))$	0.81353	0.63207	0.12596	−0.22433	−0.55614	−0.79110	A1 > A2 > A3 > A4 > A5 > A6
E6	$W_{A1:A6}((0.7,0.8,0.8,0.9) \mid (0.8,0.9,1,1)=(0,0,1,0.2))$	0.23573	0.09424	0.01390	−0.04953	−0.12826	−0.16608	A1 > A2 > A3 > A4 > A5 > A6
E7	$W_{A1:A6}((0.7,0.8,0.8,0.9)=(0.1,0.2,0.2,0.3) \mid (0.8,0.9,1,1)=(0,0,1,0.2))$	0.88785	0.82216	0.07247	−0.30042	−0.60528	−0.87678	A1 > A2 > A3 > A4 > A5 > A6
E8	$W_{A1:A6}((0.7,0.8,0.8,0.9)=(0.2,0.3,0.4,0.5);(0.8,0.9,1,1)=(0,0,1,0.2))$	1.02745	0.47248	−0.00892	−0.25037	−0.55996	−0.68069	A1 > A2 > A3 > A4 > A5 > A6
E9	$W_{A1:A6}((0.4,0.5,0.5,0.6)=(0.8,0.9,1,1))$	1.12329	1.04067	0.03012	−0.42401	−0.73602	−1.03405	A1 > A2 > A3 > A4 > A5 > A6
E10	$W_{A1:A6}((0.4,0.5,0.5,0.6)=(0.7,0.8,0.8,0.9))$	1.06027	0.98389	0.02513	−0.38983	−0.70172	−0.97774	A1 > A2 > A3 > A4 > A5 > A6
E11	$W_{A1:A6}((0.4,0.5,0.5,0.6)=(0.5,0.6,0.7,0.8))$	1.03120	0.95654	0.01876	−0.37171	−0.67456	−0.96023	A1 > A2 > A3 > A4 > A5 > A6
E12	$W_{A1:A6}((0.4,0.5,0.5,0.6)=(0.2,0.3,0.4,0.5))$	0.85766	0.85514	0.10120	−0.26939	−0.63202	−0.91260	A1 > A2 > A3 > A4 > A5 > A6
E13	$W_{A1:A6}((0.4,0.5,0.5,0.6)=(0.1,0.2,0.2,0.3))$	0.89257	0.88786	0.11478	−0.26149	−0.66070	−0.97301	A1 > A2 > A3 > A4 > A5 > A6
E14	$W_{A1:A6}((0.4,0.5,0.5,0.6)=(0,0,1,0.2))$	0.99828	0.99645	0.14805	−0.27094	−0.74759	−1.12425	A1 > A2 > A3 > A4 > A5 > A6
E15	$W_{A1:A6}=(0.2,0.3,0.4,0.5)$	0.84950	0.36129	−0.02881	−0.21413	−0.44149	−0.52636	A1 > A2 > A3 > A4 > A5 > A6
E16	$W_{A1:A6}=(0.1,0.2,0.2,0.3)$	0.51000	0.21667	−0.01667	−0.13167	−0.26000	−0.31833	A1 > A2 > A3 > A4 > A5 > A6

Table 12. Sensitivity analysis for Ghoramara island.

Expt.	Definition	Net Flow							Ranking
		A1	A2	A3	A4	A5	A6	A7	
E1	$W_{A1:A7}=(0.8,0.9,1,1)$	1.35222	1.28686	0.33314	−0.13326	−0.55523	−0.74940	−1.53434	A1 > A2 > A3 > A4 > A5 > A6 > A7
E2	$W_{A1:A7}=(0.7,0.8,0.8,0.9)$	1.16317	1.10476	0.28444	−0.10921	−0.47746	−0.64508	−1.32063	A1 > A2 > A3 > A4 > A5 > A6 > A7
E3	$W_{A1:A7}=(0.5,0.6,0.7,0.8)$	0.96063	0.92345	0.24696	−0.08365	−0.39102	−0.54305	−1.11332	A1 > A2 > A3 > A4 > A5 > A6 > A7
E4	$W_{A1:A7}((0.7,0.8,0.8,0.9)=(0.8,0.9,1,1))$	1.18279	1.09959	0.34173	−0.14459	−0.47819	−0.67825	−1.32309	A1 > A2 > A3 > A4 > A5 > A6 > A7
E5	$W_{A1:A7}((0.7,0.8,0.8,0.9)=(0.5,0.6,0.7,0.8))$	0.99129	0.94775	0.29020	−0.08863	−0.41894	−0.57902	−1.14264	A1 > A2 > A3 > A4 > A5 > A6 > A7
E6	$W_{A1:A7}((0.7,0.8,0.8,0.9) \mid (0.8,0.9,1,1)=(0,0,1,0.2))$	0.26045	0.25206	0.09720	0.00926	−0.09017	−0.17380	−0.35499	A1 > A2 > A3 > A4 > A5 > A6 > A7
E7	$W_{A1:A7}((0.7,0.8,0.8,0.9)=(0.1,0.2,0.2,0.3) \mid (0.8,0.9,1,1)=(0,0,1,0.2))$	1.52513	0.58751	0.26256	0.18021	−0.45133	−0.58665	−1.51743	A2 > A1 > A3 > A4 > A5 > A6 > A7
E8	$W_{A1:A7}((0.7,0.8,0.8,0.9)=(0.2,0.3,0.4,0.5);(0.8,0.9,1,1)=(0,0,1,0.2))$	1.85700	1.83793	0.55921	0.04419	−0.61140	−1.15564	−2.53129	A1 > A2 > A3 > A4 > A5 > A6 > A7
E9	$W_{A1:A7}((0.4,0.5,0.5,0.6)=(0.8,0.9,1,1))$	1.24248	1.19363	0.31546	−0.13514	−0.51065	−0.69855	−1.40723	A1 > A2 > A3 > A4 > A5 > A6 > A7
E10	$W_{A1:A7}((0.4,0.5,0.5,0.6)=(0.7,0.8,0.8,0.9))$	1.19969	1.14115	0.30386	−0.13478	−0.49483	−0.67948	−1.33562	A1 > A2 > A3 > A4 > A5 > A6 > A7
E11	$W_{A1:A7}((0.4,0.5,0.5,0.6)=(0.5,0.6,0.7,0.8))$	1.12737	1.05933	0.31750	−0.11497	−0.45948	−0.65147	−1.27827	A1 > A2 > A3 > A4 > A5 > A6 > A7
E12	$W_{A1:A7}((0.4,0.5,0.5,0.6)=(0.2,0.3,0.4,0.5))$	1.06432	0.96907	0.34668	−0.11163	−0.40794	−0.62704	−1.23347	A1 > A2 > A3 > A4 > A5 > A6 > A7
E13	$W_{A1:A7}((0.4,0.5,0.5,0.6)=(0.1,0.2,0.2,0.3))$	1.05605	0.94646	0.36518	−0.11078	−0.39451	−0.62985	−1.23254	A1 > A2 > A3 > A4 > A5 > A6 > A7
E14	$W_{A1:A7}((0.4,0.5,0.5,0.6)=(0,0,1,0.2))$	1.06607	0.94076	0.39429	−0.11112	−0.38725	−0.64799	−1.25477	A1 > A2 > A3 > A4 > A5 > A6 > A7
E15	$W_{A1:A7}=(0.2,0.3,0.4,0.5)$	0.57698	0.56218	0.16274	−0.04127	−0.22970	−0.33638	−0.69455	A1 > A2 > A3 > A4 > A5 > A6 > A7
E16	$W_{A1:A7}=(0.1,0.2,0.2,0.3)$	0.34833	0.33500	0.10000	−0.02667	−0.13167	−0.20333	−0.42167	A1 > A2 > A3 > A4 > A5 > A6 > A7

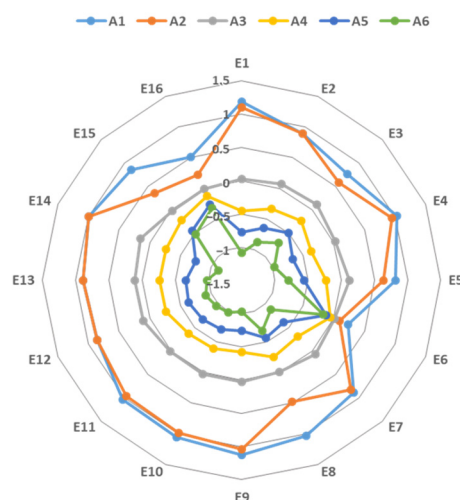


Figure 4. Sensitivity analysis for Gaidouromantra.

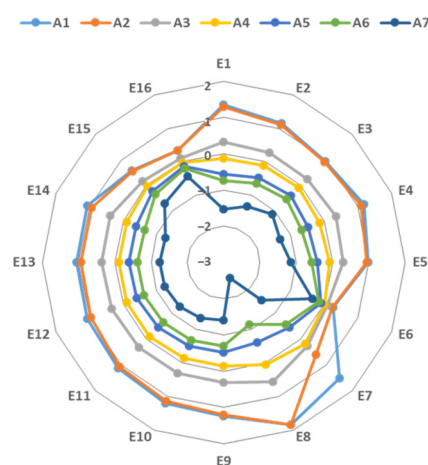


Figure 5. Sensitivity analysis for Ghoramara island.

4.6. Comparison with Fuzzy TOPSIS

The effectiveness of the deployed fuzzy PROMETHEE II is demonstrated by comparing it with another MCDM method, fuzzy TOPSIS, with the objective of identifying differences in the final ranking. Fuzzy TOPSIS was compared with the fuzzy PROMETHEE II method in a case study [60] as comparisons can be drawn due to the same dataset usage in both methods. By using the criterion weight and performance ratings for the alternatives, the fuzzy positive ideal solution and fuzzy negative ideal solution were computed followed by estimating relative distances and relative closeness coefficients (Table 13). The top three rankings for business models A1, A2, and A3 remained the same, while interchanging was only observed in lower rankings, i.e., A5, A6, and A7. The Fuzzy PROMETHEE II method deliberates pairwise comparison of alternatives with criteria values, leading to the formation of a priority function, while the latter approach only measures the distance of each alternative from fuzzy positive and negative ideal solutions. Hence, the proposed method in this work is effective and more applicable.

Based on the above comparisons, the proposed fuzzy PROMETHEE II method is characterized by some advantages: A complete ranking of alternatives is offered, it conducts pairwise evaluations of criteria values, it selects varied preference functions, it converts criterion information ambiguity into comparable values, and it is robust when it experiences criterion weight variabilities.

Table 13. Fuzzy TOPSIS results for Gaidouromantra and Ghoramara island.

	d_i^+	d_i^-	CC_i	Rank		d_i^+	d_i^-	CC_i	Rank
A1	0.3015	0.3155	0.5113	1	A1	0.3806	0.5092	0.5722	1
A2	0.3322	0.3376	0.5040	2	A2	0.4217	0.4993	0.5422	2
A3	0.4483	0.3893	0.4647	3	A3	0.5225	0.4569	0.4665	3
A4	0.4594	0.3210	0.4113	5	A4	0.4808	0.4034	0.4562	4
A5	0.4372	0.2956	0.4034	6	A5	0.7323	0.5211	0.4158	6
A6	0.4381	0.3234	0.4247	4	A6	0.5651	0.4111	0.4211	5
					A7	0.6866	0.3122	0.3126	7

5. Discussion

Recent changes in market conditions and support incentives highlight the increasing importance of self-consumption, local balancing, and Community Energy Storage (CES) while revealing the inadequacy of existing business models. Local energy initiatives provide a compelling motivation for the advancement and application of CES. Some energy communities have recently integrated CES into their energy mix. CES effectively facilitates the harmonization of local renewable energy demand and supply by enabling greater penetration of renewables and facilitating energy sharing and self-consumption of locally generated power. Additionally, CES can provide diverse energy services to other communities or larger energy systems, such as ancillary services, balancing, and demand response, thereby creating synergies.

However, CES is still in its early stages, and local energy initiatives for demonstration and operational applications are limited. The growing energy consumption necessitates investments in energy storage technology, services, and sharing models. Therefore, the identification of appropriate business models is crucial to overcome the fundamental challenges of investments and sustainability. More precisely, the act of choosing CES technology constitutes a groundbreaking concept within the realm of community energy initiatives, where a multitude of objectives must be harmonized. These objectives span a wide spectrum encompassing economic, technological, social, and environmental factors, making the entire adoption and implementation process notably intricate and multifaceted [61]. Certainly, the broader adoption and implementation of CES in local energy initiatives present several key challenges [62–66]:

- *Technology Selection Complexity:* As mentioned earlier, choosing the right CES technology can be a daunting task. Different technologies offer varying benefits and drawbacks, and the optimal choice depends on the specific goals of the local energy initiative.
- *Cost:* CES technologies often come with significant upfront costs, which can be a barrier for local communities with limited budgets. The cost of CES systems, including installation and maintenance, must be carefully weighed against the expected benefits and savings in energy costs.
- *Regulatory and Policy Frameworks:* The regulatory environment can significantly impact the feasibility and attractiveness of CES projects. Local energy initiatives may face challenges related to grid integration, permission, and compliance with local and national energy policies. Clear and supportive regulatory frameworks are essential for the successful implementation of CES projects.
- *Community Engagement:* Engaging and educating the local community is crucial for the success of CES initiatives.
- *Interconnection Challenges:* CES systems need to be seamlessly integrated into the local energy grid. Compatibility issues, grid capacity limitations, and technical challenges may arise when connecting CES to the existing infrastructure. Coordination with utility companies and grid operators is essential.
- *Funding and Financing:* Securing funding for CES projects can be challenging. Communities may explore various financing options, including grants, loans, public–private partnerships, or community-based fundraising.

Integrating an efficient decision-making method supports the evaluation and ranking of suitable CES models. Given the uncertain nature of CES business models in the context of wind and solar projects, the fuzzy PROMETHEE II method was employed. The findings indicate that Community Cooperative, Energy Arbitrage, and Energy Arbitrage Peak Shaving models are prioritized for CES implementation using renewable energy. The fourth, fifth, and sixth ranks are obtained by ER-VS, CEO-ELR, and AES, respectively, for both case studies. Furthermore, VTMG secured the last rank at Ghoramara island, suggesting that the grid-to-vehicle model is proven for e-mobility in energy communities, but the bidirectional functionality remains a long-term scenario for CES systems in the local energy generation market.

Concerning the methodology used in this study, certain limitations may occur with the variants of Fuzzy PROMETHEE as fuzzy sets lack the ability to transmit the decision maker's approval and resistance synchronously. During vague and uncertain scenarios, the cognitive behavior decision manifests the confirmation, denial, and hesitancy degree features [37]. The choice of the parameters expressing the preference or opinion of the decision maker, as anticipated, greatly influences the outcome. Since the opinion of different persons may not coincide, in most cases, there is not a single generally accepted solution and the results may be viewed from this perspective [67]. In addition, the PROMETHEE method belongs to the family of outranking methods and its major drawbacks arise from the many rather non-intuitive inputs that are required [68].

CES, as an energy storage solution, enables the storage of surplus energy for later use, depending on local conditions, resources, and consumption patterns. Shared local energy storage promotes energy independence through local generation, storage, and a flexible energy network that encourages community participation. In exchange for making renewable energy available for future use within a networked system governed by community ownership and governance, the cost of investment and operation can be recovered. This objective can be achieved through the establishment of efficient cooperatives for the Gaidouromantra microgrid and Ghoramara island, surpassing current economic considerations. The environmental benefits are evident, with a substantial reduction in diesel use and greenhouse gas emissions, contributing to local zero-carbon transformation and overall energy system sustainability. This alternative arrangement may lead to competitive energy prices determined autonomously by the energy cooperative. The emergence of innovative technologies has transformed the energy landscape, requiring CES to operate with new actors, stakeholders, and institutional structures. Consequently, novel synergistic value propositions for CES systems are needed to drive the energy transition in local and virtual communities.

6. Conclusions

This paper investigates and analyzes various business models for Community Energy Storage (CES), using Multi Criteria Decision Making (MCDM) approaches and real-world case studies in Europe and India. The findings highlight the significant potential of CES in balancing local renewable energy supply and demand, promoting energy sharing, and achieving energy independence. The study prioritizes several CES business models, including Community Cooperative, Energy Arbitrage, and Energy Arbitrage Peak Shaving. These models demonstrate the ability to effectively store surplus energy for later use, providing benefits such as reduced diesel usage and greenhouse gas emissions, contributing to the local zero-carbon transformation and overall energy system sustainability.

While CES shows promising results, it is still in its early stages, and investment and sustainability challenges remain. To address these challenges, efficient decision-making methods, such as the fuzzy PROMETHEE II method, can be employed to evaluate and rank suitable CES models in the context of renewable energy projects.

Community participation and ownership play a crucial role in CES's success, and establishing efficient cooperatives has shown potential to recover costs and enable competitive energy prices. However, the constantly evolving energy landscape and the integration of

novel technologies require continuous efforts to devise innovative synergistic value propositions for CES systems. Such initiatives can drive the energy transition in local communities and facilitate the adoption of CES as a viable and sustainable energy storage solution.

It is essential to acknowledge the limitations of this research and outline avenues for future investigations. This study employed Fuzzy PROMETHEE variants, which, while effective, have certain limitations. These variants may not fully capture decision makers' simultaneous approval and resistance, particularly in scenarios marked by vagueness and uncertainty.

The selection of parameters to express decision makers' preferences greatly influences the outcomes. Given that different individuals may have divergent opinions, arriving at a universally accepted solution can be challenging. Additionally, the PROMETHEE method, as an outranking approach, demands numerous inputs that may not always be intuitive, potentially complicating the decision-making process.

Looking ahead, future research should aim to explore the technical intricacies of the assessed business models comprehensively, providing a more nuanced understanding of their feasibility and performance. Furthermore, to enhance the robustness of business model assessments, future work should consider alternative assessment procedures and methodologies, expanding the toolkit available for decision makers. By addressing these limitations and pursuing these research avenues, we can further advance our understanding of CES business models and contribute to more effective decision-making in this critical domain.

Nevertheless, this research contributes valuable insights into CES business models, providing knowledge exchange opportunities and promoting effective strategies for the development and implementation of CES in sustainable energy systems. As CES continues to evolve and mature, it has the potential to play a crucial role in meeting the growing energy demand and supporting the transition towards a cleaner and more sustainable energy future.

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Data Availability Statement: No new data were created or analyzed in this study. Data sharing is not applicable to this article.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Preference Value of Alternatives for Criterion: Gaidouromantra microgrid.

	C1	C2	C3	C4
P (A1A2)	(0.0207, 0.0350, 0.0363, 0.0518)	(0.0, 0.0, 0.0, 0.0)	(0.0700, 0.0825, 0.0850, 0.1000)	(0.0192, 0.0276, 0.0276, 0.0431)
P (A1A3)	(0.0525, 0.0890, 0.0919, 0.1312)	(0.1265, 0.2056, 0.2056, 0.2846)	(0.2249, 0.2650, 0.2731, 0.3213)	(0.0, 0.0, 0.0, 0.0)
P (A1A4)	(0.0938, 0.1580, 0.1641, 0.2344)	(0.1460, 0.2373, 0.2373, 0.3285)	(0.1369, 0.1614, 0.1663, 0.1956)	(0.0369, 0.0531, 0.0531, 0.0831)
P (A1A5)	(0.1545, 0.2610, 0.2704, 0.3863)	(0.0555, 0.0902, 0.0902, 0.1249)	(0.0875, 0.1031, 0.1063, 0.1250)	(0.0192, 0.0276, 0.0276, 0.0431)
P (A1A6)	(0.1340, 0.2260, 0.2345, 0.3350)	(0.1140, 0.1853, 0.1853, 0.2565)	(0.0700, 0.0825, 0.0850, 0.1000)	(0.0383, 0.0551, 0.0551, 0.0863)
P (A2A1)	(0.0, 0.0, 0.0, 0.0)	(0.0, 0.0, 0.0, 0.0)	(0.0, 0.0, 0.0, 0.0)	(0.0, 0.0, 0.0, 0.0)
P (A2A3)	(0.1100, 0.1856, 0.1925, 0.2750)	(0.1265, 0.2056, 0.2056, 0.2846)	(0.2516, 0.2965, 0.3055, 0.3594)	(0.0192, 0.0276, 0.0276, 0.0431)
P (A2A4)	(0.1145, 0.1930, 0.2004, 0.2863)	(0.1460, 0.2373, 0.2373, 0.3285)	(0.1636, 0.1928, 0.1987, 0.2338)	(0.0242, 0.347, 0.0347, 0.0544)
P (A2A5)	(0.1753, 0.2960, 0.3067, 0.4381)	(0.0555, 0.0902, 0.0902, 0.1249)	(0.1142, 0.1346, 0.1387, 0.1631)	(0.0, 0.0, 0.0, 0.0)
P (A2A6)	(0.1548, 0.2610, 0.2708, 0.3869)	(0.1140, 0.1853, 0.1853, 0.2565)	(0.0, 0.0, 0.0, 0.0)	(0.0192, 0.0276, 0.0276, 0.0431)
P (A3A1)	(0.0, 0.0, 0.0, 0.0)	(0.0, 0.0, 0.0, 0.0)	(0.0, 0.0, 0.0, 0.0)	(0.0, 0.0, 0.0, 0.0)
P (A3A2)	(0.0, 0.0, 0.0, 0.0)	(0.0, 0.0, 0.0, 0.0)	(0.0, 0.0, 0.0, 0.0)	(0.0, 0.0, 0.0, 0.0)
P (A3A4)	(0.0413, 0.0696, 0.0722, 0.1031)	(0.0195, 0.0317, 0.0317, 0.0439)	(0.0879, 0.1036, 0.1068, 0.1256)	(0.0369, 0.0531, 0.0531, 0.0831)
P (A3A5)	(0.1020, 0.1720, 0.1785, 0.2550)	(0.0710, 0.1154, 0.1154, 0.1598)	(0.1374, 0.1619, 0.1668, 0.1963)	(0.0192, 0.0276, 0.0276, 0.0431)
P (A3A6)	(0.0815, 0.1380, 0.1426, 0.2038)	(0.0320, 0.0520, 0.0520, 0.0720)	(0.2516, 0.2965, 0.3055, 0.3594)	(0.0383, 0.0551, 0.0551, 0.0863)
P (A4A1)	(0.0, 0.0, 0.0, 0.0)	(0.0, 0.0, 0.0, 0.0)	(0.0, 0.0, 0.0, 0.0)	(0.0, 0.0, 0.0, 0.0)
P (A4A2)	(0.0, 0.0, 0.0, 0.0)	(0.0, 0.0, 0.0, 0.0)	(0.0, 0.0, 0.0, 0.0)	(0.0, 0.0, 0.0, 0.0)
P (A4A3)	(0.0, 0.0, 0.0, 0.0)	(0.0, 0.0, 0.0, 0.0)	(0.0, 0.0, 0.0, 0.0)	(0.0, 0.0, 0.0, 0.0)
P (A4A5)	(0.0608, 0.1030, 0.1063, 0.1519)	(0.0905, 0.1471, 0.1471, 0.2036)	(0.0639, 0.0753, 0.0776, 0.0913)	(0.0242, 0.0347, 0.0347, 0.0544)
P (A4A6)	(0.0470, 0.0790, 0.0823, 0.1175)	(0.0385, 0.0626, 0.0626, 0.0866)	(0.1636, 0.1928, 0.1987, 0.2338)	(0.0192, 0.0276, 0.0276, 0.0431)
P (A5A1)	(0.0, 0.0, 0.0, 0.0)	(0.0, 0.0, 0.0, 0.0)	(0.0, 0.0, 0.0, 0.0)	(0.0, 0.0, 0.0, 0.0)
P (A5A2)	(0.0, 0.0, 0.0, 0.0)	(0.0, 0.0, 0.0, 0.0)	(0.0, 0.0, 0.0, 0.0)	(0.0, 0.0, 0.0, 0.0)
P (A5A3)	(0.0, 0.0, 0.0, 0.0)	(0.0, 0.0, 0.0, 0.0)	(0.0, 0.0, 0.0, 0.0)	(0.0, 0.0, 0.0, 0.0)
P (A5A4)	(0.0, 0.0, 0.0, 0.0)	(0.0, 0.0, 0.0, 0.0)	(0.0, 0.0, 0.0, 0.0)	(0.0, 0.0, 0.0, 0.0)
P (A5A6)	(0.0205, 0.0346, 0.0359, 0.0513)	(0.0585, 0.0951, 0.0951, 0.1316)	(0.1142, 0.1346, 0.1387, 0.1631)	(0.0192, 0.0276, 0.0276, 0.0431)
P (A6A1)	(0.0, 0.0, 0.0, 0.0)	(0.0, 0.0, 0.0, 0.0)	(0.0, 0.0, 0.0, 0.0)	(0.0, 0.0, 0.0, 0.0)
P (A6A2)	(0.0, 0.0, 0.0, 0.0)	(0.0, 0.0, 0.0, 0.0)	(0.0, 0.0, 0.0, 0.0)	(0.0, 0.0, 0.0, 0.0)
P (A6A3)	(0.0, 0.0, 0.0, 0.0)	(0.0, 0.0, 0.0, 0.0)	(0.0, 0.0, 0.0, 0.0)	(0.0, 0.0, 0.0, 0.0)
P (A6A4)	(0.0, 0.0, 0.0, 0.0)	(0.0, 0.0, 0.0, 0.0)	(0.0, 0.0, 0.0, 0.0)	(0.0, 0.0, 0.0, 0.0)
P (A6A5)	(0.0, 0.0, 0.0, 0.0)	(0.0, 0.0, 0.0, 0.0)	(0.0, 0.0, 0.0, 0.0)	(0.0, 0.0, 0.0, 0.0)

Table A2. Preference Value of Alternatives for Criterion: Ghoramara island.

	C1	C2	C3	C4
P (A1A2)	(0.1395, 0.2616, 0.2703, 0.3488)	(0.0, 0.0, 0.0, 0.0)	(0.1700, 0.2635, 0.2805, 0.3400)	(0.2074, 0.2444, 0.2518, 0.2963)
P (A1A3)	(0.1623, 0.3042, 0.3144, 0.4056)	(0.0423, 0.0634, 0.0660, 0.0951)	(0.0850, 0.1318, 0.1403, 0.1700)	(0.2074, 0.2444, 0.2518, 0.2963)
P (A1A4)	(0.1395, 0.2616, 0.2703, 0.3488)	(0.0528, 0.0791, 0.0824, 0.1187)	(0.0897, 0.1390, 0.1480, 0.1794)	(0.2074, 0.2444, 0.2518, 0.2963)
P (A1A5)	(0.2713, 0.5086, 0.5255, 0.6781)	(0.0528, 0.0791, 0.0824, 0.1187)	(0.0303, 0.0470, 0.0500, 0.0)	(0.0, 0.0, 0.0, 0.0)
P (A1A6)	(0.0707, 0.1327, 0.1371, 0.1769)	(0.0423, 0.0634, 0.0660, 0.0951)	(0.0297, 0.0460, 0.0490, 0.0594)	(0.0639, 0.0753, 0.0776, 0.0913)
P (A1A7)	(0.1168, 0.2189, 0.2262, 0.2919)	(0.0728, 0.1091, 0.1137, 0.1637)	(0.3050, 0.4728, 0.5033, 0.6100)	(0.1142, 0.1346, 0.1387, 0.1631)
P (A2A1)	(0.0, 0.0, 0.0, 0.0)	(0.0, 0.0, 0.0, 0.0)	(0.0, 0.0, 0.0, 0.0)	(0.0, 0.0, 0.0, 0.0)
P (A2A3)	(0.0228, 0.0427, 0.0441, 0.0569)	(0.0423, 0.0634, 0.0660, 0.0951)	(0.1100, 0.1705, 0.1815, 0.2200)	(0.0, 0.0, 0.0, 0.0)
P (A2A4)	(0.0, 0.0, 0.0, 0.0)	(0.0528, 0.0791, 0.0824, 0.1187)	(0.0803, 0.1245, 0.1325, 0.1606)	(0.0, 0.0, 0.0, 0.0)
P (A2A5)	(0.1318, 0.2470, 0.2553, 0.3294)	(0.0528, 0.0791, 0.0824, 0.1187)	(0.1397, 0.2165, 0.2305, 0.2794)	(0.2074, 0.2444, 0.2518, 0.2963)
P (A2A6)	(0.0688, 0.1289, 0.1332, 0.1719)	(0.0423, 0.0634, 0.0660, 0.0951)	(0.1403, 0.2175, 0.2315, 0.2806)	(0.1579, 0.1861, 0.1918, 0.2256)
P (A2A7)	(0.0228, 0.0427, 0.0441, 0.0569)	(0.0728, 0.1091, 0.1137, 0.1637)	(0.1350, 0.2093, 0.2228, 0.2700)	(0.0932, 0.1098, 0.1132, 0.1331)
P (A3A1)	(0.0, 0.0, 0.0, 0.0)	(0.0060, 0.0090, 0.0094, 0.0135)	(0.0, 0.0, 0.0, 0.0)	(0.0, 0.0, 0.0, 0.0)
P (A3A2)	(0.0, 0.0, 0.0, 0.0)	(0.0060, 0.0090, 0.0094, 0.0135)	(0.0, 0.0, 0.0, 0.0)	(0.0, 0.0, 0.0, 0.0)
P (A3A4)	(0.0228, 0.0427, 0.0441, 0.0569)	(0.0524, 0.0786, 0.0819, 0.1179)	(0.0297, 0.0460, 0.0490, 0.0594)	(0.0, 0.0, 0.0, 0.0)
P (A3A5)	(0.1090, 0.2044, 0.2112, 0.2725)	(0.0525, 0.0787, 0.0820, 0.1181)	(0.0547, 0.0848, 0.0902, 0.1094)	(0.2074, 0.2444, 0.2518, 0.2963)
P (A3A6)	(0.0915, 0.1716, 0.1773, 0.2288)	(0.0, 0.0, 0.0, 0.0)	(0.0553, 0.0857, 0.0913, 0.1106)	(0.1579, 0.1861, 0.1918, 0.2256)
P (A3A7)	(0.0455, 0.0853, 0.0882, 0.1138)	(0.0365, 0.0548, 0.0570, 0.0821)	(0.2200, 0.3410, 0.3630, 0.4400)	(0.0932, 0.1098, 0.1132, 0.1331)
P (A4A1)	(0.0, 0.0, 0.0, 0.0)	(0.0, 0.0, 0.0, 0.0)	(0.0, 0.0, 0.0, 0.0)	(0.0, 0.0, 0.0, 0.0)
P (A4A2)	(0.0, 0.0, 0.0, 0.0)	(0.0, 0.0, 0.0, 0.0)	(0.0, 0.0, 0.0, 0.0)	(0.0, 0.0, 0.0, 0.0)
P (A4A3)	(0.0, 0.0, 0.0, 0.0)	(0.0360, 0.0540, 0.0563, 0.0810)	(0.0, 0.0, 0.0, 0.0)	(0.0, 0.0, 0.0, 0.0)
P (A4A5)	(0.1318, 0.2470, 0.2553, 0.3294)	(0.0, 0.0, 0.0, 0.0)	(0.0594, 0.0920, 0.0980, 0.1188)	(0.2074, 0.2444, 0.2518, 0.2963)
P (A4A6)	(0.0688, 0.1289, 0.1332, 0.1719)	(0.0525, 0.0787, 0.0820, 0.1181)	(0.0600, 0.0930, 0.0990, 0.1200)	(0.1579, 0.1861, 0.1918, 0.2256)
P (A4A7)	(0.0228, 0.0427, 0.0441, 0.0569)	(0.0360, 0.0540, 0.0563, 0.0810)	(0.2153, 0.3337, 0.3553, 0.4306)	(0.0932, 0.1098, 0.1132, 0.1331)
P (A5A1)	(0.0, 0.0, 0.0, 0.0)	(0.0, 0.0, 0.0, 0.0)	(0.0, 0.0, 0.0, 0.0)	(0.0, 0.0, 0.0, 0.0)
P (A5A2)	(0.0, 0.0, 0.0, 0.0)	(0.0, 0.0, 0.0, 0.0)	(0.0, 0.0, 0.0, 0.0)	(0.0, 0.0, 0.0, 0.0)
P (A5A3)	(0.0, 0.0, 0.0, 0.0)	(0.0360, 0.0540, 0.0563, 0.0810)	(0.0, 0.0, 0.0, 0.0)	(0.0, 0.0, 0.0, 0.0)
P (A5A4)	(0.0, 0.0, 0.0, 0.0)	(0.0, 0.0, 0.0, 0.0)	(0.0, 0.0, 0.0, 0.0)	(0.0, 0.0, 0.0, 0.0)
P (A5A6)	(0.2005, 0.3759, 0.3885, 0.5013)	(0.0525, 0.0787, 0.0820, 0.1181)	(0.0103, 0.0160, 0.0170, 0.0206)	(0.0639, 0.0753, 0.0776, 0.0913)
P (A5A7)	(0.1545, 0.2897, 0.2993, 0.3863)	(0.0360, 0.0540, 0.0563, 0.0810)	(0.2747, 0.4258, 0.4532, 0.5494)	(0.1142, 0.1346, 0.1387, 0.1631)
P (A6A1)	(0.0, 0.0, 0.0, 0.0)	(0.0060, 0.0090, 0.0094, 0.0135)	(0.0, 0.0, 0.0, 0.0)	(0.0144, 0.0170, 0.0175, 0.0206)
P (A6A2)	(0.0, 0.0, 0.0, 0.0)	(0.0060, 0.0090, 0.0094, 0.0135)	(0.0, 0.0, 0.0, 0.0)	(0.0, 0.0, 0.0, 0.0)
P (A6A3)	(0.0, 0.0, 0.0, 0.0)	(0.0, 0.0, 0.0, 0.0)	(0.0, 0.0, 0.0, 0.0)	(0.0, 0.0, 0.0, 0.0)
P (A6A4)	(0.0, 0.0, 0.0, 0.0)	(0.0360, 0.0540, 0.0563, 0.0810)	(0.0, 0.0, 0.0, 0.0)	(0.0, 0.0, 0.0, 0.0)
P (A6A5)	(0.0, 0.0, 0.0, 0.0)	(0.0360, 0.0540, 0.0563, 0.0810)	(0.0097, 0.0150, 0.0160, 0.0194)	(0.0144, 0.0170, 0.0175, 0.0206)
P (A6A7)	(0.0460, 0.0863, 0.0891, 0.1150)	(0.0365, 0.0548, 0.0570, 0.0821)	(0.2753, 0.4267, 0.4543, 0.5506)	(0.1138, 0.1341, 0.1381, 0.1625)
P (A7A1)	(0.0, 0.0, 0.0, 0.0)	(0.0, 0.0, 0.0, 0.0)	(0.0, 0.0, 0.0, 0.0)	(0.0, 0.0, 0.0, 0.0)
P (A7A2)	(0.0, 0.0, 0.0, 0.0)	(0.0, 0.0, 0.0, 0.0)	(0.0, 0.0, 0.0, 0.0)	(0.0, 0.0, 0.0, 0.0)
P (A7A3)	(0.0, 0.0, 0.0, 0.0)	(0.0, 0.0, 0.0, 0.0)	(0.0, 0.0, 0.0, 0.0)	(0.0, 0.0, 0.0, 0.0)
P (A7A4)	(0.0, 0.0, 0.0, 0.0)	(0.0160, 0.0240, 0.0250, 0.0360)	(0.0, 0.0, 0.0, 0.0)	(0.0, 0.0, 0.0, 0.0)
P (A7A5)	(0.0, 0.0, 0.0, 0.0)	(0.0160, 0.0240, 0.0250, 0.0360)	(0.0, 0.0, 0.0, 0.0)	(0.0, 0.0, 0.0, 0.0)
P (A7A6)	(0.0, 0.0, 0.0, 0.0)	(0.0, 0.0, 0.0, 0.0)	(0.0, 0.0, 0.0, 0.0)	(0.0490, 0.0578, 0.0595, 0.0700)

Table A3. Summary of Preferential Outranking Alternatives for Criterion: Gaidouromantra microgrid and Ghoramara island.

Gaidouromantra Microgrid	C1	C2	C3	C4
Most Preferred	A1 [A1 > A2 > A3 > A4 > A5 > A6]	A1 [A1 > A2 > A3 > A4 > A5 > A6]	A1 [A1 > A2 > A3 > A4 > A5 > A6]	A1, A2 [A1 = A2 > A3 > A4 > A5 > A6] [A2 = A1 = A3 > A4 > A5 > A6]
More Preferred	A2, A5 [A2 > A3 > A4 > A5] [A5 > A3 > A4 > A6]	A2, A3 [A2 > A3 > A4 > A5 > A6] [A3 > A4 > A5 > A6]	A2, A3 [A2 > A3 > A4 > A5 > A6] [A3 > A4 > A5 > A6]	A3, A4 [A3 > A4 > A5 > A6] [A4 > A5 > A6]
Less Preferred	A6 [A6 > A2 > A4]	A4, A5 [A4 > A5 > A6] [A5 > A6]	A4, A5 [A4 > A5 > A6] [A5 > A6]	A5 [A5 > A6]
Least Preferred	A3, A4 [A3 = A4] [A4 = A3]	A6 [Not Preferred]	A6 [Not Preferred]	A6 [Not Preferred]
Ghoramara island	C1	C2	C3	C4
Most Preferred	A1 [A1 > A2 > A3 > A4 > A5 > A6 > A7]	A1 [A1 = A2 > A3 > A4 > A5 > A6 > A7]	A1 [A1 > A2 > A3 > A4 > A5 > A6 > A7]	A1 [A1 > A2 > A3 > A4 = A5 > A6 > A7]
More Preferred	A2, A3 [A2 > A3 > A4 > A5 > A6 > A7] [A3 > A4 > A5 > A6 > A7]	A2, A3 [A2 = A1 > A3 > A4 > A5 > A6 > A7] [A3 > A4 > A5 > A6 > A7]	A2, A3 [A2 > A3 > A4 > A5 > A6 > A7] [A3 > A4 > A5 > A6 > A7]	A2, A3, A4 [A2 > A3 > A4 > A5 > A6 > A7] [A3 = A2 = A4 > A5 > A6 > A7] [A4 = A2 = A3 > A5 > A6 > A7]
Less Preferred	A4, A5 [A4 = A2 > A5 > A6 > A7] [A5 > A6 > A7]	A4, A5 [A4 > A5 > A6 > A7] [A5 = A4 > A6 > A7]	A4, A5 [A4 > A5 > A6 > A7] [A5 > A6 > A7]	A5 [A5 = A1 > A6 > A7]
Least Preferred	A6, A7 [A6 > A7] [A7 Not Preferred]	A6, A7 [A6 > A7] [A7 Not Preferred]	A6, A7 [A6 > A7] [Not Preferred]	A6, A7 [A6 > A7] [A7 Not Preferred]

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