Fuzzy Axiomatic Approach to Blue-green Infrastructure Strategy Selection: A Sustainability Perspective

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Abstract— Flood risk management (FRM) is a global problem that has received significant attention from scholars. Their interest is on the minimisation of flood occurrence and its aftermath. This study uses FRM sustainability criteria to contribute a framework to the interest mentioned above. It designed the framework for a blue-green technology selection using a best-worst method, fuzzy axiomatic method and VIKOR method. Data from Lekki, Lagos, Nigeria, was used to test this framework applicability. Six blue-green technologies, which include bypass floodway, rainwater and floodwater harvesting, and porous pavement, were considered as potential technology for the case study. From the framework implementation results, this study observed that techno-economic criteria contributed about 88.18% to the ranking of blue-green technology. The framework identified rainwater and floodwater harvesting as the most suitable blue-green technologies for a community. It also identified a bypass floodway as the least suitable blue-green technologies for a community. With these results, the proposed framework will aid decision-makers strategic and tactical criteria that can be used to evaluate blue-green technology selection.

Keywords— Flood, multi-criteria, blue-green technology, sustainability, fuzzy logic.

1   Introduction

As the earth experiences climate change, stakeholders have organised several fora on how to handle the effect of this change effectively. Flood and drought are among the aftermath of this change. Scholars have reported that flood destroys several communities annually, especially in developing countries with urban plans [1], [2]. One of the recommendations of scholars is the use of a sustainability approach to arrest this problem [3], [4]. The issue of flood management should not be considered as an engineering problem [4]. It requires a multi-disciplinary approach to harness the contributions from other disciplines during flooding management. For instance, the decision on appropriate blue-green technology for flood-prone areas can be solved from a multi-disciplinary perspective.

This perspective is desired because of the need to find a sustainable solution to flooding. It is, therefore, the responsibility of stakeholders to include sustainability into consideration when such a solution is recommended. Sustainability - which is the analysis of technical, social, economic and environmental requirements of a system - helps to cater to the present and future needs of different generations. The criteria that constitute sustainability requirements are system dependent. Hence, decision-makers are required to carry out a preliminary analysis of these requirements and present them in a framework to stakeholders – investors, government, and public. Since some of the criteria in a sustainable framework can only be expressed in linguistic forms, it is the duty of decision-makers to make their findings as simple as possible to the stakeholders. To create a simplified framework that embeds sustainability requirements, scholars have accepted multi-criteria modelling approaches as being robust for this purpose.

Multi-criteria decision-making (MCDM) tools combine a system's requirements to determine the best course of action. Examples of MCDM tools are VIKOR, TOPSIS, and axiomatic method, just to mention a few. Their applications involve careful planning of system requirements to generate practical solutions for real-world problems. Currently, research domains such as energy, maintenance, and supply chain management have established fundamental elements that constitute system requirements for the design of MCDM frameworks for domains mentioned above [5]. Unfortunately, scholars in flood risk management (FRM) domain are yet proposed a framework that contains sustainability

requirements. This study aims to use stakeholders' perspectives requirements to develop a sustainability framework for FRM. In the framework, the socio-economic requirements of a community were considered [2]. Apart from these needs, this study considered the technical, environmental, and policy requirements for blue-green technology adoption. Three MCDM tools were used to combine the requirements mentioned above synergically. The framework determines sub-criteria importance using a best-worst method. A fuzzy axiomatic method was used to relate design requirements with system requirements for alternative solutions to blue-green technology adoption. VIKOR was used to combine the sustainability criteria to determine the most suitable blue-green technology for a system.

2. Flood Risk Management

FRM is an activity that deals with flood preparation, prevention and mitigation, just to mention a few [6]. Because of the importance of FRM to human survival, several studies have been published on FRM[1], [7]–[9]. For example, [9] stated that the justification for selecting a flood risk strategy could be improved when information on flood-risk design is combined with a decision-making model for FRM. [10] presented a methodology for household vulnerability assessment to flood. Their work considered the damages caused by flood to property, water contamination, physical and mental impairments, and exposure to hazard. [7] noted that while pushing for a flood strategy, there is a need to incorporate the issue of landscape quality to protect cultural heritage, and to account for the spatial and building requirements of a community.

To deploy an FRM strategy, the contributions of stakeholders are required. When their contributions are considered, it will not only address the immediate need for flood control; it will also sustain the environment for the next generation [11]. To improve the FRM decision-making process, [12] presented a framework that aggregates social requirements, such as household vulnerability, to flood management. Beyond such requirements, it is equally essential that a decision support system for FRM contains economic, technical, and environmental requirements. This consideration is suitable for long-term analysis of flood control [13]. Another critical issue in the design of an FRM strategy is uncertainty consideration.

The uncertainty in an FRM strategy can be understood by classifying a model as a preventive or mitigation model [14]. This classification improves how an FRM model adjusts to the emerging needs of communities [2]. Scholars have used different approaches to solve this problem. For instance, [15] used a hydraulic modelling approach to evaluate policies for FRM. They generated flood risk maps using used a regular levee system. The generated maps showed that the non-structural method reduces the damages caused by a flood. Apart from policy uncertainty, financing an FRM strategy introduces uncertainty into flood management [16]. It is, therefore, imperative that government policies and the socio-economic needs of a community are understood before settling for any FRM strategy. This issue can be addressed by using stakeholders inputs to design an FRM programme [2], [17].

Since stakeholders' inputs increase the dynamics of FRM, scholars need to understand a community's evolving social and physical needs. Hence, attention must be given to the relationship between policy-makers' expectations and human behaviours [8]. This is because robust flood management depends on a community's socio-economic and environmental needs, as well as its flood policy [17]. There are several aspects of this relationship that should be considered as scholars seek a robust FRM strategy for a community. First, governments should continuously evaluate the effectiveness of water channels and storage systems, and flood warning and evacuation systems. The evaluation process should cover the techno-economic considerations of these systems [18]. Second, insurance policy needs to be provided for people living in flood-prone areas [17]. Third, more emphasis should be given to the non-structural measures of FRM over the structural measures [2].

From the forthgoing, three facts emerged from the literature. FRM problem is a multi-criteria problem, and analysis on this problem must include the socio-economic benefits for adopting a strategy. Stakeholders' inputs are essential to the success of an FRM strategy. Uncertainty must be considered when selecting an FRM strategy for a community. Motivated by these findings, the current study presents a framework that used the facts as mentioned above to design a decision-making tool for blue-green technology selection for developing countries.

3. Methodology

This study considered the FRM problem as a decision-making problem because there is often a conflict of interest among stakeholders that constitute a team for an FRM strategy adoption [19]. Hence, it uses multi-criteria tools to address the blue-green technology problem. Figure 1 illustrates the relationships between the different MCDM tools in this work. Because of the difficulty of using a quantitative approach to select flood management strategy, this study considers qualitative information for the current problem analysis.
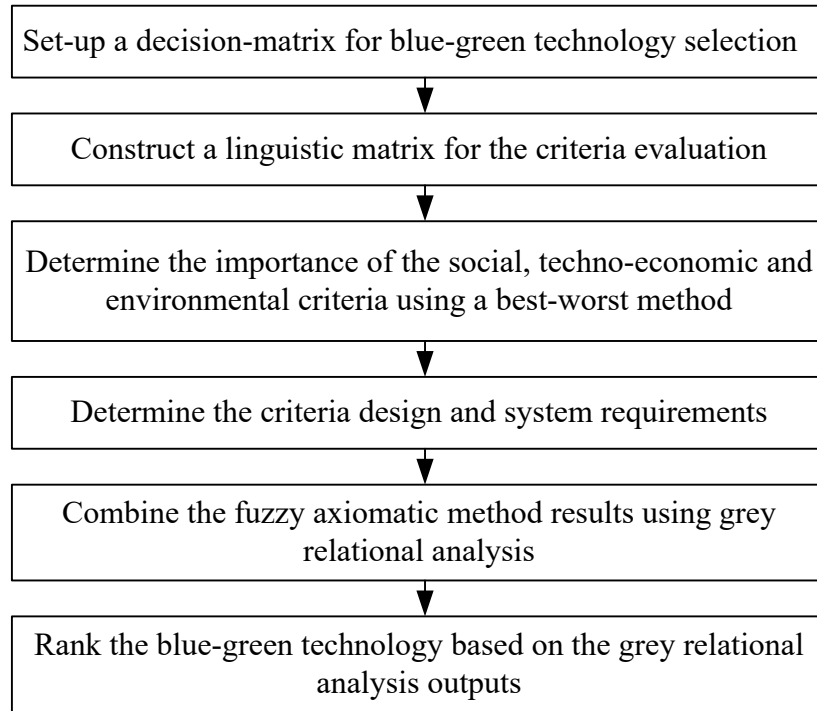
Fig. 1. Schematic flow of the proposed methodology

3.1 Best worst method

This study addresses the problem of optimal weight determination for criteria using a best-worst method. The method uses sets of non-linear equations to determine criteria importance. It synchronises experts' judgments through non-linear equations. The equations are organised in a way that the distance between the best and worst criteria are optimised for all sub-criteria [20]; this makes the best-worst method a unique method for criteria importance evaluation. Furthermore, this attribute gives it an edge over an analytical hierarchy process [21]. The steps for implementing a grey best worst method are expressed as follows [22]:

Step 1: Select the criteria for the blue-green technology evaluation.

Step 2: Determine a scale for the socio-economic, technical, and environmental criteria evaluation.

Step 3: Constitute a panel of experts that will evaluate the criteria importance.

Step 4: Determine the best (Equation 1) and worst (Equation 2) criteria.

Error! Bookmark not defined. $A_B = \{a_{B1}, a_{B2}, a_{B3}, \ldots, a_{Bn}\}$

$$(1)$$

$$A_W = \{a_{1W}, a_{2W}, a_{3W}, \ldots, a_{nW}\} \qquad (2)$$

where A_B and A_W denote the vector of the best and worst criteria for a decision-making process, respectively.

Step 5: Construct a pairwise comparison of the criteria, starting from the best criterion to other criteria in decreasing order.

Step 6: Use Equations (3) to (7) to determine the criteria importance.

$$Min \; \xi \tag{3}$$

s.t.

$$\left| \frac{w_B}{w_i} - a_{Bi} \right| \leq \xi \tag{4}$$

$$\left| \frac{w_i}{w_B} - a_{wi} \right| \leq \xi \tag{5}$$

$$\sum_{i=1}^{n} w_i = 1 \tag{6}$$

$$0 \leq w_i \leq 1 \qquad i = 1,2,3,\ldots n \tag{7}$$

Where w_i denotes criterion i weight.

3.2 Fuzzy axiomatic method

Axiomatic method is a multi-criteria approach that incorporates design requirements into a decision-making process. It uses information content to rank alternatives based on the relationship between design and system requirements. Because of the uniqueness of this method, scholars have used fuzzy logic to increase its application [23]. Its fuzzy version uses fuzzy numbers to convert linguistic terms to crisp values using either triangular or trapezoidal fuzzy numbers. The steps below give a summarised description of a weighted fuzzy axiomatic method:

Step 1: Identify alternative solutions to a decision-making process.

Step 2: Select the criteria for the evaluation process and state linguistic terms for the criteria. Also, select an appropriate method for the criteria importance evaluation.

Step 3: Identify experts that will evaluate the identified alternatives in step 1.

Step 4: Define the criteria's design requirements using the use of the experts' judgements.

Step 5: Aggregate the experts' judgement using an appropriate method. The current study used [24] aggregation expressions in Equations (8) to (11) to aggregate experts' judgements and [23] weighted expression for trapezoidal fuzzy numbers to generate the weighted aggregated values for functional requirements (Equation 12).

$$l_i = \min\left\{ (l_{ik}) \right\} \tag{8}$$

$$m_i^2 = \frac{1}{k} \sum_{k \in K} m_{ik}^1 \tag{9}$$

$$m_i^2 = \frac{1}{k} \sum_{k \in K} m_{ik}^2 \tag{10}$$

$$u_i = \max\{(u_{ik})\} \tag{11}$$

$$fr_i = ((l_i + (m_{1i} - l_i) \times w_i), m_{1i}, m_{2i}, (u_i + (u_i - m_{2i}) \times w_i)) \tag{12}$$

Step 6: Evaluate the alternatives common areas using Equation (13). This area is the triangle created by the intersection between a system and design requirements (Figure 2).

$$CR = \frac{(\delta_2 - \alpha_1)^2}{2(\delta_2 - \beta_2 + \beta_1 - \alpha_1)} \tag{13}$$

Step 7: Compute the alternatives' system requirements using Equation (14).

$$SR = \frac{\tau_1 \delta_1 + \frac{1}{3}(\tau_1 + \delta_1)^2 + \beta_1 \alpha_1 + \frac{1}{3}(\beta_1 + \alpha_1)^2}{\tau_1 + \delta_1 - \beta_1 - \alpha_1} \tag{14}$$

Step 8: Calculate the alternatives' chance of meeting the design requirements using Equation (15)

$$p_{ij} = \frac{CR}{SR} \tag{15}$$

Step 9: Compute the criteria information contents using Equation (16) and the alternatives' total information content using Equation (17).

$$I_{ij} = \log_2\left(\frac{1}{p_{ij}}\right) \tag{16}$$

$$A_i = \sum_{j=1}^{n} I_{ij} \tag{17}$$

Step 10: Rank the alternative based on the lowest total information content, the better the alternative.
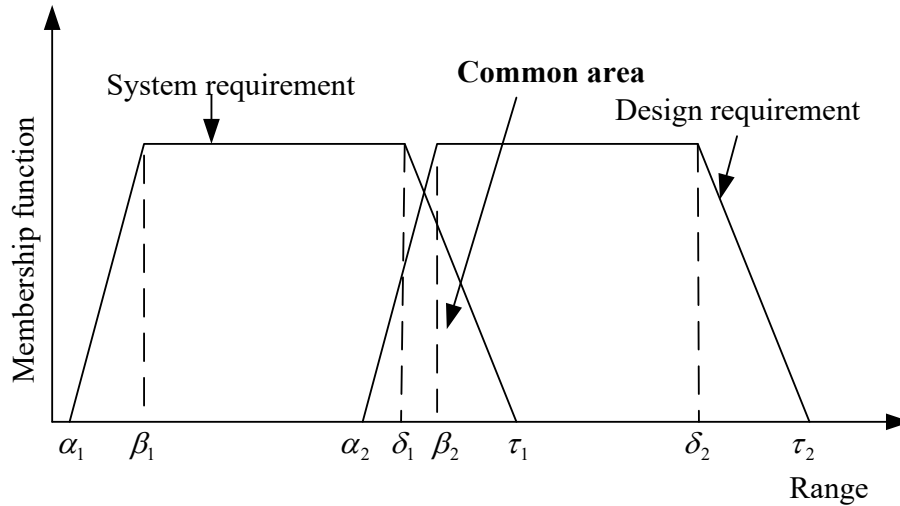
Fig. 2. Common area between a design and a system requirement

3.3 Grey relational analysis

The steps below outlines the procedure for this method application [25], [26]:

Step 1: Construct a decision-matrix for a MCDM problem (Equation 18)

$$D = \begin{bmatrix} r_{11} & r_{12}, \ldots, & r_{1m} \\ r_{21} & r_{22}, \ldots, & r_{2m} \\ r_{n1} & r_{n2}, \ldots, & r_{nm} \end{bmatrix} \tag{18}$$

Step 2: Normalise the information in the matrix. Criteria which are benefit-oriented are normalised with Equation (19), while Equation (20) is used to normalised criteria which are cost-oriented.

$$x_i(k) = \frac{r_i(k) - r_i^{\min}}{r_i^{\max} + r_i^{\min}} \tag{19}$$

$$x_i(k) = \frac{r_i^{\max} - r_i(k)}{r_i^{\max} + r_i^{\min}} \tag{20}$$

where $x_i(k)$ and $r_i(k)$ denote the normalised and real values for criteria k for alternative i, $r_i^{\max}$ and $r_i^{\max}$ denote the maximum and minimum values of criterion k.

Step 3: Specific an ideal sequence $(x_0(k))$ for the evaluation process.

Step 4: Evaluate the deviation of the normalised decision matrix from the specified ideal sequence. The process requires that an identification coefficient value be defined for the evaluation process.

$$\xi_i(k) = \frac{\Delta_{\min} + \xi\Delta_{\max}}{\Delta_{o,i}(k) + \xi\Delta_{\max}} \qquad (21)$$

$$\Delta_{o,i}(k) = \left\| x_o(k) - x_i(k) \right\| \qquad (22)$$

$$\Delta_{\min} = \min_{\forall i} \min_{\forall k} \left\| x_o(k) - x_i(k) \right\| \qquad (23)$$

$$\Delta_{\max} = \max_{\forall i} \max_{\forall k} \left\| x_o(k) - x_i(k) \right\| \qquad (24)$$

Step 5: Determine the alternatives' grey relational grade by combining the grey relational coefficients with criteria importance (Equation 25).

$$\gamma(k) = \frac{1}{n} \sum_{i=1}^{n} w_i \xi_i(k) \qquad (25)$$

Step 6: Rank the alternatives using a higher-the-better approach.

4. Case Study

Lekki, a community in Lagos, Nigeria, was used as a case study. This community, which was designed as a blue-green city, has about 3.4 and 1.9 million for residential and non-residential people, respectively. Its large population is because it is a free trade zone. Dangote oil refinery is among the multi-billion-dollar project in this community. Its annual temperature is about 3.3°C annual, while its maximum monthly rainfall is 91.6 mm. This location's geographical coordinates are 6° 25' 0" North and 4° 6' 0" East (Figure 3). This community has been transformed from a rural community to an urban community. However, the poor implementation of its urban development plan has made it to become a flood-prone community. This problem is affecting its commercial activities, such as fishing and tourism.

During the implementation of the proposed framework (Figure 1), this study considered six blue-green technologies (Table 1). These technologies were evaluated based on the criteria in Table 2. This study used a well-structured questionnaire to obtain information for the evaluation process [27], [28]. The questionnaire has two sections. Information about the criteria importance is contained in the first section; blue-green technologies information is contained in the second section. Three of the decision-makers, i.e., experts, were selected from academics and industry. These experts' minimum working experience and qualifications are eight years and a masters' degree in civil and environmental engineering. Their contributions to the evaluation process are 0.2 for Expert 1 (E1), 0.3 for Expert 2 (E2), and 0.5 for Expert 3 (E3) [29]. The experts were asked to evaluate the criteria importance based on the linguistic variables in Table 3.
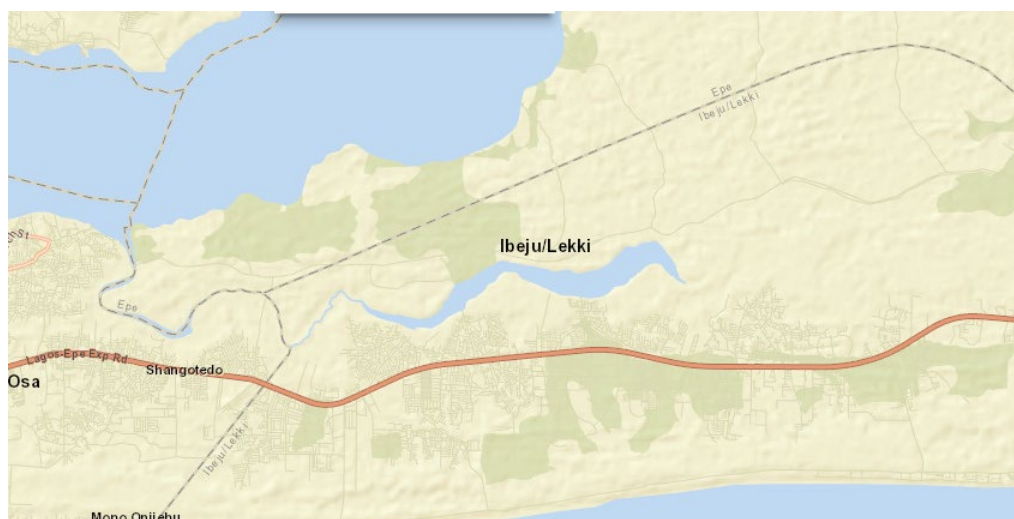
Fig. 3. Lekki spatial location [30]

Table 1. Selected blue-green technology

Blue-green Technology	Description
Rainwater and floodwater harvesting (A_1)	This technology harvests runoff waters for agriculture purposes.
Pumped hydropower systems (A_2)	This technology uses flood water stored in a reservoir to generate hydropower.
Transport basin (A_3)	This technology is used to manage stormwater runoff. It has the capacity to prevent improve water quality in an area.
Porous pavement (A_4)	This technology uses a porous pavement to manage stormwater.
Retention lake (A_5)	This technology uses an artificial pond to prevent downstream erosion and flooding.
Bypass floodway (A_6)	This technology uses a sizeable man-made channel to control excess flood waters.

Table 2. Evaluation criteria

Criteria	Description
Economic criteria	
Investment cost (C_{11})	This criterion measures the cost that will be incurred in order to purchase a blue-green technology for a community [31].
Operation and maintenance cost (C_{12})	This criterion measures the running expenses that will be incurred in order to provide acceptance flood management service to a community [31].
Ease of partnership funding (C_{13})	This criterion measures the ease of getting a public-private partnership that will be used to execute a blue-green technology in a community (Experts).
Implementation cost (C_{14})	This criterion measures the cost of implementing a selected blue-green technology in a community [7].
Environmental	
Adaptability to climate change (C_{21})	This criterion measures the ease of incorporating a blue-green technology into the climate change policy of a community [4].
Land use (C_{22})	This criterion evaluates looks that the impact of a blue-green strategy at it affects the use of land for other productive use (Yazdandoost and Bozorgy, 2008)
Air quality improvement (C_{23})	This criterion looks at the impact of a blue-green technology concerning its implications of air quality in an area (Experts).
Habitat connectivity (C_{24})	This criterion measures the impact of a blue-green technology as it affects the relationship among different habitats in a community (Experts).

Social	
Improvement in water quality (C$_{31}$)	This criterion evaluates the impact of a blue-green technology on the provision of quality water for a community (Experts).
Public realm improvement (C$_{32}$)	This criterion measures how a blue-green technology will affect areas that are allocated for public use [11].
Job generation (C$_{33}$)	This criterion evaluates the opportunity opportunities that will be created based on a selected blue-green technology for a community (Experts).
Technology acceptability by the public (C$_{34}$)	This criterion measures the level of acceptance that a blue-green technology will receive from the members of a community (Experts).
Technical (C4)	
Ease of integration into an urban plan (C$_{41}$)	This criterion evaluates the ease at which a blue-green technology can be incorporated into an urban community plan (Experts).
Resistance (C$_{42}$)	It denotes the capacity of a blue-green technology to prevent floods [31] [31].
Resilience(C$_{43}$)	It denotes the capacity of the blue-green technology system to recover from floods [31].
Technological capacity and support (C$_{44}$)	This criterion looks at the level of technical skills that are available for the implementation of a blue-green technology in a community (experts).
Sensitivity (C$_{45}$)	The ability of technology to adapt to change in the operating condition of an environment; this criterion overs the robustness and flexibility of a technology [31].
Safety (C$_{46}$)	This criterion measures how safe blue-green technology is when installed in a community [9].

The selected experts evaluated the criteria importance using the linguistic terms in Table 3 - their responses are presented in Table 4. This study developed four optimisation models. The first model was developed for the economic criteria evaluation, the second model was developed for the environmental criteria evaluation, the third model was developed for the social criteria evaluation, and the last model was developed for the technical criteria evaluation. The formulated models were solved using Microsoft excel solver (Table 5).

Table 3. Linguistic terms and their crisp values

Linguistic variable	Crisp value
Equal importance (EI)	1
Weak importance (WI)	3
Moderate importance (MI)	5
Strong importance (SI)	7
Very strong importance (VS)	9

Table 4. Linguistic variables for the blue-green technologies importance

	Economic criteria					
	C$_{11}$/C$_{12}$	C$_{11}$/C$_{13}$	C$_{11}$/C$_{14}$	C$_{12}$/C$_{13}$	C$_{12}$/C$_{13}$	C$_{13}$/C$_{14}$
E1	EI	MI	SI	SI	MI	SI
E2	VS	SI	VS	VS	VS	VS
E3	MI	MI	SI	SI	WI	SI
	C$_{21}$/C$_{22}$	C$_{21}$/C$_{23}$	C$_{21}$/C$_{24}$	C$_{22}$/C$_{23}$	C$_{22}$/C$_{23}$	C$_{23}$/C$_{24}$
E1	SI	MI	VS	VS	VS	SI
E2	VS	SI	VS	SI	VS	SI
E3	SI	SI	SI	VS	SI	SI
	C$_{31}$/C$_{32}$	C$_{31}$/C$_{33}$	C$_{31}$/C$_{34}$	C$_{32}$/C$_{33}$	C$_{32}$/C$_{33}$	C$_{33}$/C$_{34}$
E1	MI	SI	SI	MI	MI	MI
E2	MI	WI	WI	SI	WI	VSI
E3	MI	SI	MI	MI	MI	M1
	C$_{41}$/C$_{42}$	C$_{41}$/C$_{43}$	C$_{41}$/C$_{44}$	C$_{41}$/C$_{45}$	C$_{41}$/C$_{46}$	C$_{42}$/C$_{43}$
E1	SI	MI	MI	MI	VS	VS
E2	VS	SI	VS	SI	VS	VS
E3	VS	SI	VS	SI	SI	SI

	C_{42}/C_{44}	C_{42}/C_{45}	C_{42}/C_{46}	C_{43}/C_{44}	C_{43}/C_{45}	C_{43}/C_{46}
E1	SI	MI	VS	MI	SI	VS
E2	VS	VS	VI	SI	VS	VS
E3	MI	SI	SI	SI	MI	VS
	C_{44}/C_{45}	C_{44}/C_{45}	C_{45}/C_{46}			
E1	MI	VS	VS			
E2	VS	VS	VS			
E3	VS	SI	VS			

Table 5. Best worst method results

Economic	C_{11}	C_{12}	C_{13}	C_{14}		
0.6730	0.46	0.37	0.13	0.04		
Environmental	C_{31}	C_{32}	C_{33}	C_{34}		
0.0647	0.49	0.36	0.10	0.05		
Social	C_{41}	C_{42}	C_{43}	C_{44}		
0.0528	0.53	0.27	0.13	0.07		
Technical	C_{21}	C_{22}	C_{23}	C_{24}	C_{25}	C_{26}
0.2088	0.31	0.37	0.21	0.03	0.05	0.03

Table 6 presents the linguistic terms used to evaluate technology appropriateness for the case study. Using these terms, Table 7 shows the experts' rating of the technologies' appropriateness for the case study.

Table 6. Linguistic terms for the technologies evaluation

Benefit-based criterion		Cost-based criterion	
Linguistic terms	Trapezoidal fuzzy numbers	Linguistic terms	Trapezoidal fuzzy numbers
Very low	0.0, 0.1,0.2,0.3	Very low	0.6,0.7,0.8,0.9
Low	0.2,0.3,0.4,0.5	Low	0.4,0.5,0.6,0.7
High	0.4,0.5,0.6,0.7	High	0.2,0.3,0.4,0.5
Very high	0.6,0.7,0.8,0.9	Very high	0.0, 0.1,0.2,0.3

Table 7. Linguistic values for the blue-green technologies

	C_{11}	C_{12}	C_{13}	C_{14}	C_{21}	C_{22}	C_{23}	C_{24}	C_{31}	C_{32}	C_{33}	C_{34}	C_{41}	C_{42}	C_{43}	C_{44}	C_{45}	C_{46}
									E1									
A1	H	H	H	VH	VH	VH	H	H	VH	VH	L	H	VH	H	VH	H	H	VH
A2	VH	VH	H	VH	H	L	L	L	L	L	H	L	VH	H	H	H	VH	VH
A3	VH	VH	H	H	H	L	L	H	H	L	L	H	H	H	H	H	L	VH
A4	VL	H	L	H	H	H	H	L	H	H	L	H	VH	H	H	L	L	VH
A5	H	H	L	L	H	H	L	L	H	H	VL	L	VH	H	H	L	H	VH
A6	VH	L	H	L	H	L	VL	L	VH	H	L	L	VH	VH	VH	VH	L	VH
									E2									
A1	VH	H	L	VH	VH	VH	H	VH	H	H	VH	H	L	VH	H	VH	L	VH
A2	VH	VH	H	VH	H	H	H	VH	H	H	VH	H	H	H	L	H	VH	H
A3	VH	L	L	VH	VH	H	L	H	H	H	L	VH	H	H	H	H	L	H
A4	H	H	L	VH	L	H	L	H	L	VL	H	H	L	L	H	VH	H	L
A5	VH	H	L	VH	L	H	L	H	H	L	L	H	VL	L	VL	L	L	H
A6	H	L	H	H	H	VH	H	H	VH	VH	H	H	H	H	H	H	VL	H
									E3									
A1	H	H	VH	H	H	H	H	H	H	H	VH	H	VH	H	H	VH	H	VH
A2	VH	H	H	H	L	H	L	H	L	L	L	VH	H	H	H	H	L	H
A3	H	H	L	L	H	H	H	H	H	H	L	H	H	H	L	L	L	L
A4	L	H	L	L	L	L	L	L	H	L	VL	L	L	H	H	L	L	H
A5	H	L	VH	H	L	L	H	L	L	H	L	H	H	H	L	VH	H	L
A6	L	VH	L	L	H	H	L	H	L	H	L	VH	L	H	L	H	L	L

Using Equations (8) to (11), the linguistic values in Table 7 were converted and aggregated into fuzzy values (Table 8). Equation (12) is used to generate the weighted aggregated values for the technologies' based on the information tables 5 and 8. Table 9 presents the results obtained for these values. This study used the concept of optimistic (a), pessimistic (m) and most likely design requirements (b) to generate the design requirements (Table 10). It considered Expert 1 has an optimist, Expert 2 has a realist, and Expert 3 has a pessimist.

$$DR = \frac{a + 4m + b}{6}$$
(26)

Equation (13) was used to generate the common requirements for the technologies using the information in tables 9 and 10. Furthermore, Equation (14) was used to compute the system requirements of the technologies. Table 11 presents the results for the technologies common and system requirements. Equation (15) was used to calculate the technologies' probabilities of meeting the design requirements. This study used Equation (16) to compute the technologies' information contents (Table 12).

Table 8. Aggregated values of the technologies

	C_{11}	C_{12}	C_{13}	C_{14}		
A1	(0.00, 0.23, 0.33,0.50)	(0.20, 0.30, 0.40, 0.50)	(0.00, 0.37, 0.47, 0.90)	(0.00, 0.17, 0.27, 0.50)		
A2	(0.00, 0.10, 0.20, 0.30)	(0.00, 0.17, 0.27, 0.50)	(0.20,0.30,0.40, 0.50)	(0.00, 0.17, 0.27, 0.50)		
A3	(0.00, 0.17,0.27, 0.50)	(0.00,0.37,0.47,0.90)	(0.20,0.57,0.67,0.90)	(0.00, 0.37, 0.47, 0.90)		
A4	(0.20,0.43,0.53,0.90)	(0.20,0.30,0.40,0.50)	(0.60,0.70,0.80,0.90)	(0.00,0.37,0.47,0.90)		
A5	(0.00,0.23,0.33,0.50)	(0.20,0.43,0.53,0.90)	(0.00,0.50,0.60,0.90)	(0.00,0.37,0.47,0.90)		
A6	(0.00,0.37,0.47,0.90)	(0.00,0.50,0.60,0.90)	(0.20,0.43,0.53,0.90)	(0.20,0.57,0.67,0.90)		
	C_{21}	C_{22}	C_{23}	C_{24}		
A1	(0.40,0.63,0.73,0.90)	(0.40,0.63,0.73,0.90)	(0.40,0.50,0.60,0.70)	(0.40,0.57,0.67,0.90)		
A2	(0.20,0.43,0.53,0.70)	(0.20,0.43,0.53,0.70)	(0.20,0.37,0.47,0.70)	(0.20,0.50,0.60,0.90)		
A3	(0.40,0.57,0.67,0.90)	(0.20,0.43,0.53,0.70)	(0.20,0.37,0.47,0.70)	(0.40,0.50,0.60,0.70)		
A4	(0.20,0.37,0.47,0.70)	(0.20,0.43,0.53,0.70)	(0.20,0.37,0.47,0.70)	(0.20,0.37,0.47,0.70)		
A5	(0.20,0.37,0.47,0.70)	(0.20,0.43,0.53,0.70)	(0.20,0.37,0.47,0.70)	(0.20,0.37,0.47,0.70)		
A6	(0.40,0.50,0.60,0.70)	(0.20,0.50,0.60,0.90)	(0.20,0.50,0.60,0.90)	(0.20,0.43,0.53,0.70)		
	C_{31}	C_{32}	C_{33}	C_{34}		
A1	(0.40,0.24,0.29,0.90)	(0.40,0.57,0.67,0.90)	(0.20,0.57,0.67,0.90)	(0.40,0.50,0.60,0.70)		
A2	(0.20,0.16,0.20,0.70)	(0.20,0.37,0.47,0.70)	(0.20,0.50,0.60,0.90)	(0.20,0.37,0.47,0.70)		
A3	(0.40,0.21,0.26,0.70)	(0.20,0.43,0.53,0.70)	(0.20,0.30,0.40,0.50)	(0.40,0.57,0.67,0.90)		
A4	(0.20,0.19,0.23,0.70)	(0.00,0.30,0.40,0.70)	(0.00,0.30,0.40,0.70)	(0.20,0.43,0.53,0.70)		
A5	(0.20,0.19,0.23,0.70)	(0.20,0.43,0.53,0.70)	(0.00,0.23,0.33,0.50)	(0.20,0.43,0.53,0.70)		
A6	(0.20,0.24,0.29,0.90)	(0.40,0.57,0.67,0.90)	(0.20,0.37,0.47,0.70)	(0.20,0.37,0.47,0.70)		
	C_{41}	C_{42}	C_{43}	C_{44}	C_{45}	C_{46}
A1	(0.20,0.57,0.67,0.90)	(0.40,0.50,0.60,0.70)	(0.40,0.57,0.67,0.90)	(0.40,0.63,0.73,0.90)	(0.20,0.43,0.53,0.70)	(0.60,0.70,0.80,0.90)
A2	(0.40,0.57,0.67,0.90)	(0.20,0.43,0.53,0.70)	(0.20,0.43,0.53,0.70)	(0.40,0.50,0.60,0.70)	(0.20,0.57,0.67,0.90)	(0.40,0.63,0.73,0.90)
A3	(0.40,0.50,0.60,0.70)	(0.20,0.43,0.53,0.70)	(0.20,0.43,0.53,0.70)	(0.20,0.43,0.53,0.70)	(0.20,0.30,0.40,0.50)	(0.20,0.57,0.67,0.90)
A4	(0.20,0.43,0.53,0.90)	(0.20,0.43,0.53,0.70)	(0.20,0.43,0.53,0.70)	(0.20,0.43,0.53,0.90)	(0.20,0.37,0.47,0.70)	(0.20,0.50,0.60,0.90)
A5	(0.00,0.47,0.57,0.90)	(0.20,0.43,0.53,0.70)	(0.00,0.33,0.43,0.70)	(0.20,0.43,0.53,0.90)	(0.20,0.43,0.53,0.70)	(0.20,0.57,0.67,0.90)
A6	(0.20,0.50,0.60,0.90)	(0.20,0.50,0.60,0.90)	(0.20,0.50,0.60,0.90)	(0.40,0.57,0.67,0.90)	(0.20,0.43,0.53,0.90)	(0.20,0.57,0.67,0.90)

Table 9. Weighted aggregated values of the technologies

	C_{11}	C_{12}	C_{13}	C_{14}		
A1	(0.11,0.23,0.33,0.58)	(0.24,0.30,0.40,0.54)	(0.05,0.37,0.47,0.96)	(0.01,0.17,0.27,0.51)		
A2	(0.05,0.10,0.20,0.35)	(0.06,0.17,0.27,0.59)	(0.21,0.30,0.40,0.51)	(0.01,0.17,0.27,0.51)		
A3	(0.08,0.17,0.27,0.61)	(0.14,0.37,0.47,1.00)	(0.25,0.57,0.67,0.93)	(0.01,0.37,0.47,0.92)		
A4	(0.31,0.43,0.53,1.00)	(0.24,0.30,0.40,0.54)	(0.61,0.70,0.80,0.91)	(0.01,0.37,0.47,0.92)		
A5	(0.11,0.23,0.33,0.58)	(0.29,0.43,0.53,1.00)	(0.07,0.50,0.60,0.94)	(0.01,0.37,0.47,0.92)		
A6	(0.17,0.37,0.47,1.00)	(0.19,0.50,0.60,1.00)	(0.23,0.43,0.53,0.95)	(0.21,0.57,0.67,0.91)		
	C_{21}	C_{22}	C_{23}	C_{24}		
A1	(0.51,0.63,0.73,0.98)	(0.48,0.63,0.73,0.96)	(0.41,0.50,0.60,0.71)	(0.41,0.57,0.67,0.91)		
A2	(0.31,0.43,0.53,0.78)	(0.28,0.43,0.53,0.76)	(0.22,0.37,0.47,0.72)	(0.22,0.50,0.60,0.92)		
A3	(0.48,0.57,0.67,1.00)	(0.28,0.43,0.53,0.76)	(0.22,0.37,0.47,0.72)	(0.41,0.50,0.60,0.71)		
A4	(0.28,0.37,0.47,0.81)	(0.28,0.43,0.53,0.76)	(0.22,0.37,0.47,0.72)	(0.21,0.37,0.47,0.71)		
A5	(0.28,0.37,0.47,0.81)	(0.28,0.43,0.53,0.76)	(0.22,0.37,0.47,0.72)	(0.21,0.37,0.47,0.71)		
A6	(0.45,0.50,0.60,0.75)	(0.31,0.50,0.60,1.00)	(0.23,0.50,0.60,0.93)	(0.21,0.43,0.53,0.71)		
	C_{31}	C_{32}	C_{33}	C_{34}		
A1	(0.32,0.24,0.29,1.23)	(0.45,0.57,0.67,0.96)	(0.25,0.57,0.67,0.93)	(0.41,0.50,0.60,0.71)		
A2	(0.18,0.16,0.20,0.97)	(0.25,0.37,0.47,0.76)	(0.24,0.50,0.60,0.94)	(0.21,0.37,0.47,0.72)		
A3	(0.30,0.21,0.26,0.93)	(0.26,0.43,0.53,0.75)	(0.21,0.30,0.40,0.51)	(0.41,0.57,0.67,0.92)		
A4	(0.19,0.19,0.23,0.95)	(0.08,0.30,0.40,0.78)	(0.04,0.30,0.40,0.74)	(0.22,0.43,0.53,0.71)		
A5	(0.19,0.19,0.23,0.95)	(0.26,0.43,0.53,0.75)	(0.03,0.23,0.33,0.52)	(0.22,0.43,0.53,0.71)		
A6	(0.22,0.24,0.29,1.23)	(0.45,0.57,0.67,0.96)	(0.22,0.37,0.47,0.73)	(0.21,0.37,0.47,0.72)		
	C_{41}	C_{42}	C_{43}	C_{44}	C_{45}	C_{46}
A1	(0.31,0.57,0.67,0.97)	(0.44,0.50,0.60,0.74)	(0.44,0.57,0.67,0.95)	(0.41,0.63,0.73,0.91)	(0.21,0.43,0.53,0.71)	(0.60,0.70,0.80,0.90)
A2	(0.45,0.57,0.67,0.97)	(0.29,0.43,0.53,0.76)	(0.25,0.43,0.53,0.74)	(0.40,0.50,0.60,0.70)	(0.22,0.57,0.67,0.91)	(0.41,0.63,0.73,0.91)
A3	(0.43,0.50,0.60,0.73)	(0.29,0.43,0.53,0.76)	(0.25,0.43,0.53,0.74)	(0.21,0.43,0.53,0.71)	(0.21,0.30,0.40,0.51)	(0.21,0.57,0.67,0.91)
A4	(0.27,0.43,0.53,1.00)	(0.29,0.43,0.53,0.76)	(0.25,0.43,0.53,0.74)	(0.21,0.43,0.53,0.91)	(0.21,0.37,0.47,0.71)	(0.21,0.50,0.60,0.91)
A5	(0.14,0.47,0.57,1.00)	(0.29,0.43,0.53,0.76)	(0.07,0.33,0.43,0.76)	(0.21,0.43,0.53,0.91)	(0.21,0.43,0.53,0.71)	(0.21,0.57,0.67,0.91)
A6	(0.29,0.50,0.60,0.99)	(0.31,0.50,0.60,1.00)	(0.26,0.50,0.60,0.96)	(0.41,0.57,0.67,0.91)	(0.21,0.43,0.53,0.92)	(0.21,0.57,0.67,0.91)

Table 10. Design requirements

	Trapezoidal fuzzy numbers
C_{11}	(0.27,0.33,0.43,0.57)
C_{12}	(0.28,0.34,0.44,0.58)
C_{13}	(0.37,0.46,0.56,0.67)
C_{14}	(0.32,0.42,0.52,0.62)
C_{21}	(0.34,0.44,0.54,0.64)
C_{22}	(0.36,0.46,0.56,0.66)
C_{23}	(0.31,0.41,0.51,0.61)
C_{24}	(0.34,0.44,0.54,0.64)
C_{31}	(0.34,0.44,0.54,0.64)
C_{32}	(0.34,0.44,0.54,0.64)
C_{33}	(0.26,0.36,0.46,0.56)
C_{34}	(0.41,0.51,0.61,0.71)
C_{41}	(0.33,0.42,0.50,0.59)
C_{42}	(0.29,0.38,0.46,0.54)
C_{43}	(0.26,0.34,0.43,0.51)
C_{44}	(0.33,0.41,0.49,0.58)
C_{45}	(0.25,0.33,0.42,0.50)
C_{46}	(0.36,0.44,0.52,0.61)

Table 11. The alternatives' common and system areas

	A1	A2	A3	A4	A5	A6	A1	A2	A3	A4	A5	A6
	Common area						System area					
	Economic											
C_{11}	0.025	0.002	0.004	0.225	0.025	0.144	0.320	0.180	0.300	0.610	0.320	0.560
C_{12}	0.064	0.002	0.132	0.064	0.210	0.324	0.370	0.280	0.530	0.370	0.600	0.580
C_{13}	0.030	0.004	0.240	0.484	0.144	0.072	0.470	0.360	0.600	0.760	0.520	0.550
C_{14}	0.006	0.006	0.056	0.056	0.056	0.306	0.240	0.240	0.450	0.450	0.450	0.580
	Environmental											
C_{21}	0.380	0.090	0.272	0.042	0.042	0.169	0.720	0.520	0.700	0.500	0.500	0.580
C_{22}	0.342	0.072	0.072	0.072	0.072	0.144	0.700	0.500	0.500	0.500	0.500	0.620
C_{23}	0.210	0.064	0.064	0.064	0.064	0.210	0.560	0.450	0.450	0.450	0.450	0.570
C_{24}	0.272	0.169	0.169	0.042	0.042	0.090	0.640	0.560	0.560	0.440	0.440	0.470
	Social											
C_{31}	0.008	0.070	0.021	0.043	0.043	0.008	0.600	0.440	0.480	0.440	0.440	0.560
C_{32}	0.272	0.042	0.090	0.009	0.090	0.272	0.670	0.470	0.500	0.400	0.500	0.670
C_{33}	0.420	0.289	0.049	0.049	0.012	0.110	0.600	0.580	0.360	0.380	0.280	0.450
C_{34}	1.960	0.563	3.063	1.103	1.103	0.563	0.560	0.560	0.650	0.470	0.470	0.560
	Technical											
C_{41}	0.304	0.304	0.192	0.105	0.152	0.192	0.630	0.680	0.570	0.580	0.550	0.610

C_{42}	0.253	0.152	0.152	0.152	0.152	0.253	0.570	0.510	0.510	0.510	0.510	0.620
C_{43}	0.467	0.203	0.203	0.203	0.080	0.321	0.670	0.490	0.490	0.490	0.400	0.590
C_{44}	0.444	0.203	0.111	0.111	0.111	0.321	0.670	0.550	0.470	0.530	0.530	0.640
C_{45}	0.218	0.490	0.063	0.134	0.218	0.218	0.470	0.590	0.360	0.440	0.470	0.530
C_{46}	0.538	0.380	0.267	0.160	0.267	0.267	0.750	0.670	0.580	0.560	0.580	0.580

Table 12. The alternatives' information contents

	A1	A2	A3	A4	A5	A6
Economic						
C_{11}	0.272	0.158	0.161	0.695	0.272	0.510
C_{12}	0.395	0.144	0.499	0.395	0.661	1.190
C_{13}	0.253	0.154	0.757	1.536	0.540	0.341
C_{14}	0.190	0.190	0.333	0.333	0.333	1.085
Total	1.110	0.646	1.751	2.959	1.806	3.128
Environmental						
C_{21}	1.086	0.396	0.734	0.281	0.281	0.562
C_{22}	0.969	0.358	0.358	0.358	0.358	0.475
C_{23}	0.708	0.355	0.355	0.355	0.355	0.695
C_{24}	0.811	0.579	0.579	0.296	0.296	0.420
Total	3.573	1.688	2.026	1.290	1.290	2.152
Social						
C_{31}	0.162	0.377	0.223	0.299	0.299	0.165
C_{32}	0.770	0.288	0.405	0.183	0.405	0.770
C_{33}	1.947	0.995	0.348	0.338	0.222	0.493
C_{34}	1.426	2.039	0.25	3.419	3.525	1.426
Total	4.305	3.699	1.226	4.239	4.451	2.854
Technical						
C_{41}	0.952	0.862	0.637	0.406	0.538	0.599
C_{42}	0.853	0.571	0.571	0.571	0.571	0.773
C_{43}	1.920	0.784	0.784	0.784	0.432	1.139
C_{44}	1.689	0.694	0.481	0.444	0.444	1.005
C_{45}	0.901	3.732	0.396	0.585	0.901	0.779
C_{46}	2.084	1.224	0.893	0.553	0.893	0.893
Total	8.398	7.867	3.762	3.343	3.779	5.189

Aggregation of the information in Table 12 was carried out using GRA. During this process, an identification coefficient of 0.5 to analyse the blue-green technologies [32]. Equation (20) was used to normalised the information in Table 13 because of the FA method rank output in terms of the smaller-the-better. Table 14 presents the GRA output for the blue-green technology problem.

Table 13. Normalised decision-matrix for GRA application

	C1	C2	C3	C4
A1	0.187	1.000	1.000	0.955
A2	0.000	0.895	0.174	0.767
A3	0.445	0.083	0.322	0.000
A4	0.932	0.000	0.000	0.934
A5	0.467	0.086	0.000	1.000
A6	1.000	0.365	0.378	0.505

Table 14. GRA outputs for the blue-green technology problem

	C1	C2	C3	C4	Grade
A1	0.647	0.308	0.298	0.211	0.132
A2	1.130	0.336	0.878	0.251	0.225
A3	0.406	1.156	0.651	1.019	0.153
A4	0.239	1.539	1.490	0.215	0.148
A5	0.394	1.144	1.490	0.204	0.153
A6	0.226	0.626	0.593	0.338	0.085

Discussion of Results

The best-worst results for the current problem showed that the techno-economic criteria contributed about 88.18% to the ranking of blue-green technology. In terms of the economic sub-criteria, the contributions of C_{11} and C_{12} to the technology selection was about 83% (Table 5). In comparison, Table 5 showed that C_{21} and C_{22} contributed about 85% to the technology selection. The contributions of C_{31} and C_{32} to the selection problem in terms of social criterion were about 8%. This study observed that at least three technical sub-criteria account for about 80% of the sub-criteria that affect these technologies selection. Another unique feature of the technical sub-criteria is that the first criterion was not ranked as the most important criterion; instead, it was C_{42} that was the most crucial criterion.

Figure 3 shows the selected blue-green technologies rank in terms of the FA and GRA methods. When the FA method results aggregated with the GRA method, the most and least suitable technology for the case study was A1 and A6, respectively; these rankings are consistent with the economic criteria ranks for the case study. The GRA method results showed that the suitability of A3 and A5 for the case study area is the same (Figure 4). The technical and environmental criteria FA method results showed A4 is the most suitable technology, while A1 is the least suitable technology (Figure 4). In terms of the social criterion, the most suitable technology is A3, while A5 is the least suitable technology.
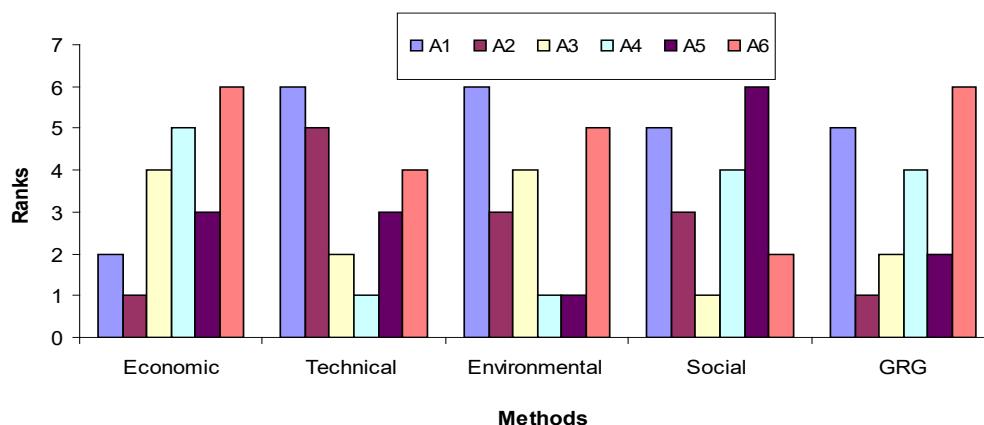

Figure 4: Comparison of different methods for blue-green technology ranking

Policy implications

This study outputs have several policy implications to FRM problem in developing countries. First, it has been able to establish that MCDM tools can be used to provide bounded-rational on the most suitable technology for flood control. With this knowledge, corporate responsibility can be taken whenever a technology fails. This identification process will absolve a particular person from bearing the effect of a policy failure. Second, policy failure can be tacked from strategy and tactical level. When considering a strategic level to policy failure, policy-makers can trouble-shoot failure by considering economic, social, environmental and technical requirements for this technology selection. On the other hand, policy failure can be traced to the sub-criteria that constitute each of the criteria, as mentioned earlier at a strategic level.

5. Conclusion

This study has developed a framework for blue-green technology selection. It used a multi-criterion modelling approach to developed the framework. Sustainability criteria were embedded into the framework to account for stakeholders' requirement during the selection process. Lekki, a community in Lagos, Nigeria, was used as a case study for the framework evaluation. Based on three experts' responses about six blue-green technologies, which include bypass floodway, rainwater and floodwater harvesting, and porous pavement, the most and least suitable technologies were identified for the case study. The framework identified rainwater and floodwater harvesting as the most suitable blue-green technologies for a community. It also identified a bypass floodway as the least suitable blue-green technologies for a community.

The use of a best-worst method to address the problem of optimal weight determination for criteria is a contribution of this study. Another contribution of the current study is the fuzzy axiomatic method to incorporate decision-makers' preference into blue-green technology selection. Also, this study contributed to the use of optimistic, pessimistic and most likely design requirements approach to fuzzy axiomatic method application as another contribution to FRM. Also, it applied GRA to FRM problem as a contribution to FRM. One of the limitations of this study is that it did not consider the political and institutional constraints that affect blue-green technology selection. This study, therefore, expects future studies to incorporate these factors into blue-green technology analysis.

Acknowledgements

Conflict of Interest

The authors declare that there is no conflict of interest.

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