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A decision-making framework for green substations: Insights from AHP and fuzzy TOPSIS

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A B S T R A C T

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In today's dynamic and uncertain environments, effective decision-making processes are essential for navigating complex challenges. This paper proposes an innovative approach utilizing Fermatean fuzzy sets to enhance decision-making within heterogeneous group dynamics. Through a systematic mathematical framework, our method integrates expert preferences to find out the comparative weight of decision attribute, leveraging both Fermatean fuzzy sets and entropy calculations. Furthermore, we introduce a novel technique to assess the significance of individual experts' opinions, accounting for specific contextual factors. By synthesizing performance ratings, criteria weights, and expert inputs, our approach offers a comprehensive decision-making model. We introduce the concept of the proximity coefficient to address existing methodological limitations, enhancing the accuracy of decision outcomes. To validate our methodology, we apply it to a practical scenario involving warehouse location selection. Additionally, analysis of sensitivity is conducted to evaluate the robustness of our method across diverse scenarios, demonstrating its efficacy in uncertain environments. This research contributes to advancing decision-making practices in complex and uncertain contexts, offering a valuable tool for addressing real-world challenges.

1. Introduction

Two main types of energy inputs for any production industry are – fossil fuels /gases /furnace oils and electrical energy. Electrical energy is probably the main energy source for not only operating production processes, but also for operating offices. Many of the recent automated equipment operate using electricity, not fuels. In the era of 4th Industrial Revolution, companies are leaning towards using automated equipment and machineries (Calik, 2021). Thus, the importance of electricity is growing very fast. It is completely impossible to undermine the value of electrical energy for any production industry. But the dark side of ever-increasing necessity of electrical energy is pollution related to energy generation, transmission/distribution and feeding into the production industry through electrical substation. Electrical substations require some equipment, like transformers, circuit breakers, batteries, and many more equipment, which require zinc and other metal plates, acids and oils of various types (Dahiya, 2022). These are highly prone to environmental pollution. As a result, there is growing concern over selecting the right supplier of these electrical equipment, in terms of environmental compliance (Dugaya & Shandilya, 2017; Thanh & Lan, 2022). Although electrical energy is essential for any industry, it has negative sides also, especially when the environment is of concern. Electricity generation, distribution/transmission and input to users, are all exposed to environmental hazards. Increased economic growth brings with it pollution for society. This paper addressed the end use of electrical energy and associated pollution. The ending side of the transmission line requires a substation to first step-down the high voltage of the transmission line before feeding into users' facilities. The substations consist of several equipment, which use cooling oils, acids, zinc and other plates, etc., which are all environmentally hazardous. In the last one decade or so, the need for sustainability, in terms of environmental pollution, has gained wide focus and attention from all sections of the society at large, including government, civil society, internal employees, as well as common people. This emphasizes the necessity

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of practices of compliance related measures across the supply chain, in each and every activity – procurement, production, storage, transportation, installation and use.

People tend to give more attention towards chemical industries though. Recently, experts realize that both electrical energy and fossil fuel burning are no less for generating pollution. Thus, it is time to give higher attention to electrical energy related sustainability measures across the supply chain of various types of industrial sectors which need electricity for energy inputs. The producers of these electrical equipment must have environmental compliance for future sustainability. For any other production industry, requiring electrical substations, must select those substation equipment manufacturers and suppliers, who have higher compliance. This compliance issue has multiple criteria, such as recycling facilities, ISO14000 EMS, green purchasing practices, etc. Thus, selection of suppliers (also manufacturers) of substation equipment necessitates multi-criteria decision making (MCDM) (Siddiquee et al., 2024; Hasin et al., 2025).

Evaluation and selection of the right suppliers of electrical equipment have caught the attention of the research as well as the business world. This involves developing quantitative performance metrics for multi-criteria evaluation, assessment and selection for eco-friendly sustainability, such as energy efficiency, waste minimization, establishment of reverse supply chain through recycling and re-use, etc. The practice of environmental management systems, such as ISO14000, Hazard Analysis and Critical Control Point (HACCP), Good Manufacturing Practice (GMP), etc., are also strongly suggested, although effectiveness of these documentation-based systems are always questioned by certain sections of academicians. But there is no debate regarding resource conservation through increased use of green re-design, re-use and recycling. Electrical equipment are not exceptions (Hasin et al., 2025).

This paper deals with pollution related to electrical energy substations and selection of green suppliers of electrical devices for specifically electrical substations. Expert opinions were solicited from several electrical equipment manufacturers, regarding criteria and their weightages (or importance) of green suppliers. Some reputed Bangladeshi electrical equipment, machineries and battery manufacturers, and their business clients (B2B) requiring constructing substations were thoroughly studied to identify potential areas of pollution.

This research used Saaty's traditional Analytic Hierarchy Process (AHP) method (Saaty and Vargas 2012), with eight criteria, deemed essential to select green suppliers of substation equipment. Then the final results were compared with the outputs obtained earlier from another technique Fuzzy TOPSIS (Hasin et al., 2025). The research proposed another avenue to further analyze the results, in case conflicting results are obtained from two separate MCDM methods – AHP and Fuzzy TOPSIS. The research demonstrated the use of life-cycle economic analysis and higher Normalized Value (of AHP) for conflict resolution.

Sustainability implications

The global trend of circular economy means that a large number of companies follow a reverse chain in order to reuse and recycle as many components as possible. This helps in preserving resources, less consumption of energy (both fossil fuel and electricity) and reduced cost also. But this requires appropriate supplier selection, monitoring, collaboration with suppliers and strict control on material or product movement and storage (Singh, 2024). This approach has positive results, by ensuring ecological preservation of nature in the long run. To ensure not only a reverse supply chain for a single company, but also a circular economy at large, consolidated efforts are required by establishing collaboration and information sharing among suppliers and buyers. Collaboration encompasses right from design, material and component selection, storage mechanism, transportation mechanism, installation, maintenance and many more. Befitting environmental policy for all collaborating companies is also essential (Ashraf et al., 2020, Tseng et al., 2019). Recent publications reveal that use of modified and automated technologies, along with improved processes and methods of business practices are also necessary (Al-Awamleh et al., 2022, Aslam et al., 2018).

In Bangladesh, a noticeable positive aspect is that many apparel companies are not only making their supply chain green, but also their offices. Even on the material side, the left-over materials of fabrics are processed to produce new threads and knitwear products. This is basically an instance of recycling and reuse. In the electrical equipment business, an increased amount of domestic investment can be observed. Apart from some international companies, many local companies have started operations to produce substation equipment, like transformers, circuit breakers, motors, relays, batteries, etc. The trend in the local market indicates near-future self-sufficiency in this sector. The reason behind this rapid growth is clear – an increased number of industries, in various sectors, are either already operating or being contemplated in the foreseeable future. This creates a high demand of electrical energy substations and its equipment. Thus, in-depth study on demand estimation and green implications is necessary. This automatically justifies the necessity to create a framework to select the right green supplier (manufacturer of substation equipment).

Why MCDM techniques?

Although plenty of research can be found addressing the popular issue of green supplier selection in various industrial sectors, the electrical substation equipment sector has not been addressed sufficiently. Large majority of the research focuses on varied methods of multi-criteria decision making (MCDM). The main reason is its simplicity and ease of computation even when business characteristics are complex in nature, thereby making optimization techniques very complex (Puška & Stojanović, 2022; Salimia et al., 2022; Selvaraj, 2019). The MCDM techniques can provide very good solutions through relatively simple computation processes and more importantly quickly. The main reason behind these positive aspects is its ability to handle judgmental pairwise comparisons among qualitative and quantitative criteria and alternatives, which can be done quite comfortably and with noticeable ease (Kabir & Hasin, 2011).

The most recent trend in use of MCDM techniques is centered around consideration of green criteria (Remadi & Frikha, 2020; Rashidi & Cullinane, 2019). Hasin et al. (2025) used fuzzy TOPSIS to select green suppliers specifically for electrical energy substation equipment. This current research aims at finding some contradictory results from different MCDM techniques and provides an in-depth resolution to that.

Problem hypothesis

Increase in industrialization in a country means an associated increase in demand for electricity. This in turn means an increased number of installations of electrical energy substations. Almost all medium to large industries of any product require construction and installation of substations. The earlier sections have outlined equipment required in a substation and associated pollution. It is time to take measures to minimize the negative impact of pollution through waste minimization, pollution prevention, recycling and reuse as much as possible (Rahman et al., 2022). There are plenty of scopes for such measures. The only concern is whether other industries requiring construction of electrical substation would give due importance to green supplier selection or not. There is a possibility of giving importance mainly to cost factor (initial purchase price only), and ignoring green issues. The companies often fail to realize that a green supply chain is not only a concern for the society alone, but also for themselves, as it helps to reduce cost through reuse and recycle. Thus, it is essential to focus on green business and select the right (green) supplier through appropriate selection techniques.

This research identified a series of hypotheses, which are answered and resolved in this paper. The major hypotheses are –

1. What kind of pollution is associated with electrical energy substations?
2. Which criteria are suitable for selecting green suppliers in case of electrical energy substations?
3. Can a single MCDM method give a reliable decision? Will a different MCDM method give a different priority to suppliers?
4. In case, conflicting or contradictory priority lists are obtained from two different MCDM methods, then which one will be adopted?
5. Is it possible to logically derive an alternative mechanism to select the supplier in such a conflicting situation? What should be the basis for an alternative mechanism?

The above six questions and their answers can help in preparing a comprehensive selection framework.

Energy Substations and nature of pollution

Any medium to heavy production industry or a service facility (such as a university, or hospital) requires a substation to ensure right specifications for inputs of electrical energy. Higher or lower specifications (loads) of substations (e.g., voltage, current or power) may push the production or service facility into high risk or complete non-functionality of resources. Thus, substations are of high importance for any organization, requiring a right A substation is an important part of any medium to heavy industry for electrical power inputs. Substations play a very important part in power generation, transmission, and distribution segments. Taking electrical power from grid lines into a production industry requires a substation (Miesner & Gallo, 2022; Nogda, 2023).

The long distance of consumers from power generation plants technically necessitates the use of substations, and there is no alternative to that, unless a production industry constructs their own power plant inside the factory premise. This alternative arrangement would require too high a cost, which is avoidable. There are several reasons why the power plants are located away from the localities. The reasons are partly environment related and partly health and safety related, but unavoidable by any definition (Hasin et al., 2025).

Nevertheless, substations themselves are risky and polluting, but of course in lesser scale and extent than a full-fledged power generation plant.

The basic components of an electrical substation are – different types of transformers, huge storage batteries, bus-bar, circuit breakers, lightning arrestors, isolators, high voltage earthing switches, conductors, fuses, etc. These electrical equipment and machinery use huge amounts of cooling and other oils, sulfuric and other acids, different metal plates, etc. which are highly toxic, non-biodegradable and environmentally hazardous.

There is ever increasing necessity to recycle and reuse different components of the above equipment, if economically feasible and technically possible. In the last two decades or so, many electrical equipment companies have been doing this. This is helping the country to conserve nature, and create a base for a circular economy through sustainability (Dugaya & Shandilya, 2017; Khezri & Bevrani, 2017). Literature identifies 3 major equipment, namely transformers, batteries and circuit breakers, which require special attention for such initiative.

The main equipment of an electrical substation is a transformer. The specifications and size of a transformer depends on energy requirements of the client production organization, which in turn depends on the type of machinery used for production. Quite a high number of oils are used in transformers for their technical operations, including cooling. However, these oils have a negative hazardous impact on the environment (Hasin et al., 2025). Although there is an alternative dry transformer, its high operating costs make it partly infeasible. Similar kinds of oils are used in good quantities in oil circuit breakers also.

Commercial transformers, available in the market and used in substations, generally use fossil fuel-based non-biodegradable naphthenic oil or paraffinic oil, several national standards organizations and international environmental organizations, such as the English and Wales law (Regulations, 2005) has identified and classified electrical oils as hazardous wastes, both for health-safety and environment. These oils are flammable, and thus, risky for fire. Moreover, these oils emit gases to the troposphere layer, which create unwanted tropospheric ozone, a major green-house gas, responsible for Smog and acid rain (Hasin, 2019).

A second major equipment is industrial batteries, used not only for substations, but also for running control rooms in case of blackout and many other independently operated material handling equipment. For instance, forklifts, electric vehicles, etc. use motive power batteries. Industries often use multi-pack lead-acid battery cells. These are, without any doubt, essential, but can be extensively recycled and reused through the reverse supply chain for green practices (Shorinwa, 2023; Qing et al., 2023).

About 70% of the lead, used in batteries, is disposed of in an open environment, either as gaseous emission, or solid waste. Both of these two scenarios are alarmingly toxic, and thus harmful for public health, air, water reservoirs and soils. As far as air contamination is concerned, these batteries emit Oxides of Nitrogen and Sulfur, which are harmful for both tropospheric and stratospheric ozone layer (Hasin, 2019).

Oil Circuit Breakers are extensively used in electrical substations, whose primary purpose is to enable the power delivery circuit to switch on and off when emergency requires to do so. This equipment also contains oils for cooling and switch activation purposes. This oil is also harmful for the environment.

2. Literature Review and the proposed study

Although numerous literatures reveal that green supplier selection and other issues have been a very popular research topic now-a-days, a few can be found on how energy destroys the environment. Moreover, even the few literature addressing the issue of how energy can destroy the environment, are mostly around fossil fuel as energy, not exactly electricity as energy source. Specifically, electrical substations are not found in literature. As such, there is urgent necessity to focus on how this issue hampers environment, and hampers sustainability (Hasin, 2025; Nogda, 2023).

A large number of papers have focused on food supply chain (Ghadge et al., 2017; Puška & Stojanović, 2022), hospital (Geethai et al., 2019; Salimian et al., 2022) and pharmaceutical (Al-Awamleh, 2022; Badi & Ballem, 2018; Siddiquee et al., 2024) industries. Some others are found in areas like textile dyeing, metal industry, etc. However, too many literates are found on common generic criteria selection for any kind of industry (Siddiquee et al., 2024; Carter et al., 2020; Rahman et al., 2022; Tsenga et al., 2019). Some papers identified drivers of green supply chain, which indicates direct implications of these drivers with potential pollution possibility (Aslam, 2018).

A major focus has been given on use of multi-criteria decision making (MCDM) techniques as a useful tool to select the right green supplier. As mentioned in the reference list, a large number of papers addressed this popular issue (Siddiquee et al., 2024). Since too many papers are found on this, a comprehensive literature list is avoided in this paper. Majority of these paper used a single MCDM method, such as TOPSIS, ANP, AHP, SWARA-WASPAS, VIKOR, ELECTRE, PROMETHEE, COPRAS, CODAS, BWM, Multi-MOORA, EDAS, and some more (Hasin et al., 2025). Some of these used a single MCDM technique, while a few can be found using two techniques for comparison of results. However, there is a problem in using two methods simultaneously in the same problem-area. The results can be contradictory, thereby creating an additional issue of resolution between two results. This paper addressed this issue.

Recent trends reveal that the above-mentioned selection attributes, used in MCDM techniques, can be fuzzy in nature. This has been solved by many applying either a fuzzy MCDM technique or expert system or artificial intelligence (AI) (Lee et al., 2009; Rashidi & Cullinane, 2019; Siddiquee et al., 2024). Very recently, AI-based intelligent purchasing systems are gaining popularity. This can analyze huge supplier databases, past records, demand and supply data, market trends, and other information, by matching the specific needs of a company. This needs data analytics also (Guida et al., 2023; Saad & Khamkham, 2022).

Analytic Hierarchy Process method was developed by Saaty (2012), with demonstration on different problem areas. Since its development, it has been probably the most popular analytic method to select the best one from many alternatives in varieties of problem areas, including green supplier selection (Dominic et al., 2021). Calik (2021) used it for green supplier selection with special focus on Industry 4.0. Kabir and Hasin compared the performances of AHP and fuzzy AHP. Luthra et al. used AHP to evaluate sustainability in consumption and production initiatives. Apart from these researches, many more can be found on application of AHP method in selecting alternatives in areas like strategy selection, location selection, warehousing decision, investment alternatives, defect identification, and numerous more. (Dominic et al., 2021).

When green issues are concerned, including supplier selection, 'Sustainability' of a manufacturer or 'Circular economy' of a society or country, have been coined popularly. This popular term 'sustainability' has been identified as the single most important determinant of its success in the long term, because of increasing emphasis on green supply chain by almost all countries of the world. Out of many factors of sustainability, depending on the kind or nature of sustainability, a major one for the production industry is green supplier selection (Guo et al., 2017; Romano et al., 2023,). A host of criteria have been used by many researchers (Hasin et al., 2025; Siddiquee et al., 2024)

The following long list of criteria can be traced in numerous research publications, as mentioned in references. The most commonly found criteria in those publications are listed below:

1. Raw Material Cost
2. Transportation Cost
3. Payment Terms
4. Quality Management System (QMS), ISO9000
5. Other Quality Assurance, such as HACCP, GMP
6. Continuous Process Improvement (Kaizen)
7. Total Quality Management (TQM)
8. Procurement Lead Time
9. Delivery performance
10. On-time delivery, and quantity flexibility
11. Supply Chain Responsiveness
12. Green design, Green purchasing
13. Green Packaging, Green warehousing
14. Environmental Management System (ISo14000)
15. Waste Management, Lean system
16. Recycling / Reuse, reverse supply chain
17. Pollution Prevention, source reduction
18. Emission (source) Control, Air Treatment Plant (ATP)
19. Top Management commitment
20. Organization-wide training and awareness

Apart from the above criteria, which are more generic and can be applied to any industry or sector, many more criteria are found which are industry-specific, or case-specific.

Substation Equipment Supplier Selection using TOPSIS

Multi Criteria Decision Making technique TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) is widely used for different purposes, including green supplier selection (Rashid & Cullinane, 2019; Calik, 2021). It is basically a 'minimization" solution, thus, a kind of optimization technique. It minimizes deviations from an ideal solution (Opricovic & Tzeng, 2004). The currently considered problem is to select green suppliers for supplying electrical substation equipment to any kind of production industry, requiring electrical energy inputs. This paper compares the results obtained from fuzzy TOPSIS (Hasin et al., 2025; Siddiquee et al., 2024) with a similar analysis using AHP method. In case two conflicting results are obtained from TOPSIS and AHP, two logical compromise solutions have been proposed and demonstrated. The earlier research considered a total five groups of expert evaluators (EE), comprising 15 evaluators for MCDM analysis (Hasin et al. 2025). Another group of final decision makers (DM) were included in this study. The DMs were grouped in four, comprising 5 members each, thus having a total 20 DMs. That means, information was gathered from a total 35 professional experts, either in the rank of evaluators or decision makers. This sufficiently justifies Normal; distribution, in case validity of results arises.

The case considered eight criteria for both fuzzy TOPSIS and AHP methods, as in Table 1.

Table 1
Criteria used

Code	Criteria
C1	Cost or price (purchased material cost, or market price)
C2	Quality (of equipment)
C3	Suppliers' delivery performance, flexibility and reliability
C4	Data visibility and readiness to mutually sharing information
C5	Green Management issues (e.g. Green design, green office, etc.)
C6	Environment Management and compliance issues
C7	Recycling, Re-use and related reverse chain issues
C8	Cooperation between buyer and supplier in the complete chain

Total five suppliers (S1, S2…S5) were considered for evaluation and selection. Qualitative performance ratings were assigned by 35 expert evaluators and emission makers. The qualitative assignments were converted to numerical fuzzy values in a Likert Scale. Through complete computational procedure, performed in MS Excel, of Fuzzy TOPSIS, the final Relative Closeness Ratio (RC or RCR) were obtained as given in Table 2 (Hasin et al., 2025).

Table 2
Values of Relative Closeness (ratio)

	S1	**S2**	**S3**	**S4**	**S5**
RCR	0.835622	0.928745	0.965634	0.565781	0.726534

The results, in Table 2 shows a preference choice or ranking as – S3>S2>S1>S5>S4. However, it was not clearly decisive, as Supplier 2 and Supplier 3 have marginal differences in their RC values. That means, a minor inconsistency in assignment may totally reverse the choice between S2 and S3. As a result, another MCDM technique AHP was used, to find if there is really any possibility of such a situation.

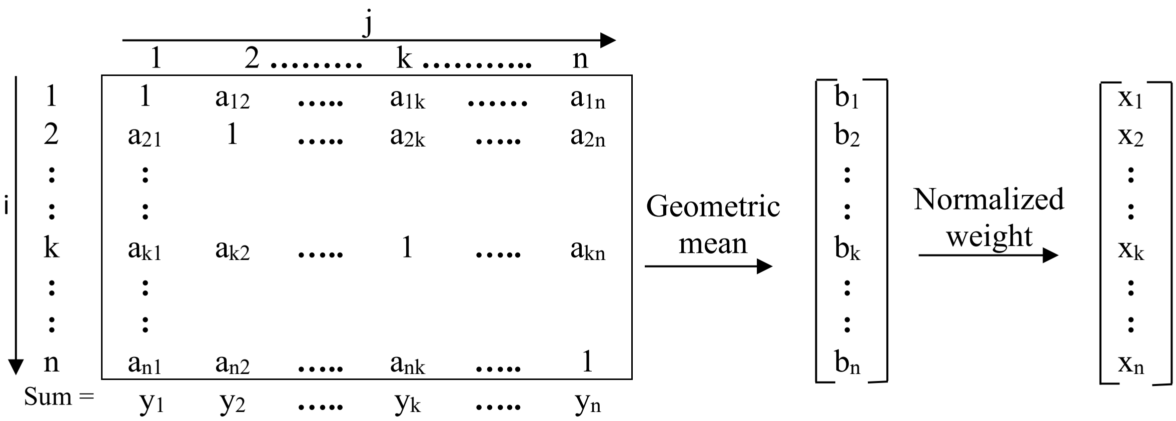
The same case has been analyzed again by another method, the fundamental Analytic Hierarchy Process (AHP), proposed by Thomas L. Saaty of University of Pittsburg, USA. The results obtained from two methods will be further analyzed for better decision making.

Theories on Analytic Hierarchy Process

The Analytic Hierarchy Process (AHP) is a Multi Criteria Decision Making (MCDM) technique, where both quantitative and qualitative performance factors are considered to select a supplier out of a few short listed ones. A decision, out of several possible alternatives, may be taken through multi criteria judgment, by taking into account both qualitative and quantitative factors/criteria, even when they are conflicting in nature. The most commonly used MCDM technique is the Analytic Hierarchy Process (AHP) method, developed by Saaty (2012).

Although relatively simple, this method can be used in a wide range of problems, like supplier selection, machine or equipment or method selection, marketing options, etc. The main advantage of using AHP method is its ability to handle a complex problem in a simple way.

It compares different alternatives (i) against different attributes (j) through an n×n judgment matrix as follows:



where, i and j are alternatives or attributes to be compared, and
a_{ij} is a value which represents comparison between alternatives / attributes i & j.

In the matrix, $y_k = \sum_{i=1}^{n} a_{ij}$, where k = 1, 2….n and j = 1, 2…….n (1)

Geometric mean is calculated from the elements of rows as follows:

$$b_k = [(a_{k1}).(a_{k2}).....(a_{kn})]^{1/n} \quad (2)$$

Normalized weights are calculated as follows:

$$x_k = \frac{b_k}{\sum_{k=1}^{n} b_k} \tag{3}$$

Saaty's measure of consistency is done in terms of Consistency Index (C.I.), as follows:

$$C.I. = \frac{\lambda_{max} - n}{n-1}, \text{ where } \lambda_{max} = y_1 x_1 + y_2 x_2 + ... + y_n x_n = \sum_{k=1}^{n} y_k x_k \tag{4}$$

Some randomly generated consistency index (R.I.) values (proposed by Saaty) are:

n	1	2	3	4	5	6	7	8	9	10
R.I.	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

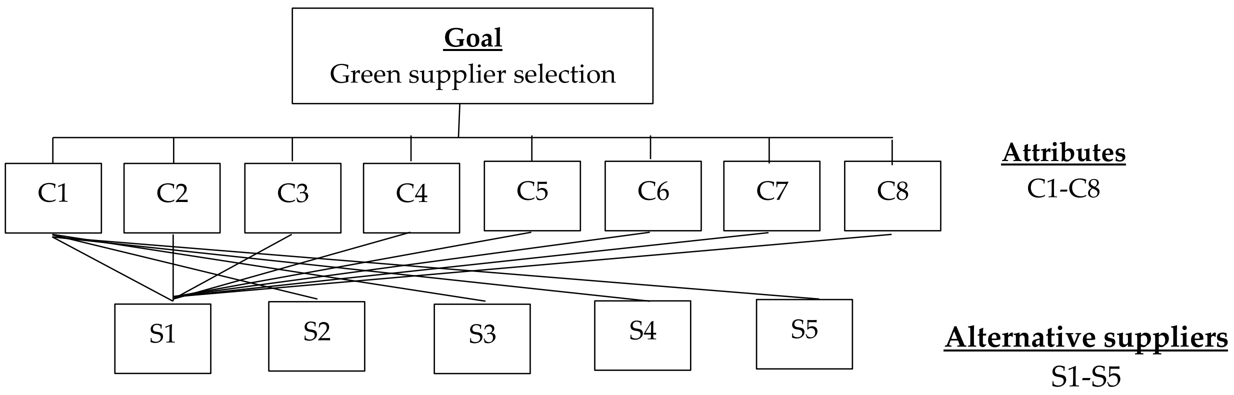
Acceptability of alternative or attribute is measured in terms of Consistency Ratio (C.R.):

$$C.R = \frac{C.I.}{R.I.} \tag{5}$$

If C.R. ≤ 10%, then the alternative, or attribute is accepted. Otherwise, the alternative, or attribute is rejected. The overall constancy may also be measured to justify the validity of selection.

Case of Electrical Substation equipment

Green supplier selection for electrical equipment of substations is mapped in the following Attribute-Alternative Mapping diagram. Supplier or vendor selection decision involves several qualitative and quantitative criteria. The qualitative criteria are judged by expert opinions, whereas quantitative criteria are judged against the collected and calculated quantitative data. The evaluation for 8 criteria or attributes (C1 to C8) and 5 suppliers (S1 to S5) are shown in Fig. 1.



Note: In fact, arrows connect all attributes with all alternative suppliers.

Fig. 1. Attribute-Alternative Mapping

For pair-wise comparison, i.e. relative importance of one option over another, is done using a "Scale of relative importance", which is similar to Likert Scale, widely used in marketing research. The basic AHP theory, developed by Saaty, which suggests a scale (1-9), with one additional scale value of 10 (So highly important that it cannot be compared with any other attribute or alternative) and slight rephrasing, is shown below:

Scale	Importance over other
1	Equal
3	Moderately better

Scale	Importance over other
5	Strongly better
7	Very strongly better

Scale	Importance over other
9	Extremely better
10	No comparison at all

The intermediate scale values of 2, 4, 6, 8 etc. may also be used.

Then comparison matrices are prepared at the first level, i.e. attribute/criteria level, as given in Table 3. Here, GM is Geometric Mean and NV is Normalized Weight. Criteria C1, C2 and C3 are not exactly green SCM attributes, rather normal supply chain attributes. Criteria C4 to C8 are truly green SCM attributes or criteria. A non-green traditional supply chain has more focus (weight) on C1-C3, with less focus (significantly less weight, often zero) on C4-C8. But a GSCM should consider all criteria at the same level. Following theories of GSCM, it is logical to assume that GSCM practices will help in reducing cost (C1). Thus, GSCM attributes are all higher ranked in comparison to cost attributes.

Table 3
Evaluation at level 1: Attribute/Criteria Comparisons

Attributes	C1	C2	C3	C4	C5	C6	C7	C8	GM	NV
C1	1	1	5	1/4	1/2	1/3	1/5	1/2	0.6164	0.0633
C2	1	1	2	1	1	1	1	1	1.0905	0.1120
C3	1/5	1/2	1	1/4	1/3	1/3	1/6	1/5	0.3724	0.0382
C4	4	1	4	1	2	2	1/3	1	1.4660	0.1505
C5	2	3	3	1/2	1	3	1/3	2	1.4352	0.1473
C6	3	1	3	1/2	1/3	1	1/4	1	0.8846	0.0908
C7	5	1	6	3	3	4	1	4	2.8473	0.2923
C8	2	1	5	1	1/2	1	1/4	1	1.0283	0.1056
Sum	18.20	9.5	29.0	7.5	8.66	12.66	3.53	10.7	9.7407	

Note: GM – Geometric Mean; NV – Normalized Value

$\lambda_{max} = 9.0394$

For the assignments in the above judgment matrix,

n =8, C.I. = 0.1484; R.I. = 1.41

C.R. = 0.1052 = 10.52, which is marginally higher than maximum limit of 10% value. This can be attributed to rounding up of several decimal values. Thus, the assignments are reasonably acceptable.

The next 2nd-level evaluation takes place at alternative-level, among suppliers S1-S5, as shown in Fig. 2. These comparisons are among five suppliers, S1-S5, against the seventh criteria (C7), which is "Recycling and Re-use". Details of this evaluation is given in Table 4, whereas the summarized results of other 7 evaluations are given in Table 5.

Table 4
Evaluation at level 2: Suppliers performance against "Recycling".

Suppliers	S1	S2	S3	S4	S5	GM	NV
S1	1	1/3	1/2	2	3	0.999	0.174
S2	3	1	2	4	2	2.169	0.378
S3	2	1/2	1	3	2	1.431	0.249
S4	1/2	1/4	1/3	1	2	0.608	0.106
S5	1/3	1/2	1/2	1/2	1	0.529	0.092
Sum	6.833	2.583	4.333	10.50	10.00	5.736	

$\lambda_{max} = 5.277$
For the assignments in the above judgment matrix,

n = 5, C.I. = 0.0693; R.I. = 1.12; C.R. = 0.0618 = 6.18%, which is well below standard limit 10%, thus, acceptable.

For other 7 criteria (i.e. C1-C6, C8), along with C7, the full and final evaluation indices are given in Table 5.

Table 5
Validity of assignments against all 7 criteria

Criteria No.	C.I.	R.I.	C.R	Decision
C1	0.0731	1.12	0.0652 = 6.52%	Acceptable, so assignments are consistent
C2	0.1113	1.12	0.0993 = 9.93%	Acceptable, so assignments are consistent
C3	0.0397	1.12	0.0354 = 3.54%	Acceptable, so assignments are consistent
C4	0.1002	1.12	0.0894 = 8.94%	Acceptable, so assignments are consistent
C5	0.0936	1.12	0.0835 = 8.35%	Acceptable, so assignments are consistent
C6	0.0877	1.12	0.0783 = 7.83%	Acceptable, so assignments are consistent
C7	0.0693	1.12	0.0618 = 6.18%	Acceptable, so assignments are consistent
C8	0.0998	1.12	0.0891 = 8.91%	Acceptable, so assignments are consistent

Although some criteria had initially C.R. values greater than 10%, those were re-assigned by the experts, and inconsistencies were eliminated. The final decision matrix is given in Table 6.

Final Evaluation:

In Table 4, the normalized values (NV) of 5 suppliers are given for criterion 7 (C7), which is "Recycling and Re-use". The similar normalized values of other 7 criteria (C1-C6 and C8) are shown in Table 6. Then, the final weighted normalized values

(WNV, or composite weights) are computed as given in the same table. The final evaluation of 5 suppliers, taking into account eight criteria is shown in the last column.

Table 6
Final evaluation with relative ranking of suppliers

Suppliers ↓	Attributes/Criteria and their weights: Cost (C1) 0.0633	Quality (C2) 0.1120	Delivery (C3) 0.0382	Share Info. (C4) 0.1505	Green Mgt. (C5) 0.1473	Compliance (C6) 0.0908	Recycling (C7) 0.2923	Strat. Partner. (C8) 0.1056	Composite weights	Over-all ranking
Supplier 1	0.200	0.186	0.174	0.188	0.190	0.170	0.174	0.172	0.1809	3
Supplier 2	0.299	0.380	0.304	0.311	0.391	0.337	0.378	0.355	0.3561	1
Supplier 3	0.221	0.252	0.289	0.297	0.250	0.265	0.249	0.237	0.2566	2
Supplier 4	0.126	0.097	0.097	0.086	0.069	0.099	0.106	0.079	0.0939	5
Supplier 5	0.154	0.085	0.136	0.118	0.100	0.129	0.092	0.157	0.1121	4

The decision regarding priority of suppliers is – S2>S3>S1>S5>S4. It is interesting to note that the ranking, obtained from fuzzy TOPSIS, was – S3>S2>S1>S5>S4 (Hasin et al., 2025). While rankings for S1, S4 and S5 remained unchanged, ranking for S2 (Supplier 2) and S3 (Supplier 3) interchanged. This discrepancy can probably be attributed to natural human inconsistency of assignments from experts, decision makes, and planners, which is hard to eliminate. This research followed a simple logic in deciding the priority between Supplier 2 and Supplier 3, as shown in Fig. 2.

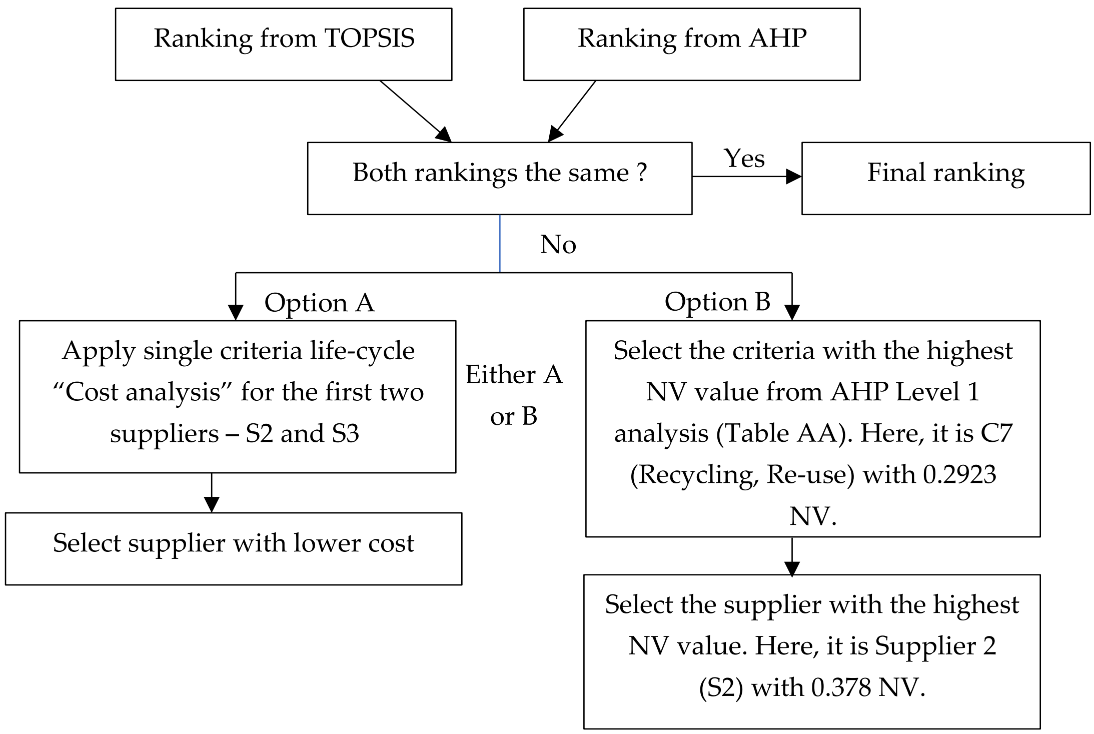


Fig. 2. Simple logic of selecting conflicting suppliers.

Life-cycle Cost Analysis

In the above two MCDM analyses (using AHP and TOPSIS), the "Cost factor" (or attribute, or criteria) usually considers only first cost (i.e. purchase and commissioning cost), not annual maintenance cost and replacement cost for oil, acid, zinc and other metal plates, etc. But these are essential, especially when green substation is under consideration. As such, further engineering economy analysis becomes important to finally decide which option (in this case, between S2 and S3) is a better choice. This section considers two exemplary substations – a small one with 100KVA rating and a bigger one with 20MVA rating.

As contradictory or conflicting order of preference of suppliers (between S2 and S3) was found, this research suggested and introduced the idea of using cost factor in further detail, by including life-cycle cost assessment. This means parts return or reverse supply chain, in terms of regular maintenance of the substation equipment, are included in cost analysis. Net Present Value (NPV or Net Present Worth, NPW) can give very good decisions in this regard (Thuesen & Fabrycky, 2000).

Considering the total 20 years life cycle, the initial cost and regular green technical maintenance costs are taken into account in this analysis. The following cost data are obtained from two conflicting suppliers, S2 and S3.

i) Analysis for smaller capacity substation (100 KVA)

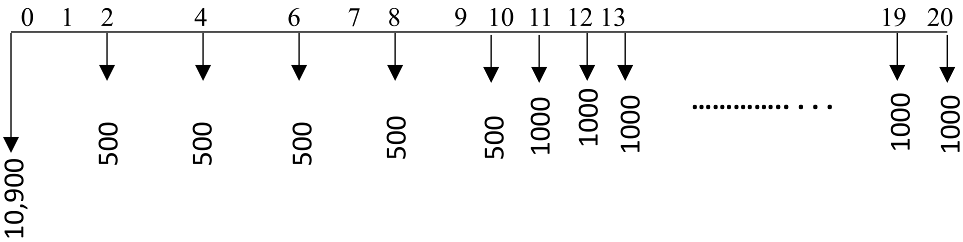
The two conflicting suppliers (S2 and S3) incurs the following costs –

• A small substation (100 KVA) • Internal Rate of Return 15% per year (i)	Supplier 2	Supplier 3
Initial cost	12,00,000 Taka (10,900 US$)	10,50,000 Taka (9500 US$)
1st 10 years maintenance and replacement (for reverse supply chain) costs	500 $ every two years	700 $
2nd 10 years maintenance and replacement (for reverse supply chain) costs	1000 $ every year	1500 $

Note: Taka is Bangladesh currency, exchange rate is about 1.00 US$ = 110 Taka

For Supplier 2:

There are two phases of cash flow – 1) Total 5 disbursements of (–500$) each two years, i.e. at 2, 4, 6, 8 and 10th years. These five future transactions were converted to present worth individually, using equation 1 and then summing up. 2) Total 10 annual equal payment series of (–1000$) each year, from 11th up to 20th year. This annuity is first converted to present worth on the 10th year, and then again converting this future worth to present worth at time zero.



For cycle 1 (up to 1st 10 years) :

$P_0(15\%) = \sum F(P/F, 15\%, n)$ = 1167 \$, where F = 500 \$; n = 2,4,6,8 and 10

For cycle 2 (from 11th to 20th years), using annuity (or Equal Payment Series Present Worth factor):

$P_{10}(15\%)$ = A (P/A, 15%, n) = 1000 (P/A, 15%, 10) = 1000 (5.0188) = 5019 \$
$P_0(15\%)$ = F(P/F, 15%, 10) = 5019 (0.2472) = 1240 \$

So, P_{Total} = 10,900 + 1167 + 1240 \$ = 13,307 \$, which is an expenditure for 20 years life.

For Supplier 3:

Similar analysis to Supplier 2 gives the following results. For cycle 1 (up to 1st 10 years) :

$P_0(15\%) = \sum F(P/F, 15\%, n)$ = 1634 \$, where F = 700 \$; n = 2,4,6,8 and 10

For cycle 2 (from 11th to 20th years), using annuity (or Equal Payment Series Present Worth factor):

$P_{10}(15\%) = A\ (P/A, 15\%, n) = 1500\ (P/A, 15\%, 10) = 1500\ (5.0188) = 7528$ \$
$P_0(15\%) = F(P/F, 15\%, 10) = 7528\ (0.2472) = 1860$ \$

So, $P_{Total} = 9{,}500 + 1634 + 1860$ \$ = 12,994 \$, which is an expenditure for 20 years life.

Since Present Worth expenditure for Supplier 3 (12,994 $) is lower than that of Supplier 2 (13,307 $), it is better to select Supplier 3, although its maintenance costs are higher.

ii) Analysis for medium capacity substation (20 MVA)

The two conflicting suppliers (S2 and S3) incurred initial costs of substations in the range of 2,51,00,000 Taka (about 2,28,180 US$) to 2,75,00,000 Taka (2,50,000 US$). Similar analysis shows interesting results for S2 and S3. Total cost for S2 = 265,000 $, whereas, Total cost for S3 = 2,73,000 $. This means that S3 is about 8000 $ more expensive (including maintenance costs, which also includes parts, acid and oil recycling and refill). Here, Supplier 2 (S2) is preferable. The results of preference for suppliers are again changed, when specification of equipment changed. Thus, selection is never fixed. One must note that all literature on AHP and TOPSIS generally consider only the initial equipment cost (as "Cost attribute"), not subsequent maintenance and recycle costs throughout its life cycle. Here, the contract period has been considered as the life cycle. Thus, it is safe to state that if both AHP and TOPSIS (or any other two MCDM methods) give the same preference of suppliers, then that one can be selected. In case, results are different in two different methods, then further economic analysis or single-criterion NV values can be selected, as has been done in this research.

3. Conclusion

Numerous research works have been conducted on application of varied MCDM methods to select a supplier, or green supplier. Some researchers have used two methods and selected one supplier after comparison of results. But the issue of conflicting priority of selection of suppliers has not been addressed widely. This research suggests a methodology to select the right supplier when two different methods provide two different priority rankings of suppliers. Generally, the MCDM method uses the initial purchase price as the cost factor. This research used life-cycle cost assessment, which is valid because of green or reverse supply chain involvement, which comes as part of regular maintenance, change and replacement. However, some companies may prefer to use "recycling or re-use" as the single criteria analysis, especially when a green or sustainable supply chain is of concern. One must note that electrical substations, as the electrical energy inputs of any production industry, have not been addressed widely so far in literature as a major source of pollution. This paper outlined how potential suppliers of equipment and machinery of electrical energy substations, as major sources of pollution, can be evaluated using MCDM methods, for right selection. This research suggests single criterion analysis when two different MCDM methods give two different, or conflicting results. Some may decide to use a third MCDM technique, such as fuzzy AHP, or Best-Worst Method (BWM), or any other method in such a conflicting result. However, the use of a third method, in case of conflicting results, may potentially further complicate the decision process, since another supplier may arise as the number one in priority ranking.

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