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Sustainability implications in electrical energy substations: Green supplier's performance evaluation using fuzzy TOPSIS method

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A B S T R A C T

Sustainability is getting preference now-a-days in most of the countries in the world. This implies industrial and other developments for economic growth, and of course civilization, but certainly not at the cost of environmental degradation. Environmental conservation is a must. One of the major components of industrial sectors is their electrical energy inputs through electrical substation. Numerous research addresses the issue of energy pollution, cantering on fossil fuel. A very few research can be found which address the issue of pollution generated from electrical energy. This research addresses this issue, with special attention to electrical substations. In the last two or three decades, several electrical equipment manufacturers have started producing this equipment in Bangladesh, which were previously import-oriented. This equipment use various types of oils, acids, zinc and other metals, which are all environmentally hazardous. Thus, any industrial company, buying such equipment from substation manufacturers, should consider green aspects. As such, now it is of prime importance to select green suppliers of substation equipment. Since selection of right or green supplier involves multi-criteria evaluation, Multi-criteria Decision Making (MCDM) technique is essential. Additionally, both qualitative and quantitative criteria require fuzzy analysis to make it more precise and realistic. This research addressed the issue of environmental pollution, its sources, nature and severity, and their mitigation through selecting green suppliers.

1. Introduction

The increasing number of media to heavy industries in Bangladesh has not only created a higher contribution of the industrial sector in the national economy, but also some challenges, especially in terms of sustainability through environmental degradation. Medium to heavy industries require more materials handling in warehouse, transportation, loading and unloading, etc. in place of previous manual handling. Handling of materials requires the use of heavier equipment, such as forklifts, carts, etc. They need batteries for operation, which use oils and acids. Also increased use of electronic control systems for both production operations, monitoring and other operations require energy storage, more importantly in case of low voltage, load shedding and occasional blackouts. The necessity of huge electrical energy inputs is extremely important in case process type industries, such as edible oil, cosmetics, soap-shampoo and detergents, sugar, oil refineries, cement, etc. These industries even require small standby power generation plants to ensure 24 hours continuous supply of electrical energy. Additionally, other types of industries also require electrical substations, where transformers, circuit breakers, monitoring, and control rooms, etc. are essential. All these facilities require oils, acids, etc., which are hazardous for the environment. As a result, battery and transformer manufacturers are increasingly leaning towards reverse supply chains, through recycling and re-use, thereby making their supply chain green. Thus, any industry requiring such electrical equipment should think of evaluating and selecting green suppliers as part of overall sustainability. Although it is true that Bangladesh is not yet even close to a circular economy, there is increasing pressure from environmentalists to do so.

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2. Rationale of the research

Increased awareness regarding smog (an outgrowth of ground level ozone), global warming and acid rain, several international environmental treaties and protocols have been introduced as either obligatory or optional for signatory countries. Some of those are the Kyoto Protocol (later Paris Agreement), Montreal Protocol, Ramsar convention, etc. very important. Along with these international policies and rules, Bangladesh Government has also formulated some national level legislative rules, regulations, and policies. Environment Policy (1992), Environmental Conservation Act (1995) and Environment Conservation Rule (ECR, 1997) are some vital rules. According to (ECR 1997), battery manufacturing, power plant (including substation), cables and wires, etc. fall either in Red or Orange B category. According to the definition of ECR (1997), both two categories are extremely hazardous for the environment, requiring all types of compliance and clearance certifications. This necessitates careful introduction of green supply chain practices, which includes green supplier selection of electrical equipment manufacturers and suppliers.

Circular economy suggests green supply chain management (GSCM) for as many companies as possible in a society. This requires close monitoring and controlling suppliers' performance (Singh, 2024). The positive aspect of this endeavor is that increasing numbers of businesses are contemplating incorporating ecological practices into their policy and supply chain design (Ashraf et al., 2020, Tseng et al, 2019). Research reveals that better technology, coupled with better methods of practices are being designed and proposed (Aslam et al, 2018). Many companies are focusing on not only green supply chain practices, but also green offices. Reverse Logistics are also becoming popular day-by-day around the world (Al-Awamleh et al., 2022). There are many apparel companies in Bangladesh who are producing knit products using recycled and reused materials. They are also making their offices green. Increasing pressure from the international buyers and community at large is forcing companies to adopt green practices. To safeguard the environment, businesses are being forced to embrace green practices. In Bangladesh, this is highly visible in RMG (Ready Made Garments) and pharmaceutical sectors. This is creating a base for sustainability. Research on many areas of supply chain sustainability is being done globally to further environmental sustainability efforts. Problems, like selection of green suppliers, is a complex decision problem, requiring multiple criteria, which are often conflicting and a combination of both qualitative issues and quantitative issues. Such problems require use of Multi-criteria Decision Making (MCDM) which are relatively simple in comparison to optimization techniques but can give very good solutions (Puška & Stojanović, 2022, Salimia et al, 2022, Selvaraj, 2019). Research reveals that linguistic evaluation-based multi-criteria decision-making techniques helps in making a best selection decision by using a weighting process within the current alternatives through pairwise comparisons, as demonstrated by Kabir and Hasin (2011) to classify inventory. There are numerous occasions when MCDM methods were used to solve selection problems by considering green criteria (Remadi & Frikha, 2020, Rashidi & Cullinane, 2019).

Production of electrical equipment and their commissioning in substations of different other production industries require a variety of different organic and inorganic compounds and acids. It is essential to minimize their adverse impact on environment and health, as well as their proper disposal and possible recycling, requires huge attention, in terms of sustainable supply chain (Rahman et al., 2022). The number of industries in Bangladesh is growing very fast, all requiring electrical substations. This scenario has pushed another business forward, which is the electrical power supply system. Multiple companies have started producing electrical substation equipment, such as transformers, circuit breakers, storage batteries, etc. in Bangladesh over the last 20 years or so. Although this sector contributes to a significant amount of pollution, there has been no study on sustainable supplier selection for the electrical substation industry using MCDM techniques in Bangladesh. This research aims at filling this gap and develop a comprehensive selection framework, with two major objectives:

1. Which criteria are suitable for evaluating the technical, business and management issues related to green practices in electrical substation equipment production, distribution and installation in other industries?
2. Comparative judgment of criteria assigning importance to identified evaluation criteria.

3. What a solution is?

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, 2022). Power plants are the sources where electrical energy is generated. A technical reason to locate power plants far away from cities and residential areas is its hazardous nature. The black carbon, smoke, heat, electro-magnetic impact, flux, oil and gas leakage, sound, etc. are major reasons behind this. Because of the long distance between power generation and consumption, it's essential to carry electrical loads through long high-voltage transmission lines and distribution mechanisms. Electrical energy loss (i.e. system loss) is another negative outcome of distance. To reduce this electrical loss, generated power is first stepped-up right after power plants prior to feeding into the transmission line. This is because losses occur less in high voltages, and they can then travel longer distances. The concept is like the idea of modulation in case of signal transmission. At the other end of consumer usage, the opposite event takes place. As high voltage cannot be fed directly to equipment and machinery, which require lower-voltage inputs, it is of paramount importance to step-down the voltage and current. This function is performed by an electrical power substation at the end of the transmission line and at the beginning of the industrial input point. An electrical substation performs the function of an electrical energy input coupling system for other production industries (Dahiya, 2022). This is thus similar to an adapter for mobile phones. Many components and equipment are required to construct a substation, including transformers, batteries, control panels, circuit breakers, isolators, fuses, switching panels, conductors, fire protection systems, etc. These use huge amounts of oils, acids, etc. which are highly hazardous for the environment.

4. Major areas of pollution in energy input substation

In the majority of cases, production industries get energy input through electrical substation. There are several pieces of equipment in a substation which use a considerable number of acids and oils, both of which are harmful for the environment. Among several equipment or apparatus, some important ones are – Lightning Arrestor, Earthing switches, Power Transformer, Instrument Transformer, Bus-Bar, Wave Trapper, Isolator, Circuit Breaker, Batteries, and so on (Dahiya 2022). Several equipment of the overall power system contributes to pollution, which necessitates recycling and re-use for sustainability and cost reduction (Khezri & Bevrani, 2017). Power systems are thus getting increasing attention for sustainability initiatives (Dugaya & Shandilya, 2017). Literature identifies 3 major equipment, namely transformers, batteries and circuit breakers are some items, which require special attention for such initiative.

4.1 Transformers

Electric substations are the main source of energy input to industry. They are equipped with a group of high voltage equipment of varied individual sizes. It fully depends on the energy requirements of the company, which again subsequently depends on production machinery used for production operations. In most cases, power transformers have the responsibility to change voltage levels according to substation purposes, based on specifications of the production machinery. On the input side, primary equipment governs operation voltages. These equipment cause environmental damage the most (Dahiya 2022, Miesner 2022). Although oils are required in transformers for technical reasons, those have damaging effects also. The main functions of oils in a transformer are to act as coolant and insulation. These oils remain hidden to environmentalists because focus remains on fossil fuels used in production. But typical data shows that quite a considerable number of oils are used in transformers, as shown in the following Table 1.

Table 1
Oil required in transformers.

Transformer capacity (KVA)	Oil used (Liter)
50	135
100	200
160	250
500	500-800 (132-211 gallons)

It is evident that oils used in a transformer are considerable, which are replenished on a regular basis. Oil circuit breakers also use oil in large amounts. There is opinion from environmental experts regarding feasible availability of alternative solutions. Technical experts suggest Dry transformers, which does not require oils. But business experts reject that on the strong ground which suggests that Dry transformers use more energy and entail significantly higher operational costs. Available transformers in the market usually contain naphthenic oil or paraffinic oil, both of which come from fossil fuels and are not biodegradable. Electrical oils are classified as hazardous wastes in many countries' laws. For instance, the English (and Wales) law (Regulations 2005) states that governing the removal, transportation and storage of waste transformer oils is highly "Hazardous Wastes". This is an area of grave concern. They also carry a high fire risk. Additionally, the gases emitted from these oils go to the troposphere to create damaging ozone, which is one of the major green-house gases. Moreover, they are also responsible for creating acid rain.

4.2 Batteries

An industrial facility uses a large number of batteries not only at substation, but also for running many industrial machineries and equipment. There are many different types and sizes of industrial batteries for varied industrial applications. Although technically useful, batteries are harmful for the environment also, if users do not follow green practices (Shorinwa, 2023). Batteries are used in the control room of substation for several purposes, one important being its use as a backup power supply in the control room if there is power outage. However, industrial battery's main function is to provide storage of energy in case of necessity. This energy storage is required for several purposes, such as – i) revolving (spinning) reserve at electricity generating power stations at the initial part, ii) energy load smoothing (leveling) at the end substations, and iii) peak shaving in the consumer meter. Apart from its use in the substation control room, batteries are also used for many other purposes in the production industry. Most of the time, the input requirements suggest Multi-cell industrial battery packs. (Dahiya, 2022; Miesner, 2022). Even batteries are required to operate and run material handling equipment, such as forklift. electric vehicles, and many more. This equipment basically required a motive power battery. Lead-acid batteries are often used for industrial purposes with two major focuses: stationery and traction. Stationary batteries are mostly used as standby options to provide backup power when the grid line electricity supply fails. Additionally, these are also used for backup energy storage in electricity networks, especially in remote area applications, such as mobile towers. Lead-acid batteries are also used for 'traction' to provide motive power for various types of industrial materials handling equipment, such as for warehouse, loading and unloading, etc. (Qing et al. 2023). A recent study reveals that about 70% of the lead from lead acid batteries are released into the environment as solid wastes and gaseous emissions. These wastes or emissions are highly harmful for public health, by contaminating groundwater, soil and crop cultivation. In many of these batteries, Sulfuric acid is used, which is the major concern for ozone in the troposphere as well as acid rain. It must be stated that two major chemicals of acid rain are – Oxides of Nitrogen and Sulfur. First of all, these two oxides are responsible for the creation of ground level ozone, and also for causing acid rains. Secondly, lead and zinc are also bad pollutants. These make the necessity of recycling lead and zinc important. Thus, such industrial batteries are harmful against sustainability.

4.3 Circuit breakers

Another important equipment used in substation is an Oil Circuit Breaker, which requires oil for operation. At the input and output side in a substation, oil Circuit Breakers are required for maneuvering switch circuits and other control equipment. These are filled with a special kind of oil for cooling purpose, as well as preventing arcing when one or more switches are activated. As such, it is also against sustainability (Dahiya 2022, Miesner 2022).

5. Literature review

A comprehensive literature review on multi-criteria decision making and green supply chain options has been done. The publications reveal that despite electrical substations' alarming environmental exposure (Nogda,2023), it has never been addressed in any research papers. This is more significant in the sense that substations are necessary for almost any medium to large production companies, as well as a big service organization, like a university. Many researchers identified some common criteria to evaluate green aspects of backward linkage (Fahim et al., 2024, Carter et al, 2020). They also created a common discussion base to identify green aspects for other sectors also (Tsenga et al. 2019). Some researchers discussed the importance of identifying the right criteria for supplier evaluation (Rahman et al., 2022). Others stated that some common criteria are well applicable to any situation, like 'price' or 'cost' of maintaining green chain, specially to ensure service and related costs, product quality and delivery performance (Badi and Ballem, 2018). Some papers identified drivers of green supply chain, which indicates direct implications of these drivers with potential pollution possibility (Aslam, 2018).

Many papers can be tracked who identified green supply chain drivers, as well as supplier evaluation criteria in varied other industrial and service sectors. The health sector is one of the major areas to be affected by absence of green activities, especially in disposal (Geethai et al, 2019). The dairy sector also requires careful attention in incorporating green activities in the supply chain. Otherwise, this food chain can be disastrous not only for environmental pollution but can also bring risk in human health (Kaklamanou, 2017; Lee et al., 2009). Thus, sustainability will be at bay. A very large number of papers addressed applications of different MCDM techniques, a list and discussion of which may be exhaustive. The identified techniques include – AHP, ANP, TOPSIS, SWARA-WASPAS, PROMETHEE, VIKOR, ELECTRE, CODAS, COPRAS, Multi-MOORA, BWM, EDAS, and some more. Application areas are also interesting and exhaustive, such as – supplier selection, green aspects selection, alternative distribution channel selection, material selection, power plant site or location selection, inventory classification, facility location and layout, machine selection, business area selection for investment, strategy selection, and many more. Recent trends show integration of fuzzy analysis and artificial intelligence with the basic MCDM technique. A comprehensive list of research papers is given in the reference and avoids lengthy discussion. Sustainability of a manufacturer is a major determinant of its success in the long term. Out of many factors of sustainability, a major one is green supplier selection (Guo et al., 2017, Romano et al., 2023,). A host of criteria have been used by many researchers. The most found criteria are listed in the following Table 2.

Table 2
Frequently used criteria for green supplier selection (Modiefied from Fahim et al., 2024)

	Virgin Material Cost	Transportation Cost	Payment Terms	Quality Management issues	Advance Quality Assurance	Kaizen Improvement	Purchasing Lead Time	Responsiveness	Delivery performance	Timeliness in delivery	Green Product Design	Green issues in Purchasing	Green material in Packaging	Env. Management System	Management of waste	Recycling / re-use	Prevention of pollution	Effluent and Emission Ctrl.	Top Mgt. Commitment
Ghorabaee (2016)	✓					✓	✓	✓		✓		✓		✓		✓			✓
Puška and Stojanović (2022)	✓			✓		✓	✓					✓		✓		✓		✓	✓
Salimian (2022)	✓			✓		✓				✓				✓			✓		✓
Çalık A. (2021)			✓		✓				✓	✓	✓			✓			✓		
Remadi, Frikha (2020)	✓			✓		✓				✓		✓				✓			✓
Ashraf (2020)	✓	✓		✓							✓		✓		✓				
Fahim et al. (2024)	✓			✓		✓					✓		✓		✓				✓
Ghea et al. (2024)		✓		✓									✓	✓		✓			✓
Romano et al. (2023)				✓				✓	✓			✓	✓	✓		✓			✓
Qing et al. (2023)	✓			✓			✓	✓			✓					✓			✓

Apart from the above publications, study reveals that a host of other publications also addressed the above issues, which show that the selection of green suppliers is a very popular topic now-a-days.

6. Methodology Used

In practice, the factors related to green and supplier selection are never fixed and known with certainty. Often the values vary significantly. Additionally, qualitative, and subjective judgments or opinions are highly fuzzy. For instance, a value "Good" may have different ideas, interpretations, or different values in a Likert Scale, by different experts. Thus, the decision maker must depend on fuzzy analysis (Ghorabaee et al. 2016). That's why fuzzy approaches have been used to deal with such uncertainties, or non-concrete values. As can be seen from literature, most of the researchers used fuzzy above review, most of the studies have used fuzzy approaches in the process of green supplier selection. This study also used fuzzy decision variables, proposed originally by Zadeh (1965).

Numerous research considered fuzzy factors during supplier selection and other activities of supply chain for sustainability initiatives. Three main reasons behind fuzzy analysis are – subjective judgment of criteria, uncertainty associated with qualitative factors and variation of opinions among experts (Bobar, 2017; Ghorabaee, 2016). This research also used fuzzy criteria for such analysis.

7. Fuzzy Analysis of Events

Fuzzy set theory is not new to the world. The idea of fuzzy logic was first advanced by Lotfi Zadeh of the University of California at Berkeley in the 1960s. Since then, it observed rapid growth in concepts and of course, in application areas. This also drew high attention from the researchers, since numerous activities and events in the world are basically fuzzy in nature. Nevertheless, as the basic generic theory of fuzzy is well established, this paper avoids theoretical details of fuzziness. Only some selective theories are mentioned which are highly related to this research (Fahim et al, 2024).

Fuzzy Sets: This research used Fuzzy Numbers to evaluate the performances of a total of five potential suppliers of electrical substation equipment, in order to achieve Green Supply Chain for electrical energy related pollution. Fuzzy numbers are easy to understand by a common person and also easy to use in practice. A Triangular Fuzzy Number (TFN) has been used, which is represented by three limiting parameters – l is the lower-bound, m is the most-likely-value and u is the upper-bound (Faquir et al., 2017). As shown in Fig. 1 a TFN has linear representations to its left and right sides. The membership function of a TFN can be expressed mathematically as Eq. (1).

$$\mu(z/M)=\begin{cases}0 & \text{if} \quad z\le l\\ \dfrac{z-1}{m-1} & \text{if} \quad l\le z\le m\\ \dfrac{u-z}{u-m} & \text{if} \quad m\le z\le u\\ 0 & \text{if} \quad z\ge u\end{cases} \tag{1}$$

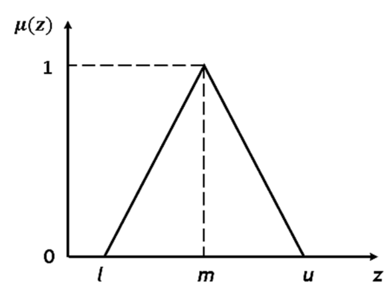

Fig. 1. Triangular Fuzzy Distribution

Fuzzy Numbers: A group of decision-makers, consisting of *N* experts, giving opinions on green criteria for electrical energy system, with fuzzy rating values of D_n (where n = 1, 2, ..., N), are denoted as a positive Triangular Fuzzy Numbers Fn (n = 1, 2, ..., N). Relevant fuzzy membership function $FMRn(z)$. An aggregate rating of evaluators is found by mathematically combining the individual ratings, as described below (Tian et al., 2018; Fahim et al., 2024):
$F = (l, m, u)$

Here,

n = 1,2, 3, ...N

$$l = \min_n\{n\}, \qquad m = 1/N \sum_{n=1}^{b} m_n , \qquad u = \max_n\{u_n\}_n. \tag{2}$$

7. Center of Gravity or Area (COG or COA) Method for Defuzzufied Value Computation

The following step-by-step computational procedure have been followed in this research (Fahim et al., 2024):

Step 1: The specific objective of this research is to investigate the problem of pollution arising out of electrical power inputs to industries. Then, the research ranks the GSCM implementation difficulties that are associated with the electrical power system.
Step 2: Decision groups are formed, comprising five individual decision-makers from several electrical substation equipment manufacturers. Seven criteria of GSCM are considered in this research.
Step 3: A fuzzy linguistic scale is developed for assessing different criteria and also alternatives with regard to each criterion.
Step 4: The group of decision-makers provide fuzzy weights for each criteria and fuzzy relative rankings of green alternatives, which are aggregated. Afterwards, these two decision parameters are used to develop a fuzzy decision matrix for further analysis.
Step 5: Crisp values are identified through defuzzification. The target output of this defuzzification procedure is a set of Non-fuzzy values known as Optimum Non-fuzzy Performance (BNFP) value. Out of three possible approaches to finding BNFP, the COG or COA has been used, because of its ease of use and computation. The BNFP value can be expressed as

$$\text{BNFP}: x_{ai} = lh_{ai} + \frac{(uh_{ai} - lh_{ai}) + (mh_{ai} - lh_{ai})}{3}, \forall a \tag{3}$$

7. Analysis using TOPSIS Method

TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) is a widely used MCDM technique, used for widely varied problems, considering multiple conflicting criteria (Rashid and Cullinane, 2019; Calik, 2021). It involves a mathematical procedure process where alternatives are compared to an ideal solution and a worst-case solution. This technique computes similarity of each alternative to a standard benchmark answer and the worst-case approach to determine their relative closeness with or distances from the benchmark. It is basically a kind of 'minimization of deviation from benchmark' problem. The basic principle is that the chosen alternative should have the shortest distance from the ideal solution and the farthest distance from the negative-ideal solution (Opricovic and Tzeng, 2004). The steps outlined by Papathanasiou et al. (Papathanasiou et al. 2018 and used by Fahim et al.) has been used here. The briefs of steps are –

Step 1 – The Decision Matrix is normalized.
Step 2 – This normalized Decision Matrix is then weighted.
Step 3 – Ideal solutions (denoted as A^*) and relevant negative solutions (A^-) are enumerated.
Step 4 – The next step calculates "separation measures" from the m-dimensional Euclidean distances.
Step 5 – All Closeness Ratings of previously found ideal solutions are computed.
Step 6 – A "Preference order" is then developed.

This study took into account five local and multinational companies, producing substation equipment, which are detonated as S1, …, S5. Five groups, comprising 3 experts each, have a total 15 evaluators. E1, E2, E3, E4, E5 are the Evaluating Experts, who assigned the importance ratings for criteria, if different criteria have different levels of importance to the cause. (Table 3). Four groups of decision makers, comprising 5 members each, have a total 20 decision members. They are denoted as D1, D2, D3 and D4, who assign ratings for alternative supplier's performance). Thus, a total 35 persons are involved in analysis, thereby justifying statistical normal distribution.

Table 3
Functional information of five experts and four final decision makers

Functional Experts and Organizational Decision Makers	Designation
E1	Supply Chain staffs
E2	Design and development staffs
E3	Production Engineers
E4	Procurement staffs
E5	Customer relationship staffs
D1	Top executives
D2	Functional Managers
D3	Compliance staffs
D4	Electrical and Environmental staffs

Two types of scales, one for experts and another for decision makers, have been used for quantifying qualitative judgments to quantitative values in this study, as shown in the following tables (Table 4 and 5 respectively) (Fahim et al. 2024). Both scales use a Likert scale of 7. Table 6 presents 8 criteria (C1-C8) for performance evaluation of all potential green suppliers in B2B buying companies as shown below, where LVs are Linguistic Variables and TFNs are Triangular Fuzzy Numbers. Table 4 shows fuzzy Scale used by functional experts for assigning "Importance Rating", whereas Table 5 shows fuzzy scale used by organizational decision makers to assign "Performance Rating".

Table 4
Importance Rating for criteria.

Qualitative LVs	Relevant TFNs
Very High	(0.8, 0.9, 1.0)
High (H)	(0.7, 0.8, 0.9)
Medium High (MH)	(0.6, 0.7, 0.8)
Medium (M)	(0.4, 0.5, 0.6)
Medium Low (ML)	(0.2, 0.3, 0.4)
Low (L)	(0.1, 0.2, 0.3)
Very Low (VL)	(0.0, 0, 0.1)

Table 5
Performance Rating for suppliers

Qualitative LVs	Relevant TFNs
Excellent (E)	(0.8, 0.9, 1.0)
Very Good (VG)	(0.7, 0.8, 0.9)
Good (G)	(0.6, 0.7 ,0.8)
Medium Good (MG)	(0.5, 0.6, 0.7)
Medium (M)	(0.3, 0.4, 0.5)
Medium Poor (MP)	(0.2, 0.3, 0.4)
Poor (P)	(0.1, 0.2, 0.3)
Very Poor (VP)	(0, 0.1, 0.2)

Table 6
Criteria for supplier selection.

Notations	Criteria or attributes
C1	Cost attribute
C2	Product quality attribute
C3	Product delivery performance and reliability
C4	Readiness to share information
C5	Green Management issues (e.g. Green design, green office, etc.)
C6	Environmental Management compliance
C7	Recycling and Re-use (Presence of Reverse chain)
C8	Strategic Cooperation between supplier and buyer (Mutual trust)

Table 7 shows the importance rating for each criterion, assigned by experts, based on Table 4. As Linguistic Values are qualitative, these require relevant quantitative Triangular Fuzzy Numbers (TFN) for further analysis, which are given in Table 10. The same is applicable to Table 5 and Table 8, as used and found by decision makers.

Table 7
Importance Ratings, assigned by experts.

	Criteria							
Experts	C1	C2	C3	C4	C5	C6	C7	C8
E1	H	VH	H	VH	H	H	VH	H
E2	H	H	M	MH	MH	MH	ML	H
E3	H	MH	VH	MH	MH	H	L	VH
E4	VH	MH	MH	MH	M	M	M	H
E5	H	MH	MH	H	M	M	ML	H

Table 8

Four Decision Maker's Performance Rating

Criteria	Judgment of Decision Maker D1 Supplier					Judgment of Decision Maker D2 Supplier				
	S1	S2	S3	S4	S5	S1	S2	S3	S4	S5
C1	M	VG	MG	VG	M	MG	MG	P	VG	M
C2	G	VG	MG	G	MG	M	G	M	G	MG
C3	M	VG	P	VG	MP	MG	MG	M	VG	M
C4	G	VG	VP	VG	M	G	G	M	G	G
C5	VP	P	VP	VP	VP	P	VP	VP	MP	P
C6	M	G	M	MG	M	M	M	P	M	P
C7	M	VG	MP	VG	G	VG	VG	M	E	G
C8	M	G	P	VG	G	MG	M	M	E	VG

Criteria	Judgment of Decision Maker D3 Supplier					Judgment of Decision Maker D4 Supplier				
	S1	S2	S3	S4	S5	S1	S2	S3	S4	S5
C1	M	G	MG	VG	E	MG	MG	MG	G	VG
C2	G	MG	MP	E	E	G	G	M	E	VG
C3	MG	MG	P	VG	MG	G	G	MP	VG	M
C4	P	VG	VP	G	M	MP	VG	VP	G	M
C5	VP	VP	VP	VP	P	MP	P	M	E	MP
C6	MP	MP	MP	P	MP	MG	MP	MP	M	MP
C7	G	VG	MP	G	G	M	VG	MP	G	G
C8	G	VG	P	MG	MG	G	VG	M	MG	MG

7. Computational Procedure

The complete computational procedure (Fahim et al, 2024) was executed in MS-Excel, for which appropriate macros were created. The software-like Excel sheet provided the results as follows:

1. Once the TFN values are found, the next step is to aggregate the TFN and defuzzified values, in order to compute importance ratings, as in Table 9. Theoretically, the defuzzified values are the "Weights" of the criteria, assigned by the experts.
2. The performance scores of alternatives are shown in Table 10. All ratings, assigned by the decision were aggregated first, and then defuzzified similarly. It has to be noted that the variability among scores given by decision makers can be attributed to manual judgment, which is highly subjective.
3. The Weighted Normalized Decision values and Ideal Solutions are given in Table 11
4. After determining separation measures, the final results are shown in Table 12, which are fundamentally the Closeness Ratio (CR).

The Excel values obtained are given below.

Table 9

Combined Weights for Each Criterion from 5 Experts' Ratings

	Aggregated	**Weight**
C1	(0.625, 0.81, 1.0)	0.8117
C2	(0.55, 0.754, 1.0)	0.7680
C3	(0.333, 0.675, 1.0)	0.6693
C4	(0.625, 0.725, 1.0)	0.7833
C5	(0.425, 0.645, 0.925)	0.6650
C6	(0.567, 0.733, 0.925)	0.7417
C7	(0.480, 0.575, 1.0)	0.6850
C8	(0.555, 0.678, 0.925	0.7193

Table 10

Combined performance scores of five alternative suppliers

	S1	**S2**	**S3**	**S4**	**S5**
C1	0.6898	0.7323	0.8539	0.5521	0.5645
C2	0.5334	0.7556	0.7775	0.4876	0.5332
C3	0.6234	0.8200	0.7556	0.2444	0.4378
C4	0.3398	0.6997	0.7556	0.2889	0.4328
C5	0.6525	0.5589	0.8334	0.2000	0.5567
C6	0.5421	0.6888	0.8980	0.3111	0.5664
C7	0.4888	0.6895	0.7678	0.2338	0.6325
C8	0.6785	0.7887	0.8224	0.3889	0.6232

Table 11
Weighted Normalized Decision Matrix and related Ideal Solutions

	Normalized values					Ideal and –ve ideal solutions	
	V1	**V2**	**V3**	**V4**	**V5**	**A***	**A$^-$**
C1	0.236391	0.237884	0.200662	0.277695	0.215437	0.327644	0.136062
C2	0.173233	0.267541	0.213879	0.255434	0.253461	0.278764	0.142879
C3	0.222654	0.212347	0.177668	0.189669	0.197657	0.222199	0.243168
C4	0.198655	0.258752	0.131522	0.328324	0.212156	0.313432	0.143212
C5	0.091043	0.122164	0.089876	0.085553	0.087682	0.132144	0.131241
C6	0.152756	0.198888	0.137545	0.255432	0.200026	0.275438	0.123543
C7	0.165587	0.226255	0.117734	0.212456	0.186544	0.213321	0.139765
C8	0.183376	0.220616	0.119845	0.220023	0.176756	0.234653	0.120657

Table 12
Relative Closeness values to the Ideal Solutions

	Closeness values for S1-S5				
Relative closeness **(RC)**	**A1 (S1)**	**A2 (S2)**	**A3 (S3)**	**A4 (S4)**	**A5 (S5)**
for five alternative suppliers	0.835622	0.928745	0.965634	0.565781	0.726534

7. Analysis of results

The complete sourcing prices require supplier evaluation and subsequent selection. Multi-criteria supplier evaluation is thus a very important sub-function of the overall sourcing process. This research evaluates a green supplier's performance using Fuzzy TOPSIS method in case of electrical substation equipment, which is essential for electrical energy inputs to any medium to heavy industry of any kind. The results, in Table 13 shows that preferred ranking for potential suppliers are as follows: A3(S3) > A2(S2) > A1(S1) > A5(S5) > A4 (S4). Supplier S3 has maximum practice on green activities in their organization, as well as in their substation equipment. Recycling and re-use is highly practiced in their company, thereby, making reverse and sustainable supply chain a reality. Investigation additionally revealed that this producer cum supplier has a proper waste minimization program, coupled with compliant environmental policies. They try to follow what has been suggested in the Environment Conservation Rule (ECR 1997) of the Bangladesh Government and have implemented ISO14000:2015 EMS. However, producer and supplier S2 is a close follower with marginal difference, due to absence of ISO14000 EMS. Other suppliers are in distant ranking in comparison to S3 and S2. Producer and supplier S4 should never be considered, when sustainability is considered. However, an interesting aspect of this study found that their price is lower and has reasonably good quality, though they are quite poor in green issues.

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