



A Type-2 Fuzzy and CoCoSo-Based Strategic Decision Framework for Evaluating Energy Supply Alternatives

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Received: 08-27-2025

Revised: 10-11-2025

Accepted: 10-26-2025

Citation: M. Abdolshah, "A type-2 fuzzy and CoCoSo-based strategic decision framework for evaluating energy supply alternatives," *J. Oper. Strateg Anal.*, vol. 3, no. 4, pp. 237–250, 2025. <https://doi.org/10.56578/josa030403>.



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Abstract: Energy supply selection has become a crucial component of organizational strategy, as firms strive to balance sustainability, reliability, and cost efficiency under uncertain market and policy conditions. This study develops a strategic decision-support framework that integrates type-2 fuzzy logic with the Combined Compromise Solution (CoCoSo) method to evaluate alternative energy supply options. The hybrid model addresses the ambiguity inherent in expert judgments by employing type-2 fuzzy sets and prioritizes competing alternatives through the CoCoSo ranking process. Six evaluation criteria—cost, reliability, maintenance, environmental impact, supply stability, and policy support—were defined based on expert consultation. The proposed framework was applied to an industrial case study, demonstrating its capacity to manage conflicting objectives and deliver a transparent, rational ranking of energy alternatives. Sensitivity analysis confirmed the robustness of the results. The findings provide actionable insights for decision-makers and policymakers seeking data-driven strategies to enhance sustainable energy planning and operational efficiency.

Keywords: Type-2 fuzzy logic; CoCoSo method; Strategic decision analysis; Multi-criteria decision-making; Energy supply planning; Uncertainty management; Decision-support framework

1 Introduction

Man's need for energy began when he wanted to strengthen his survival process in nature and use the energy available in nature to gain power. Perhaps for the first time, man was able to overcome a stronger and larger animal by using potential energy, which we use this term today, and use its meat for food and its skin for protection against other energies. Early man also used solar energy for agriculture, and perhaps the most important energy that changed his life was the discovery of fire. By controlling and mastering fire, he not only gained greater comfort for himself, but also was able to overcome natural forces. Although this energy was also used in many cases to destroy his own competitors. The discovery of new energies on the one hand and their conversion into usable energies on the other hand made humans strive to convert more and more types of energies into usable ones. The discovery of the spinning wheel and its use made humans more powerful than ever, to the point where they could travel long distances using the spinning wheel. In short, humans are currently also concerned with providing energy for their endless activities. The advancement of socio-economic conditions and infrastructure in a developing nation is significantly linked to its capacity for electricity generation, transmission, and consumption [1–4]. One of the concerns of manufacturing plants today is the uninterrupted supply of energy for their lines and, in more advanced stages, the supply of clean energy.

Energy consumption is a key driver of greenhouse gas emissions, which in turn contribute significantly to global warming and climate change. The main sectors responsible for energy use include transportation, residential, commercial, and industrial activities. In the transportation sector, fossil fuel-powered vehicles are the dominant source of energy use. In residential and commercial settings, heating, cooling, and lighting systems account for a large portion of energy consumption. Meanwhile, in the industrial sector, most energy is used in manufacturing processes and operating machinery [5–7].

On the other hand, the energy crisis in Iran in the past few years has caused frequent power outages in factories, resulting in a decrease in their productivity and production. This has led many large factories to supply their own

energy, especially electricity, to avoid the harm of constant power outages. On the other hand, in recent years, there has been progress in clean energy production technologies, and now, with the help of new technologies, clean energy can be obtained at a more affordable price. Therefore, this issue presents another opportunity for these factories, which is that they can obtain their electricity from renewable and clean sources such as sunlight. In addition, other methods of supplying electricity such as gas and diesel power plants are other options for supplying electricity to factories. Therefore, the issue that is currently on the minds of many factory managers is which is the appropriate or optimal method for supplying electricity. Research is being conducted to answer this question. In this regard, a review of the literature was conducted, and it was observed that no similar work has been carried out in this field so far. Therefore, in terms of innovation, it can be stated that, considering the recent nature of energy supply issues in Iran, no comparable study was found. Furthermore, in this research, type-2 fuzzy data were used to reduce the uncertainty of experts' opinions.

1.1 Electricity Generation Methods

Electricity generation is a cornerstone of modern society, driving industries, households, and technological advancements. Various methods are used worldwide to generate electricity, each with its own advantages and challenges. With growing environmental concerns, the transition from fossil-based energy sources to more sustainable, renewable technologies have gained significant attention [8]. This literature review provides an overview of the primary electricity generation methods, categorized into fossil fuel-based, renewable, and emerging technologies.

1.1.1 Fossil fuel-based electricity generation

These are old methods with lower efficiency to generate electricity [9] such as:

(1) Coal-fired power plants Coal-fired power plants are among the oldest and most commonly used methods of electricity generation. In these plants, coal is burned to produce steam, which drives turbines connected to electricity generators. However, this method is associated with high carbon dioxide emissions and other greenhouse gases, contributing to global warming and environmental degradation. The environmental impact, coupled with increasing regulatory pressure, has led to a decline in the use of coal for power generation in some regions.

(2) Gas-fired power plants Natural gas-fired power plants use natural gas as a fuel to generate electricity. The process involves burning gas to produce heat, which drives turbines. Gas-fired plants are more efficient and environmentally friendly compared to coal plants since they emit fewer pollutants and greenhouse gases. These plants also have the advantage of providing flexible and quick responses to demand fluctuations, making them an ideal option for balancing grid stability, especially with increasing renewable energy penetration.

1.1.2 Nuclear power plants

Nuclear power plants generate electricity through nuclear fission, where atoms of uranium or plutonium are split, releasing a large amount of energy in the form of heat. This heat is used to produce steam, which drives turbines connected to generators. Nuclear power is considered a low-carbon energy source, making it an attractive option for reducing greenhouse gas emissions. However, concerns over nuclear waste disposal, reactor safety, and high initial costs remain significant challenges.

1.2 Renewable Energy Sources

Nowadays, various renewable energy sources are used to generate electricity [10–12].

1.2.1 Solar energy

Solar power has emerged as one of the most widely adopted and fastest-growing renewable energy sources globally. Solar energy can be harnessed through photovoltaic (PV) panels that convert sunlight directly into electricity or through concentrated solar power (CSP) systems that focus sunlight to generate heat, which is then used to produce electricity. Solar power is clean, abundant, and generates zero emissions during operation. However, its intermittent nature (dependence on sunlight) and the need for significant land area for large-scale installations pose challenges.

1.2.2 Wind energy

Wind power is generated by wind turbines that convert the kinetic energy of wind into mechanical energy, which is then transformed into electricity. Wind energy is one of the most promising renewable energy sources due to its relatively low operational costs and minimal environmental impact. However, wind generation is highly intermittent, as wind speeds can vary, and wind turbines may pose risks to wildlife, such as birds and bats, and can affect the aesthetics of natural landscapes.

1.2.3 Hydropower

Hydropower is one of the most established and widely used renewable energy sources. It involves generating electricity from the potential energy of water stored at height or the kinetic energy of flowing water, such as rivers or tidal forces. Large-scale hydropower plants, such as dams, provide reliable and consistent electricity generation, while smaller-scale plants can be used in regions with flowing water. However, the environmental impact of large dams, including habitat destruction, displacement of communities, and ecological disruption, has led to growing concerns.

1.2.4 Biomass energy

Biomass energy involves the combustion or conversion of organic materials, such as wood, agricultural waste, or plant-based materials, into electricity. Biomass can also be processed into biofuels for transportation. While biomass is considered renewable and can help reduce reliance on fossil fuels, its environmental impact, particularly concerning land use, food production, and air pollution, must be managed carefully. The sustainability of biomass largely depends on the source and management of the feedstock.

1.3 Emerging Technologies in Electricity Generation

1.3.1 Fuel cells

Fuel cells are an emerging technology that generates electricity through an electrochemical reaction between hydrogen or methane and oxygen. This process produces electricity, water, and heat, making fuel cells a clean energy source with zero emissions. Fuel cells are used in a variety of applications, including in electric vehicles, portable devices, and some small-scale power generation systems. One of the main challenges is the high cost of fuel cell systems and the need for a reliable hydrogen infrastructure.

1.3.2 Tidal and wave power

Tidal and wave power are technologies that harness the kinetic energy from ocean currents and waves to generate electricity. Tidal energy relies on the predictable ebb and flow of tides, making it a reliable and consistent renewable energy source. Wave energy, on the other hand, captures energy from the surface motion of the ocean. These methods have a significant potential in coastal regions with strong tidal or wave movements, but the technology is still in its early stages, with high costs and environmental concerns regarding marine life and ecosystems.

The global energy sector is currently undergoing a profound transformation, driven by an escalating demand for electricity, the urgent imperative to mitigate climate change, and continuous technological advancements. This literature review synthesizes insights from recent Elsevier publications, to examine the evolution, challenges, and future trajectories of diverse electricity generation methods. Since 2015, renewable energy sources (RES) have seen an extraordinary surge in both deployment and technological maturity. The inherent intermittency of sources like solar and wind power remains a central research focus, spurring significant innovation in advanced energy storage solutions and sophisticated grid integration strategies. Table 1 shows some recent studies in electricity generation methods. From the information of 39 papers reviewed in Table 1, it can be inferred that no scientific work has been done so far in the field of power supplying selection with type-2 fuzzy data for the rubber industry.

Table 1. Review of articles on smart and/or sustainable supplier selection

No.	Ref.	Eval.	Solution		Type of Fuzziness								Application Type/Area	
		Paradigm		Method										
		Smart	Sust.	MCDM	Oth.	T1	T2	Intv.	Intui.	Pyth.	Rou.	Real.	Hypo.	Area
1	[13]		*	FAHP		*						*		Taiwanese electronics industry
2	[14]		*	FANP		*						*		A main producer of a Turkish white goods industry
3	[15]		*	FAHP TOPSIS		*						*		Fuel filter suppliers for a manufacturing firm in Iran automotive industry
4	[16]		*	AHP QFD									*	An illustrative example of a large retailer
5	[17]		*	FTOPSIS						*		*		An empirical study
6	[18]		*	FTOPSIS		*						*		A numerical example
7	[19]		*	FDEMATEL TOPSIS		*						*		A gear manufacturing company in China
8	[20]		*	FAHP		*							*	Global sustainable supplier selection problems observed by vulnerable to naming and shaming campaigns and civil society
9	[21]		*	FDEA	Russell measure	*						*		A resin production company in Iran

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No.	Ref.	Eval. Paradigm		Solution Method		Type of Fuzziness							Application Type/Area	
		Smart	Sust.	MCDM	Oth.	T1	T2	Intv.	Intui.	Pyth.	Rou.	Real.	Hypo.	Area
10	[22]		*	FDEA	Russell measure		*						*	Numerical experiments
11	[23]		*	FAHP FTOPSIS	Fuzzy Preference Programming	*						*		Fibers, finishing and auxiliary materials suppliers for a knitted fabric manufacturer
12	[24]		*	AHP VIKOR								*		A real world example of an automobile company in India
13	[22, 25]		*	DEMATEL ANP FVIKOR				*				*		A real case of a large supermarket
14	[26]		*		Fuzzy Delphi Method							*		Textile industry located in the emerging economy of India
15	[27]		*	FAHP FPROMETHEE FTOPSIS		*						*		A real light bulbs manufacturing company located in Île-de-France
16	[28]		*	FMOORA FGRA					*			*		A case empirical illustration
17	[29]		*	FAHP FVIKOR		*						*		A numerical application of an electronic goods manufacturing company
18	[30]		*	FAHPSort II			*	*				*		A numerical example of material suppliers
19	[31]		*	FAHP FTOPSIS		*						*		An agrifood value chain application
20	[32]		*	FTOPSIS				*		*		*		A real-world case of a home appliances manufacturer in China
21	[33]		*	FAHP TOPSIS		*						*		Thi Hien Joint Garment Stock Company in Vietnam's textile and garment industry
22	[34]	*	*		Multi-Agent Systems							*		A medical device manufacturer
23	[35]	*	*	FDEMATEL FTOPSIS							*	*		A real case study of new Chinese energy vehicle transmission suppliers
24	[36]	*		FTOPSIS		*							*	A hypothetical case study that can be generalized for firms operating under Logistics 4.0
25	[37]		*	FBWM FCoCoSo	Bonferroni functions	*						*		A real world example of Serbia home appliance manufacturer
26	[38]		*	FBWM IVIKOR		*		*				*		Wire-and-cable industry in Iran
27	[39]		*	MARCOS		*						*		Healthcare industry (in a polyclinic) in Bosnia and Herzegovina
28	[40]		*	AHP		*					*	*		Decentralized electricity generation
29	[41]		*	AHP		*					*	*		Energy system
30	[42]		*	Multicriteria Approach		*					*	*		Rural electrification
31	[43]		*	Mathematical Model		*					*	*		Photovoltaic solar power plants
32	[44]		*	TOPSIS		*					*	*		Resilient sustainable supplier selection
33	[45]		*	Fuzzy AHP		*					*	*		Sustainable supplier selection
34	[46]		*	Interval-valued fuzzy neuroomorphic information		*					*	*		Airlines
35	[47]		*	Pythagorean fuzzy DEMATELH		*					*	*		Supply chain management
36	[48]		*	Fuzzy entropy-VIKOR		*					*	*		Sustainable supplier selection

Continued on next page

No.	Ref.	Eval. Paradigm		Solution Method		Type of Fuzziness							Application Type/Area	
		Smart	Sust.	MCDM	Oth.	T1	T2	Intv.	Intui.	Pyth.	Rou.	Real.	Hypo.	Area
37	[49]		*	Fuzzy fairly operator-based MARCOS method		*					*	*		Sustainable circular supplier selection

Note: Ref. = Reference; Eval. paradigm = Evaluation paradigm; Sust. = Sustainable; MCDM = Multi-Criteria Decision-Making; Oth. = Others; T1/T2 = Type-1/Type-2; Intv. = Interval; Intui. = Intuitionistic; Pyth. = Pythagorean; Rou. = Rough; Real. = Real case; Hypo. = Hypothetical; AHP = Analytic hierarchy process; ANP = Analytic network process; BWM = Best-Worst Method.
* indicates the application of the corresponding method/type.

2 Methodology: CoCoSo Method

As observed, the purpose of this paper is to select an appropriate power supply system. In this regard, various multi-criteria decision-making (MCDM) techniques such as Vikor, AHP and Topsis can be applied. The CoCoSo technique [50] is chosen for this purpose because it is more recent compared to the previously mentioned methods. Moreover, since an expert panel has been formed to address the problem and their opinions are collected in various areas, linguistic variables are used. These variables are somewhat vague, and the experts' interpretations of descriptive terms such as "good" or "excellent" may differ. Therefore, to manage these ambiguities, type-2 fuzzy data—which are more advanced than type-1 fuzzy data—are employed.

3 Multi-Criteria Decision Making for Power Suppling Selection Using Fuzzy CoCoSo

3.1 About Parmida Rubber Company

Parmida Rubber Industries Company was established in 1993 with the production of multi-component rubber strips based on EPDM and molded rubber parts, on a site covering over 9,000 square meters. This company is the first manufacturer in Iran of two- and three-component rubber strips used across various industries, especially the automotive sector. In parallel with the development of the automotive industry in Iran and the growing market demand, Parmida has continuously updated its production capabilities and expertise in recent years by acquiring the most modern equipment and machinery from leading European countries. It has aligned its production with global standards to meet the evolving needs of the automotive industry in the country. In 2011, Parmida became the first company in Iran to launch a production line for sealing strips using Thermoplastic Elastomer (TPE) technology, utilizing its own domestic technical knowledge. To further increase production capacity and diversify its product portfolio, the company implemented a development plan in collaboration with a reputable European firm. In 2013, it launched the production of flocked rubber strips on a new site covering over 38,900 square meters using the latest state-of-the-art machinery. Currently, with the execution of these development plans, Parmida operates 7 production lines for rubber strip products, 3 lines for compound design and mixing, one line for molded parts with both injection and compression presses, and several finishing halls equipped with modern, up-to-date technology. Covering an area of over 26,000 square meters, the company produces nearly 6,000 tons annually of various rubber strips and components based on TPV/TPE and EPDM, capturing a significant share of the domestic.

3.2 Identifying the Options

Several articles in this field were reviewed and the result is that there are 4 categories of electricity generation methods, which are as follows:

- Solar
- Wind
- Fossil fuels (Gas)
- Fossil fuels (Diesel)

Moreover, these four methods are the logical available methods regarding to Parmida situations.

3.3 Defining the Criteria

At this stage, in order to be able to have a proper ranking, we need to specify the appropriate criteria to evaluate them. Considering that the purpose of the article is to choose the best electricity generation, a literature review was conducted to determine what the basics of this topic as showed in Table 2.

As a result, the six factors mentioned in the following are the criteria for selection:

1. Price (Cost)
2. Efficiency
3. Maintenance costs

4. Availability of generated energy
5. Availability of resources
6. Governmental support

Table 2. Defining the criteria with references

ID	Criteria	Description	References
C1	Price (Cost)	The total expenditure required to install, operate, and maintain the electricity generation system.	[11, 12, 15, 16, 18, 20, 25, 36]
C2	Efficiency	The percentage of input energy converted into usable electrical energy.	[15, 16, 18, 20, 21, 29, 45]
C3	Maintenance costs	The ongoing expenses related to servicing and repairing the electricity generation equipment.	[20, 25, 35, 47]
C4	Availability of generated energy	The consistency and reliability of power supply from the generation method.	[12, 13, 20]
C5	Availability of resources	The accessibility and sustainability of the fuel or natural resources needed for energy generation.	[11, 13, 20, 35]
C6	Governmental support	The extent of financial incentives, subsidies, or regulatory benefits provided by authorities for using the method.	[25, 35, 45]

3.4 Weighting the Criteria

As observed, the options and criteria were obtained through a review of the research literature. However, to assign weights to the criteria and to score the options, the opinions of experts were utilized. In this regard, an expert panel consisting of 10 specialists in the field of energy supply was formed. These individuals had at least 15 years of work experience in energy supply and held a master's or doctoral degree in a related field. In order to weighting the criteria a fuzzy methodology can be used. Table 3 shows Linguistic variables and their interval type-2 fuzzy scales.

Table 3. Linguistic variables and their interval type-2 fuzzy scales [51]

Linguistic Variables	Trapezoidal Interval Type-2 Fuzzy Scales
Absolutely Strong (AS)	(7,8,9,9; 1,1) (7.2,8.2,8.8,9; 0.8,0.8)
Very Strong (VS)	(5,6,8,9; 1,1) (5.2,6.2,7.8,8.8; 0.8,0.8)
Fairly Strong (FS)	(3,4,6,7; 1,1) (3.2,4.2,5.8,6.8; 0.8,0.8)
Slightly Strong (SS)	(1,2,4,5; 1,1) (1.2,2.2,3.8,4.8; 0.8,0.8)
Exactly Equal (E)	(1,1,1,1; 1,1) (1,1,1,1; 1,1)

As can be seen in Table 3, the five-dimensional spectrum of variables is defined in a type-2 fuzzy form. In other words, each fuzzy number in this table consists of 6 parts, which is actually a type-2 trapezoidal fuzzy number. This definition based on Table 3 is shown in Figure 1 as follows.

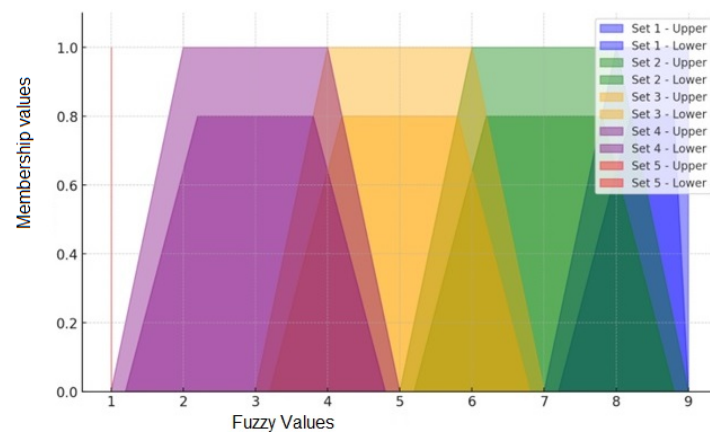


Figure 1. Fuzzy sets chart based on data from Table 2

At this stage, using the opinions of experts, pairwise comparisons are made and weights are obtained based on the pairwise comparisons are shown in Table 4.

Table 5 shows the information in Table 4 based on type-2 fuzzy data. In this table, the results of each variable have been replaced with the associated fuzzy numbers. Figure 2 also shows the results of these pairwise comparisons with the type-2 fuzzy approach in a radar chart.

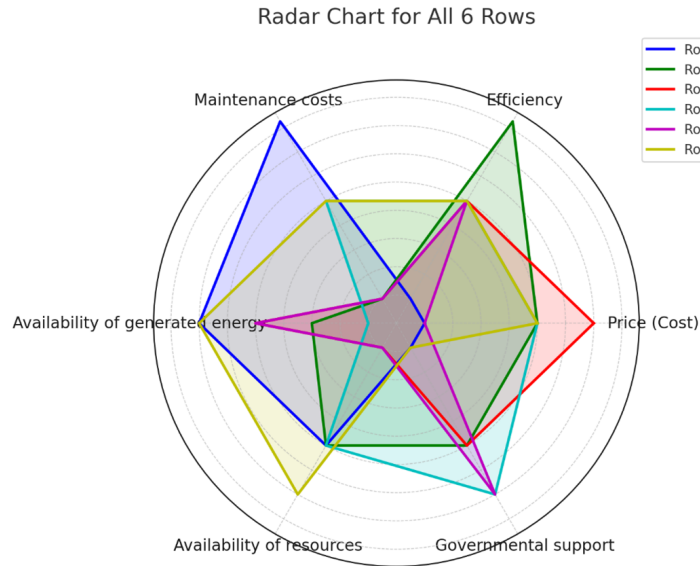
Table 4. Pairwise comparisons among criteria

	Price (Cost)	Efficiency	Maintenance Costs	Availability of Generated Energy	Availability of Resources	Governmental Support
Price (Cost)	E	1/AS	1/VS	1/FS	E	1/FS
Efficiency	AS	E	SS	FS	FS	FS
Maintenance costs	VS	FS	E	1/FS	E	FS
Availability of generated energy	FS	1/FS	FS	E	FS	VS
Availability of resources	E	1/FS	E	1/FS	E	1/VS
Governmental support	FS	1/FS	1/FS	1/VS	VS	E

Note: AS = Absolutely Strong; VS = Very Strong; FS = Fairly Strong; SS = Slightly Strong; E = Exactly Equal.

Table 5. Pairwise comparisons among criteria using fuzzy type-2

	Price (Cost)	Efficiency	Maintenance Costs	Availability of Generated Energy	Availability of Resources	Governmental Support
Price (Cost)	(1,1,1,1;1,1) (1,1,1,1;1,1)	1/(7,8,9,9;1,1) (7,2,8,2,8,8,9; 0,8,0,8)	1/(5,6,8,9;1,1) (5,2,6,2,7,8,8,8; 0,8,0,8)	1/(3,4,6,7;1,1) (3,2,4,2,5,8,6,8; 0,8,0,8)	(1,1,1,1;1,1) (1,1,1,1;1,1)	1/(3,4,6,7;1,1) (3,2,4,2,5,8,6,8; 0,8,0,8)
Efficiency	(7,8,9,9;1,1) (7,2,8,2,8,8,9;0,8,0,8)	(1,1,1,1;1,1) (1,1,1,1;1,1)	(1,2,4,5;1,1) (1,2,2,2,3,8,4,8; 0,8,0,8)	(3,4,6,7;1,1) (3,2,4,2,5,8,6,8; 0,8,0,8)	(3,4,6,7;1,1) (3,2,4,2,5,8,6,8; 0,8,0,8)	(3,4,6,7;1,1) (3,2,4,2,5,8,6,8; 0,8,0,8)
Maintenance costs	(5,6,8,9;1,1) (5,2,6,2,7,8,8,8; 0,8,0,8)	(3,4,6,7;1,1) (3,2,4,2,5,8,6,8; 0,8,0,8)	(1,1,1,1;1,1) (1,1,1,1;1,1)	1/(3,4,6,7;1,1) (3,2,4,2,5,8,6,8; 0,8,0,8)	(1,1,1,1;1,1) (1,1,1,1;1,1)	(3,4,6,7;1,1) (3,2,4,2,5,8,6,8; 0,8,0,8)
Availability of generated energy	(3,4,6,7;1,1) (3,2,4,2,5,8,6,8; 0,8,0,8)	1/(3,4,6,7;1,1) (3,2,4,2,5,8,6,8; 0,8,0,8)	(3,4,6,7;1,1) (3,2,4,2,5,8,6,8; 0,8,0,8)	(1,1,1,1;1,1) (1,1,1,1;1,1)	(3,4,6,7;1,1) (3,2,4,2,5,8,6,8; 0,8,0,8)	(5,6,8,9;1,1) (5,2,6,2,7,8,8,8; 0,8,0,8)
Availability of resources	(1,1,1,1;1,1) (1,1,1,1;1,1)	1/(3,4,6,7;1,1) (3,2,4,2,5,8,6,8; 0,8,0,8)	(1,1,1,1;1,1) (1,1,1,1;1,1)	1/(3,4,6,7;1,1) (3,2,4,2,5,8,6,8; 0,8,0,8)	(1,1,1,1;1,1) (1,1,1,1;1,1)	1/(5,6,8,9;1,1) (5,2,6,2,7,8,8,8; 0,8,0,8)
Governmental support	(3,4,6,7;1,1) (3,2,4,2,5,8,6,8; 0,8,0,8)	1/(3,4,6,7;1,1) (3,2,4,2,5,8,6,8; 0,8,0,8)	1/(3,4,6,7;1,1) (3,2,4,2,5,8,6,8; 0,8,0,8)	1/(5,6,8,9;1,1) (5,2,6,2,7,8,8,8; 0,8,0,8)	(5,6,8,9;1,1) (5,2,6,2,7,8,8,8; 0,8,0,8)	(1,1,1,1;1,1) (1,1,1,1;1,1)

**Figure 2.** Radar chart for six criteria

3.5 Defuzzification of Weighting the Criteria

In order to calculate Weighting the criteria, we must defuzzification the data. Defuzzification of type-2 fuzzy data is the process of converting fuzzy outputs into crisp (numerical) values. Since type-2 fuzzy sets involve uncertainty in the membership functions themselves (unlike type-1), the defuzzification process is more complex. In this part we use Karnik-Mendel (KM) Algorithm. This method first performs type-reduction, which transforms the type-2 fuzzy set into an interval type-1 fuzzy set. Then, it computes the centroid of this interval. The result is usually an interval $[y_L, y_R]$, and the final crisp value is the average: $y = \frac{y_L + y_R}{2}$. The calculations are as follows:

1. (7, 8, 9, 9; 1, 1), (7.2, 8.2, 8.8, 9; 0.8, 0.8)
Centroid 1: $(7 + 8 + 9 + 9)/4 = 8.25$
Centroid 2: $(7.2 + 8.2 + 8.8 + 9)/4 = 8.3$
Defuzzified: $(1 \times 8.25 + 0.8 \times 8.3)/(1 + 0.8) = 8.27$
2. (5, 6, 8, 9; 1, 1), (5.2, 6.2, 7.8, 8.8; 0.8, 0.8)
Centroid 1: $(5 + 6 + 8 + 9)/4 = 7.0$
Centroid 2: $(5.2 + 6.2 + 7.8 + 8.8)/4 = 7.0$
Defuzzified: $(1 \times 7 + 0.8 \times 7)/1.8 = 7.0$
3. (3, 4, 6, 7; 1, 1), (3.2, 4.2, 5.8, 6.8; 0.8, 0.8)
Centroid 1: $(3 + 4 + 6 + 7)/4 = 5.0$
Centroid 2: $(3.2 + 4.2 + 5.8 + 6.8)/4 = 5.0$
Defuzzified: 5.0
4. (1, 2, 4, 5; 1, 1), (1.2, 2.2, 3.8, 4.8; 0.8, 0.8)
Centroid 1: $(1 + 2 + 4 + 5)/4 = 3.0$
Centroid 2: $(1.2 + 2.2 + 3.8 + 4.8)/4 = 3.0$
Defuzzified: 3.0
5. (1,1,1,1;1,1), (1,1,1,1;1,1)
Centroid = $(1 + 1 + 1 + 1)/4 = 1.0$
Defuzzified: 1.0

At this stage, regarding to above calculations scores to each factor have been assigned based on established criteria, expert opinions, and ongoing discussions. In fact, at this stage, the expert panel held meetings to evaluate and score the options based on the established criteria. In the scoring process, efforts were made to use objective data as much as possible instead of personal opinions. For example, the prices of different generators were inquired and scores were assigned accordingly, and similarly, the level of government financial support was obtained and then scored. Table 6 shows these scores, which are the average scores each criterion received across all factors. This resulting decision matrix is as follows:

Table 6. Decision matrix

Alt./Criteria	C1	C2	C3	C4	C5	C6
Solar	1	8.27	3	5	8.27	3
Wind	1	7	1	3	1	5
Fossil fuels (Gas)	7	7	5	5	8.27	3
Fossil fuels (Diesel)	8.27	7	8.27	8.27	5	3
Weights of criteria	0.31526	0.076301	0.087201	0.077952	0.231214	0.212056

Note: Alt. = Alternatives.

3.6 Preparing the Normalized Matrix

In this step, the decision matrix needs to be normalized. This step is normalized based on the relationships below the decision matrix, the first relationship is used for positive criteria and the second relationship is used for negative criteria. In the following relations, $\max X_{ij}$ and $\min X_{ij}$ are actually the maximum and minimum value of each criterion column. Based on this normalization, all levels are between 0 and 1. These calculations are based on the following formula:

Eq. (1) —calculations for the profit factor:

$$r_{ij} = \frac{x_{ij} - \min_i x_{ij}}{\max_i x_{ij} - \min_i x_{ij}} \quad (1)$$

Eq. (2) —calculations for the cost factor:

$$r_{ij} = \frac{\max_i x_{ij} - x_{ij}}{\max_i x_{ij} - \min_i x_{ij}} \quad (2)$$

3.7 Calculating the Weighted Sum and Weighted Multiplication Values

In this step, the weighted sum (S) and weighted product (P) values for each alternative are calculated using the following formulas. In both equations, W_j represents the weight of each criterion, which serves as an input to the CoCoSo method. These weights can be determined either directly by the decision maker or through techniques

such as Shannon Entropy, AHP, BWM, and others. The S_i values are derived from the Simple Additive Weighting method, while the P_i values are obtained from the WASPAS method, as detailed below:

$$S_i = \sum_{j=1}^n (w_j r_{ij}), P_i = \sum_{j=1}^n (r_{ij})^{w_j} \quad (3)$$

Table 7 showed values of weighted sum and weighted multiplication, and then sequence and exponential weight calculations are in Table 8 as follows:

Table 7. Values of weighted sum and weighted multiplication

Alt./Criteria	C1	C2	C3	C4	C5	C6
Solar	0.0000	1.0000	0.2751	0.3795	1.0000	0.0000
Wind	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000
Fossil fuels (Gas)	0.8253	0.0000	0.5502	0.3795	1.0000	0.0000
Fossil fuels (Diesel)	1.0000	0.0000	1.0000	1.0000	0.5502	0.0000

Note: Alt. = Alternatives.

Table 8. Sequence calculations and exponential weight of the decision matrix

Alt./Criteria	C1	C2	C3	C4	C5	C6
Solar	0.0000	0.0763	0.0240	0.0296	0.2312	0.0000
Wind	0.0000	0.0000	0.0000	0.0000	0.0000	0.2121
Fossil fuels (Gas)	0.2602	0.0000	0.0480	0.0296	0.2312	0.0000
Fossil fuels (Diesel)	0.3153	0.0000	0.0872	0.0780	0.1272	0.0000

Note: Alt. = Alternatives.

3.8 The Seventh Step: Determining the Evaluation Score of Options Based on Strategies

In this section, the scores of the options are calculated using three strategies, each represented by a distinct equation. The first equation computes the arithmetic mean of the Weighted Sum Model (WSM) and Weighted Product Model (WPM) scores. The second equation measures the relative performance of WSM and WPM compared to the best-performing alternative. The third equation offers a compromise between the WSM and WPM models, where the parameter λ is set by the decision maker. Notably, when $\lambda = 0.5$, the model provides a balanced and flexible evaluation.

$$K_{ia} = \frac{P_i + S_i}{\sum (P_i + S_i)} \quad (4)$$

$$K_{ib} = \frac{S_i}{\min S_i} + \frac{P_i}{\min P_i} \quad (5)$$

$$K_{ic} = \frac{\lambda (S_i) + (1 - \lambda) (P_i)}{(\lambda \max S_i + (1 - \lambda) \max P_i)} \quad (6)$$

Based on the formulas above, relevant calculations were made and as a result, the Fossil fuels (Diesel) was selected as the best power supplying method for Parmida company. The details of the calculations are given in Table 9.

Table 9. Final calculations and ranking

Alt./Criteria	Ka	Ranking	Kc	Ranking
Solar	0.2933	3	0.9338	3
Wind	0.0850	4	0.2706	4
Fossil fuels (Gas)	0.3076	2	0.9795	2
Fossil fuels (Diesel)	0.3141	1	1.0000	1

Note: Alt. = Alternatives.

Due to the innovative nature of the CoCoSo method and the need to ensure the reliability of its results, sensitivity analysis is conducted in this section. The main objective is to evaluate how variations in input data affect the

model's performance and outcomes. While changes in the decision matrix—i.e., the scores of alternatives relative to the criteria—can influence the results, such variations often lead to inconclusive findings. As a more effective approach, this analysis focuses on altering the weights of the criteria to assess the model's sensitivity. Following the methodology of Yazdani et al. [50], 48 randomized sets of five weights were generated based on the original values, as presented in Table A1.

For each of the 48 cases, the corresponding set of calculated weights was applied to the model, and the resulting rankings of the factors were observed. These results are presented in Figure 3. As shown, the model demonstrates strong robustness against changes in weights. Notably, four factors consistently retained their original ranks across all 48 tests, and most alternatives maintained their positions despite the random variations in weight values.

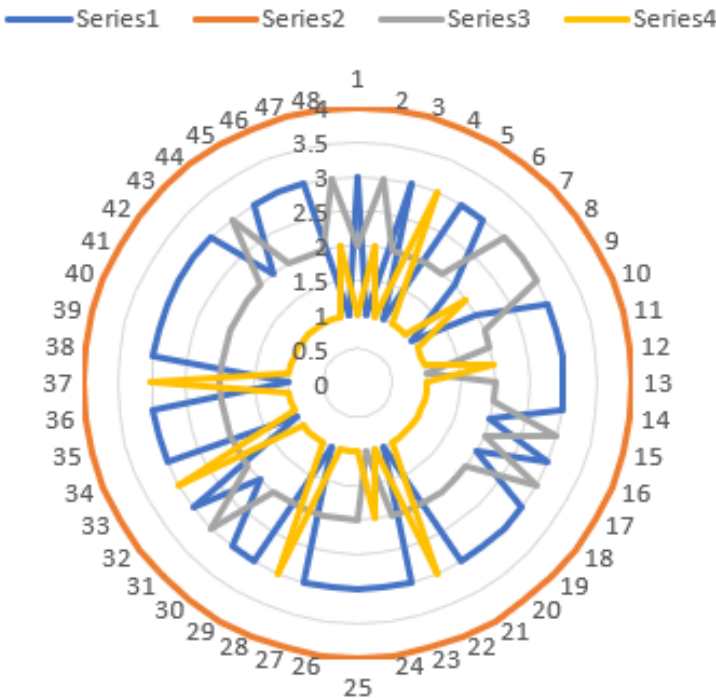


Figure 3. Sensitivity analysis of results for 48 data

4 Conclusion

As seen in this article, energy supply selection was carried out for a company manufacturing automotive rubber parts. This was a practical issue that was defined in line with the company's strategies for sustainable supply of electrical energy. In this regard, considering the nature of the work, multi-criteria decision-making theory was used and an attempt was made to solve this problem using an up-to-date technique. In addition, considering that the experts' opinions used vague concepts and linguistic words, type-2 fuzzy was used to minimize the fuzziness of the data. As a result, an effort was made to design a scientific framework for identifying sustainable sources of electrical energy so that similar companies could use it to solve their own similar problems.

Data Availability

The data used to support the research findings are available from the corresponding author upon request.

Conflicts of Interest

The author declares no conflicts of interest.

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Appendix

Table A1. Data table created for sensitivity analysis of the method

	Randomly generated weights					
Test 1	0.31526	0.076301	0.087201	0.077952	0.231214	0.212056
Test 2	0.092317	0.245743	0.039145	0.189068	0.215948	0.217778
Test 3	0.131853	0.136212	0.084158	0.145429	0.319546	0.182803
Test 4	0.045473	0.402797	0.006252	0.036527	0.26198	0.24697
Test 5	0.219581	0.072653	0.265369	0.113955	0.184401	0.144041
Test 6	0.270304	0.121089	0.111642	0.172545	0.283741	0.040679
Test 7	0.105571	0.224588	0.15399	0.063563	0.083083	0.369204
Test 8	0.013222	0.453163	0.014707	0.217818	0.197043	0.104047
Test 9	0.104507	0.28149	0.108045	0.364743	0.113903	0.027312
Test 10	0.091034	0.036865	0.035975	0.288703	0.109079	0.438344
Test 11	0.126258	0.034318	0.362367	0.22933	0.179317	0.068411
Test 12	0.231631	0.128227	0.10469	0.038523	0.291088	0.205841
Test 13	0.158645	0.045111	0.220728	0.041357	0.274808	0.259351
Test 14	0.372858	0.011343	0.071372	0.513369	0.005503	0.025555
Test 15	0.228311	0.423613	0.022515	0.201358	0.088717	0.035486
Test 16	0.317406	0.0618	0.013068	0.363479	0.031505	0.212743
Test 17	0.109671	0.314741	0.294838	0.273228	0.004003	0.003519
Test 18	0.31502	0.044408	0.023312	0.015149	0.143899	0.458211
Test 19	0.122611	0.055198	0.752127	0.024032	0.041138	0.004893
Test 20	0.064641	0.04015	0.403697	0.091592	0.046114	0.353806
Test 21	0.312436	0.250835	0.10226	0.011762	0.189186	0.133521
Test 22	0.207514	0.196523	0.029415	0.108288	0.314165	0.144095
Test 23	0.153751	0.184851	0.245517	0.271878	0.031923	0.112079
Test 24	0.401776	0.157342	0.013249	0.066345	0.293724	0.067563
Test 25	0.17798	0.062688	0.098146	0.462033	0.023717	0.175436
Test 26	0.111069	0.071397	0.38833	0.026085	0.173269	0.229851
Test 27	0.495685	0.094936	0.12594	0.028311	0.168769	0.086359
Test 28	0.015719	0.179833	0.007339	0.242449	0.50493	0.04973
Test 29	0.259447	0.015904	0.431396	0.177324	0.042188	0.073741
Test 30	0.268885	0.211325	0.252855	0.215094	0.047822	0.00402
Test 31	0.203975	0.349368	0.04471	0.177573	0.018244	0.206131
Test 32	0.055487	0.049436	0.172365	0.059554	0.002993	0.660165
Test 33	0.144484	0.199956	0.003962	0.029983	0.437176	0.184439
Test 34	0.119671	0.079171	0.300116	0.261354	0.088035	0.151654
Test 35	0.108995	0.098373	0.381045	0.141054	0.21846	0.052072
Test 36	0.158287	0.060921	0.098267	0.375359	0.145236	0.161931
Test 37	0.02726	0.220687	0.124244	0.009538	0.302069	0.316203
Test 38	0.320085	0.292404	0.102668	0.033847	0.188724	0.062272
Test 39	0.202254	0.010615	0.152046	0.187609	0.206453	0.241023
Test 40	0.322824	0.196091	0.05877	0.073131	0.107136	0.242048
Test 41	0.145797	0.000544	0.121624	0.005485	0.17961	0.54694
Test 42	0.456061	0.099919	0.190765	0.008332	0.129162	0.11576
Test 43	0.109827	0.065866	0.018402	0.165879	0.173337	0.466689
Test 44	0.297429	0.418423	0.048092	0.104809	0.069799	0.061448
Test 45	0.070474	0.089742	0.220653	0.198806	0.299976	0.120349
Test 46	0.131544	0.195532	0.152127	0.099032	0.015096	0.406669
Test 47	0.143462	0.102882	0.350674	0.136845	0.079192	0.186945
Test 48	0.075128	0.266725	0.109044	0.131641	0.323721	0.093741