Computational Intelligence Methodology based on Neutrosophic Set with Multi-Criteria Decision Making for Evaluating Natural Gas Automobiles

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Abstract

This study presents a comprehensive evaluation of natural gas automobiles, focusing on their performance, environmental impact, economic viability, and potential as an alternative fuel for transportation. Natural gas vehicles (NGVs) have gained attention as an alternative to conventional gasoline or diesel vehicles due to their lower emissions profile and potential for reducing greenhouse gas emissions. The assessment encompasses a comparative analysis of NGVs against traditional internal combustion engine vehicles, evaluating factors such as vehicle efficiency, fuel availability, infrastructure, emissions, and cost-effectiveness. Findings reveal that NGVs exhibit lower emissions of pollutants like nitrogen oxides and particulate matter than their gasoline or diesel counterparts. However, challenges persist regarding limited refueling infrastructure, reduced driving range, and upfront vehicle conversion or purchase costs. Economic evaluations highlight the potential cost savings associated with natural gas as a fuel, particularly in regions with favorable pricing and infrastructure. Despite these benefits, scalability and widespread adoption of NGVs face barriers related to infrastructure development, technological advancements, and market incentives. This evaluation provides insights into the opportunities and challenges of natural gas automobiles, emphasizing the need for a balanced approach encompassing technological innovation, infrastructure investment, and supportive policies to unlock their full potential as a viable alternative in the transportation sector. We used multi-criteria decision-making (MCDM) to deal with various criteria of natural gas automobiles. The Range of Value Technique (ROV) method ranks the alternatives. The ROV is integrated with the neutrosophic set to deal with uncertainty information. The neutrosophic set is extension of fuzzy set to overcome the vague and incomplete information. The sensitivity analysis is conducted to check the stability of the results.

Keywords: The Range of Value Technique (ROV); Neural Gas; Automobiles: MCDM: Neutrosophic Set

1. Introduction

Natural gas automobiles are vehicles that utilize natural gas as a primary source of fuel instead of conventional gasoline or diesel. Natural gas, primarily composed of methane, offers several advantages as a transportation fuel, including lower emissions, energy efficiency, and reduced dependence on fossil fuels. With advancements in technology and the availability of natural gas infrastructure, natural gas automobiles have gained attention as a viable alternative to conventional vehicles in various applications[1], [2].

Doi: https://doi.org/10.54216/IJAACI.050102
Received: June 03, 2023 Revised: November 12, 2023 Accepted: December 11, 2023

Natural gas automobiles provide an opportunity to address transportation-related environmental concerns, especially air pollution and greenhouse gas emissions. When combusted, natural gas produces lower levels of carbon dioxide (CO2), nitrogen oxides (NOx), and particulate matter than gasoline or diesel. As a result, natural gas vehicles can contribute to improved air quality and reduced carbon footprint, thereby mitigating the impact of transportation on climate change[3]–[5].

Fuel efficiency is another significant advantage of natural gas automobiles, as natural gas has a higher energy content than gasoline or diesel. This higher energy density allows vehicles to perform similarly while consuming less fuel. Additionally, natural gas costs are often lower than conventional fuels, providing potential cost savings to vehicle owners and reducing overall fuel expenses[6]–[8].

The availability of natural gas refueling infrastructure remains crucial for the widespread adoption of natural gas automobiles. Establishing a well-developed network of refueling stations is essential to ensure the convenience and practicality of using natural gas vehicles. However, the expansion of refueling infrastructure is gradually progressing in many regions, supporting the growth of natural gas as a transportation fuel[9]–[11].

Regarding vehicle options, natural gas automobiles are available in various forms, including dedicated natural gas vehicles (NGVs) and bi-fuel vehicles that can run on both natural gas and gasoline. NGVs are specifically designed to operate solely on natural gas, while bi-fuel vehicles offer the flexibility to switch between natural gas and petrol, providing extended driving range and convenience[12]–[14].

While natural gas automobiles offer numerous benefits, there are also challenges to consider. These include the limited range of natural gas vehicles compared to conventional cars, the upfront costs associated with vehicle purchase and conversion, and the need for continued investment in infrastructure development[15]–[17].

As governments, policymakers, and individuals seek to reduce emissions, improve energy efficiency, and diversify the transportation sector, natural gas automobiles emerge as an attractive alternative. By considering emissions reduction, energy efficiency, refueling infrastructure, and vehicle options, stakeholders can evaluate natural gas automobiles' viability and potential benefits in their respective contexts. With ongoing advancements and increased support, natural gas vehicles have the potential to play a significant role in the transition towards a more sustainable and environmentally friendly transportation system[18]–[20].

We used the MCDM model[21] to evaluate the natural gas automobiles. We used the ROV model to analyze the criteria and alternatives.

Zadeh [22], [23]proposed the notion of membership and the idea of fuzzy sets (FS) in 1965. Today, this generally acknowledged idea provides the foundation for the comfort and ease we take for granted daily[24]. New set structures like interval-valued fuzzy sets (IVFS), bipolar fuzzy sets (BPS), multiple-valued fuzzy sets (MVFS), single-valued fuzzy sets (SVFS), m-polar interval-valued fuzzy sets (m-PIVFS), and fuzzy rough sets (FRS) were made possible by this theory. In 1986, Atanassov expanded the notion of fuzzy sets (FS) to encompass membership and non-membership values, hence improving accuracy. This is known as intuitionistic fuzzy sets (IFS). To solve MCDM difficulties, Zhang and Xu further extended IFS to Pythagorean fuzzy sets (PFS) and offered operational guidelines and techniques for making decisions[25].

Neutronosophic sets (NS), first proposed by Smarandache[26], [27] in 1998, are a novel approach to handling ambiguous, inconsistent, and indeterminate settings. Together with membership and non-membership values (T, I, and F), which are independent of one another, NS also includes indeterminacy values. The notions of bipolar neutrosophic sets (BPNS), single-valued neutrosophic sets (SVNS), multi-valued neutrosophic sets (MVNS), interval-valued neutrosophic sets (IVNS), and multi-valued interval neutrosophic sets (MVINS) were added to NS based on these neutrosophic numbers assigned by decision-makers (DM). These ideas were immediately put to use in practical settings, especially for solving multi-criteria decision-making (MCDM) issues. Scholars have suggested a number of approaches to solve MCDM in the context of different environments.

2. Preliminaries

The fundamental principles of neutrosophic set presented in this section[28]

Definition 1

Doi: https://doi.org/10.54216/IJAACI.050102
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The set of criteria $K_1^a, K_2^b, \dots K_1^z$ be a hypersoft u by the product $F, K_1^a \times K_2^b \times \dots . \times K_n^z$

$$F: K_1^a \times K_2^b \times \dots . \times K_n^z \to P(u)$$

Definition 2

The form of neutrosophic numbers presented as:

$$F: K_1^a \times K_2^b \times \dots . \times K_n^z = \left\{\begin{matrix} \big(u, T_k(u), I_k(u), F_k(u)\big) \\ |u \in U, \\ k \in (F: K_1^a \times K_2^b \times \dots . \times K_n^z) \end{matrix}\right\}$$

$$T_k(u), I_k(u), F_k(u) \sqsubseteq [0,1]$$

Definition 3

The interval valued number can be presented as:

$$F: K_1^a \times K_2^b \times \dots . \times K_n^z = \left\{\begin{matrix} \big(u, T_k(u), I_k(u), F_k(u)\big) \\ |u \in U, \\ k \in (F: K_1^a \times K_2^b \times \dots . \times K_n^z) \end{matrix}\right\}$$

$$0 \le \sup\big(T_k(u)\big) + \sup\big(I_k(u)\big) + \sup\big(F_k(u)\big) \le 3$$

Definition 4

The power set presented as a mapping from the product of criteria as:

$$\left\{\begin{matrix} F: K_1^a \times K_2^b \times \dots . \times K_n^z \to P(u) \\ F: K_1^a \times K_2^b \times \dots . \times K_n^z = \big(u, T_k^i(u), I_k^i(u), F_k^i(u)\big) \end{matrix}\right\}$$

$$0 \le \sum_{i=1}^{a} T_k^i(u) + \sum_{j=1}^{b} I_k^j(u) + \sum_{l=1}^{c} T_k^l(u) \le 3$$

Definition 5

The multi-polar interval valued neutrosophic hypersoft set (m-PIVNHSs) presented as:

Let u and N two m-PIVNHSs and some operations presented as:

$$h_1^{\xi^c} = \{u_1, N_1\}$$

$$h_1^{\xi^c} \vee h_2^{\xi^c} = \{\max\{u_1, u_2\}, \min\{N_1, N_2\}\}$$

$$h_1^{\xi^c} \wedge h_2^{\xi^c} = \{\min\{u_1, u_2\}, \max\{N_1, N_2\}\}$$

$$h_1^{\xi^c} \oplus h_2^{\xi^c} = \left\{\sqrt{u_1^2 + u_2^2 - u_1^2 u_2^2}, N_1 N_2\right\}$$

$$h_1^{\xi^c} \otimes h_2^{\xi^c} = \left\{ u_1 u_2 \sqrt{N_1^2 + N_2^2 - N_1^2 N_2^2} \right\}$$

$$\leftthreetimes h_1^{\xi^c} = \sqrt{1 - (1 - u_1^2)^{\leftthreetimes}}, N_1^{\leftthreetimes}$$

$$h_1^{\xi^{\leftthreetimes}} = U_1^{\leftthreetimes}, \sqrt{1 - (1 - N_1^2)^{\leftthreetimes}}$$

3. Problem Definition

This study proposed an MCDM model with the interval valued neutrosophic set for evaluating natural gas automobiles. This study uses different criteria and alternatives. The criteria are used in this study organized as[29]–[32]:

1. Vehicle Availability: The availability of natural gas automobiles is a crucial criterion. It includes the accessibility of natural gas fueling infrastructure and the availability of various vehicle models from multiple manufacturers.

2. Fuel Efficiency: Natural gas automobiles should exhibit high fuel efficiency to maximize the mileage per unit of natural gas consumed. This criterion ensures that the vehicle can travel longer distances on a single fill-up, reducing the need for frequent refueling.

3. Emissions: One of the significant advantages of natural gas automobiles is their reduced emissions compared to conventional gasoline or diesel vehicles. Criteria for natural gas automobiles include meeting stringent emissions standards and contributing to lower greenhouse gas emissions and air pollution levels.

4. Performance: Natural gas automobiles should provide satisfactory performance in terms of acceleration, top speed, and overall driving experience. The vehicle's power and torque output should meet the expectations of drivers.

5. Safety: Safety is critical for any automobile, including natural gas vehicles. The vehicle should meet or exceed safety standards and incorporate advanced safety features to protect occupants during collision or other emergencies.

6. Range: The range of a natural gas automobile refers to the distance it can travel on a full tank of natural gas. A higher range allows drivers to cover longer distances without frequent refueling, enhancing convenience and practicality.

7. Cost: The cost of purchasing, operating, and maintaining a natural gas automobile is an essential criterion for consumers. It includes the initial purchase price, fuel costs, maintenance expenses, insurance premiums, and potential government incentives or subsidies.

8. Refuelling Infrastructure: The availability and accessibility of natural gas refueling stations are crucial criteria for natural gas automobiles. A well-developed refueling infrastructure ensures drivers can easily find refueling stations and eliminates concerns about running out of fuel during journeys.

9. Durability and Reliability: Natural gas automobiles should demonstrate durability and reliability in various driving conditions and climates. This criterion ensures that the vehicle can withstand regular use and deliver consistent performance over an extended period.

10. Consumer Acceptance: Consumer acceptance and perception of natural gas automobiles play a role in widespread adoption. Factors such as public awareness, perceived benefits, and ease of use contribute to the overall criteria for natural gas vehicles.

Doi: https://doi.org/10.54216/IJAACI.050102
Received: June 03, 2023 Revised: November 12, 2023 Accepted: December 11, 2023

By considering these criteria, consumers and policymakers can make informed decisions regarding adopting and promoting natural gas automobiles. These vehicles offer the potential for reduced emissions, increased energy independence, and diversification of the transportation fuel mix.

3. The Range of Value Technique (ROV)[33]–[38]

Figure 1 shows the stage of the ROV method.

Stage 1. Create the decision matrix

Stage 2. Normalize the decision matrix

For positive and negative criteria, the normalized decision matrix is computed

$$r_{ij}^{+} = \frac{o_{ij} - \min(o_{ij})}{\max(o_{ij}) - \min(o_{ij})} \tag{1}$$

$$r_{ij}^{-} = \frac{\max(o_{ij}) - o_{ij}}{\max(o_{ij}) - \min(o_{ij})} \tag{2}$$

Stage 3. Compute the values of e_i^+, e_i^-

$$e_i^{+} = \sum_{j=1}^{n} r_{ij}^{+} w_j \tag{3}$$

$$e_i^{-} = \sum_{j=1}^{n} r_{ij}^{-} w_j \tag{4}$$

Stage 4. Rank the alternatives

$$e_i = \frac{e_i^{+} + e_i^{-}}{2} \tag{5}$$

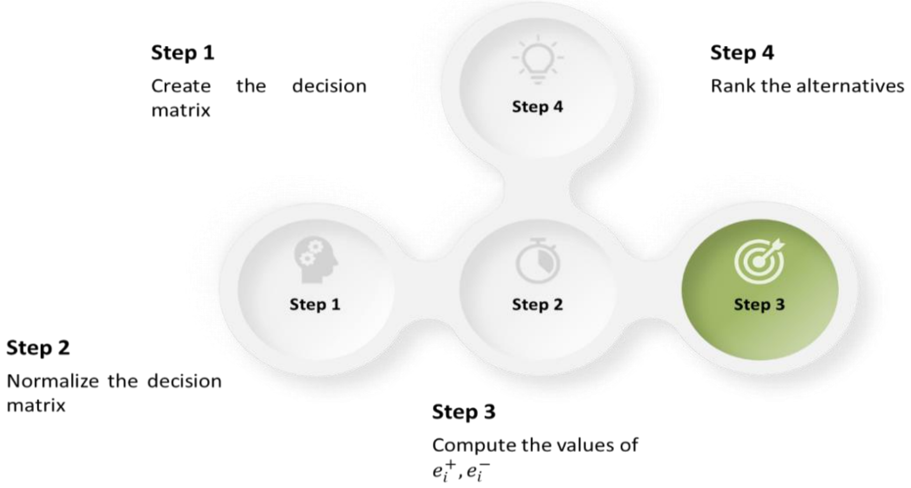

Figure 1: The steps of the proposed model.

4. Results

We proposed a decision-making model for evaluating natural gas automobiles. We used ten criteria and 16 alternatives in this study. The experts evaluated the criteria and alternatives on a scale between 1 and 9. The criteria weights are computed by the mean method to analyze the criteria. Figure 2 shows the criteria weights in this study.

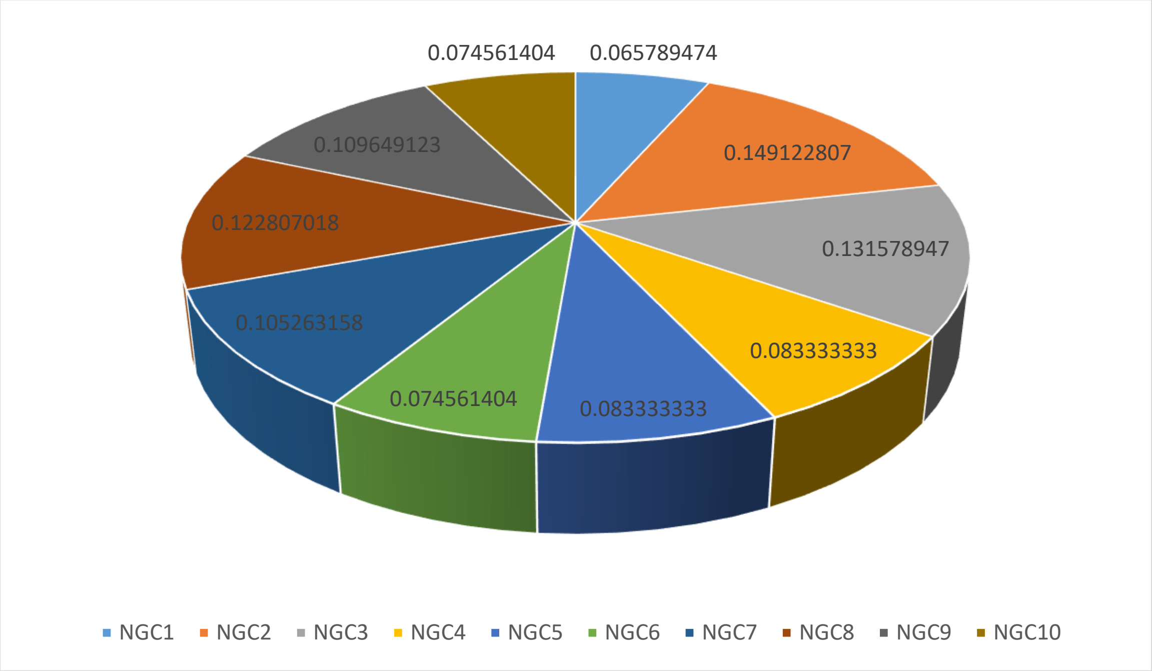

Figure 2: The criteria weights of natural gas automobiles.

Stage 1. Create the decision matrix

Stage 2. Normalize the decision matrix by Eqs. (1 and 2)

Table 1: The normalization decision matrix.

	NGC_1	NGC_2	NGC_3	NGC_4	NGC_5	NGC_6	NGC_7	NGC_8	NGC_9	NGC_{10}
NGA_1	3.714286	7.714286	6.714286	2.714286	4.714286	5.714286	8.714286	7.714286	6.714286	5.714286
NGA_2	5.714286	8.714286	7.714286	6.714286	3.714286	4.714286	5.714286	1.714286	2.714286	4.714286

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NGA_{13}	NGA_{12}	NGA_{11}	NGA_{10}	NGA_9	NGA_8	NGA_7	NGA_6	NGA_5	NGA_4	NGA_3
8.714286	7.714286	6.714286	3.714286	4.714286	5.714286	8.714286	7.714286	4.714286	1.714286	2.714286
4.714286	5.714286	6.714286	7.714286	8.714286	1.714286	2.714286	5.714286	6.714286	7.714286	8.714286
7.714286	1.714286	6.714286	3.714286	4.714286	5.714286	8.714286	6.714286	7.714286	8.714286	5.714286
1.714286	6.714286	7.714286	8.714286	7.714286	6.714286	7.714286	8.714286	8.714286	4.714286	3.714286
3.714286	5.714286	4.714286	3.714286	5.714286	8.714286	6.714286	1.714286	2.714286	4.714286	4.714286
4.714286	2.714286	3.714286	6.714286	7.714286	8.714286	4.714286	3.714286	5.714286	1.714286	3.714286
5.714286	6.714286	7.714286	8.714286	8.714286	1.714286	7.714286	7.714286	8.714286	2.714286	5.714286
7.714286	8.714286	3.714286	5.714286	4.714286	3.714286	7.714286	6.714286	7.714286	8.714286	8.714286
7.714286	8.714286	5.714286	1.714286	4.714286	3.714286	6.714286	7.714286	4.714286	8.714286	5.714286
7.714286	4.714286	8.714286	7.714286	6.714286	8.714286	7.714286	4.714286	5.714286	1.714286	3.714286

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NGA_{14}	6.714286	3.714286	8.714286	3.714286	4.714286	5.714286	8.714286	6.714286	4.714286	6.714286
NGA_{15}	7.714286	4.714286	5.714286	6.714286	7.714286	8.714286	7.714286	8.714286	8.714286	4.714286
NGA_{16}	6.714286	7.714286	8.714286	5.714286	4.714286	3.714286	6.714286	7.714286	8.714286	5.714286

Stage 3. Compute the values of e_i^+, e_i^- by Eqs. (3 and 4) a shown in Table 2.

Table 2: The values of e_i^+, e_i^-

	NGC_1	**NGC_2**	**NGC_3**	**NGC_4**	**NGC_5**	**NGC_6**	**NGC_7**	**NGC_8**	**NGC_9**	**NGC_{10}**
NGA_1	0.244361	1.150376	0.883459	0.22619	0.392857	0.426065	0.917293	0.947368	0.736216	0.426065
NGA_2	0.37594	1.299499	1.015038	0.559524	0.309524	0.351504	0.601504	0.210526	0.297619	0.351504
NGA_3	0.178571	1.299499	0.75188	0.309524	0.392857	0.276942	0.601504	1.070175	0.626566	0.276942
NGA_4	0.112782	1.150376	1.146617	0.392857	0.392857	0.12782	0.285714	1.070175	0.95514	0.12782
NGA_5	0.31015	1.001253	1.015038	0.72619	0.22619	0.426065	0.917293	0.947368	0.516917	0.426065
NGA_6	0.507519	0.85213	0.883459	0.72619	0.142857	0.276942	0.81203	0.824561	0.845865	0.351504

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NGA_7	0.573308	0.404762	1.146617	0.642857	0.559524	0.351504	0.81203	0.947368	0.736216	0.575188
NGA_8	0.37594	0.255639	0.75188	0.559524	0.72619	0.649749	0.180451	0.45614	0.407268	0.649749
NGA_9	0.31015	1.299499	0.620301	0.642857	0.47619	0.575188	0.917293	0.578947	0.516917	0.500627
NGA_{10}	0.244361	1.150376	0.488722	0.72619	0.309524	0.500627	0.917293	0.701754	0.18797	0.575188
NGA_{11}	0.441729	1.001253	0.883459	0.642857	0.392857	0.276942	0.81203	0.45614	0.626566	0.649749
NGA_{12}	0.507519	0.85213	0.225564	0.559524	0.47619	0.202381	0.706767	1.070175	0.955514	0.351504
NGA_{13}	0.573308	0.703008	1.015038	0.142857	0.309524	0.351504	0.601504	0.947368	0.845865	0.575188
NGA_{14}	0.441729	0.553885	1.146617	0.309524	0.392857	0.426065	0.917293	0.824561	0.516917	0.500627
NGA_{15}	0.507519	0.703008	0.75188	0.559524	0.642857	0.649749	0.81203	1.070175	0.955514	0.351504
NGA_{16}	0.441729	1.150376	1.146617	0.47619	0.392857	0.276942	0.706767	0.947368	0.955514	0.426065

Stage 4. Rank the alternatives as shown in Figure 3. Alternative 15 has the highest rank and alternative 8 has the lowest rank.

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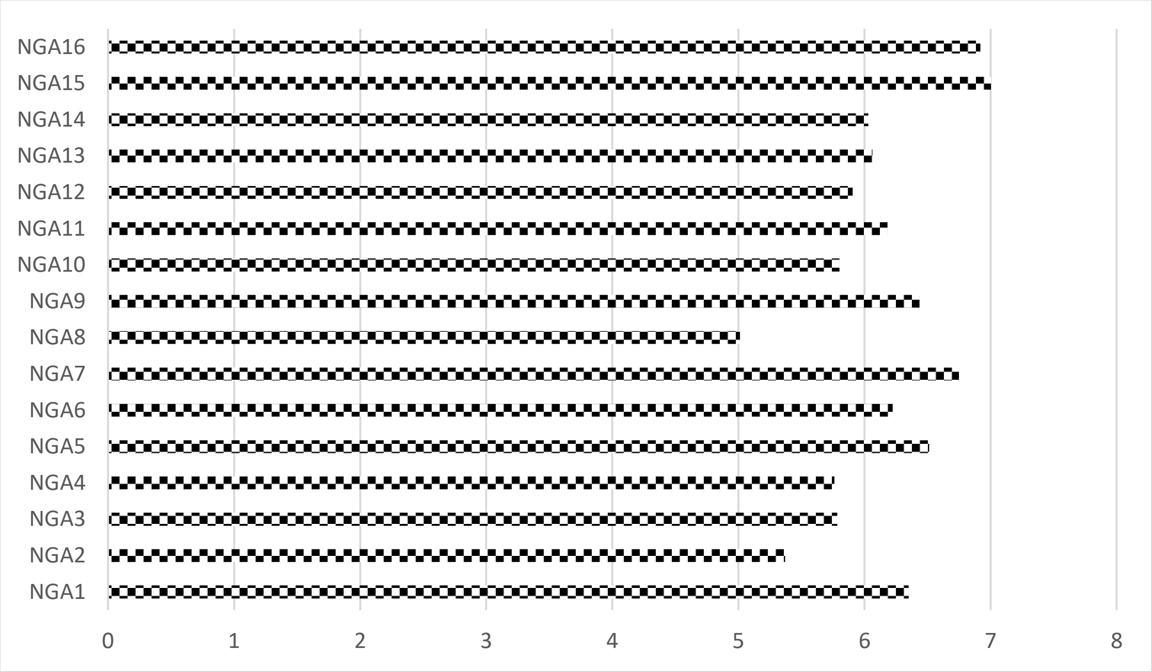

Figure 3: The rank of alternatives.

We change the weights of the criteria to show whether the rank of the alternative is stable or not. There are ten cases in weights of criteria as shown in Figure 4. We compute the rank of alternatives after changing the weights of criteria as shown in Figure 5. The results show a stable rank.

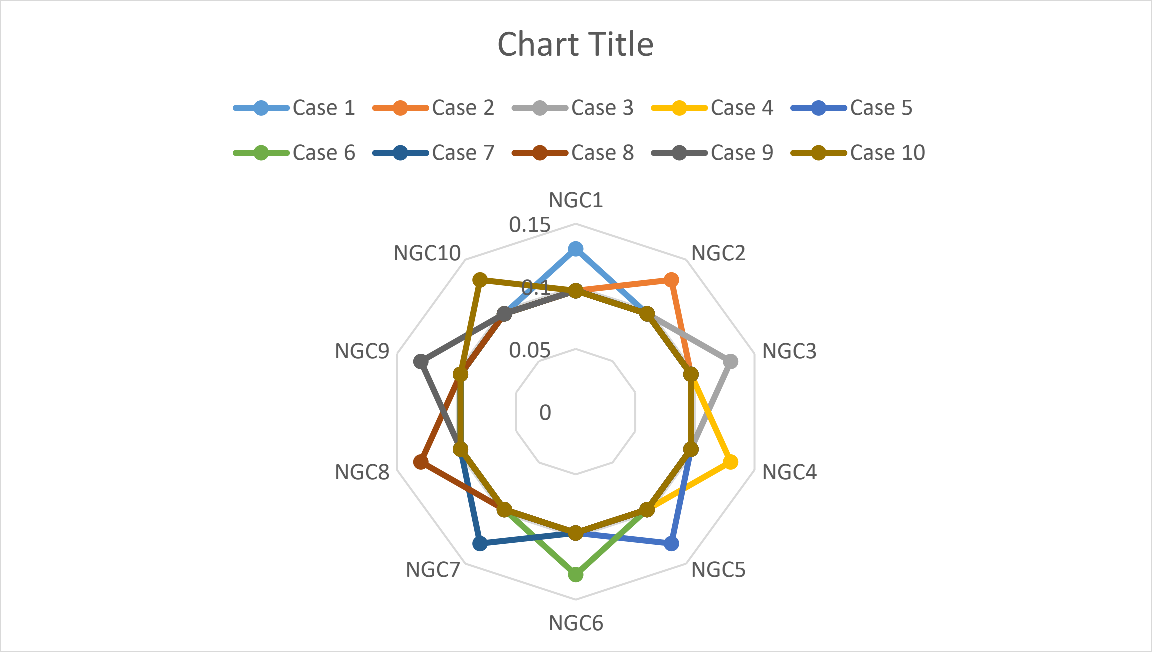

Figure 4: The ten cases in criteria weights.

Doi: https://doi.org/10.54216/IJAACI.050102
Received: June 03, 2023 Revised: November 12, 2023 Accepted: December 11, 2023

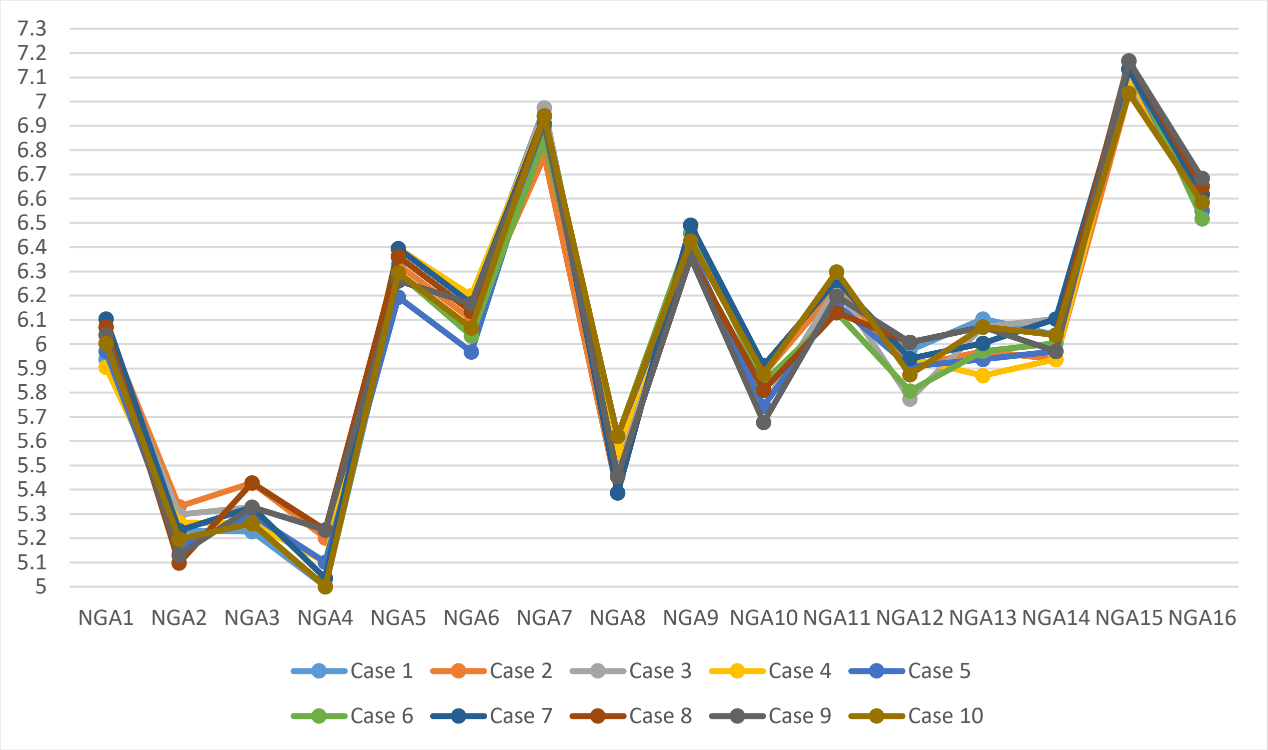

Figure 5: The different ranks of alternatives.

5. Conclusions

Evaluating natural gas automobiles underscores their potential as a promising alternative in the transportation sector. Technologically, NGVs showcase lower emissions of harmful pollutants, aligning with environmental objectives to reduce air pollution and mitigate climate change impacts. Economic analyses highlight the potential for cost savings, particularly in regions with established natural gas infrastructure and favorable pricing. However, challenges persist, including limited refueling infrastructure, reduced driving range compared to conventional vehicles, and upfront costs associated with vehicle conversion or purchase. Addressing these challenges requires concerted efforts in infrastructure development, technological advancements, and policy support. Investments in refueling infrastructure, research and development for advanced NGV technologies, and supportive policies such as tax incentives or subsidies can accelerate the adoption of natural gas automobiles. Moreover, collaboration among stakeholders, including governments, industry players, and research institutions, is essential to address market barriers and promote a smoother transition towards natural gas as a viable fuel option in the transportation sector. This study used the MCDM model to evaluate natural gas automobiles and analyze the criteria. The Range of Value Technique (ROV) method was used to rank the alternatives. We used ten criteria and 16 options in this study. The ROV method integrated with the interval valued neutrosophic set to deal with uncertainty and vague information. The sensitivity analysis shows the stability of the results.

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