Southeast Europe Journal of Soft Computing ISSN 2233 – 1859
Available online: http://scjournal.ius.edu.ba

Vol 10, No. 2, September 2021, pp. 01-12

Energy Usage and Environmental Risk Management in Residential and Commercial Sector using Fuzzy TOPSIS&Game Theory

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Article Info

Article history:

Article received on 26 November 2021

Received in revised form 29 November 2021

Keywords:

Residential Commercial Sector, Environment, Energy, Fuzzy TOPSIS, MCDM, Game Theory

ABSTRACT: Studies in recent years show that the process of energy planning has been a vital problem in the sense of sustainability, insufficient sources and increased industrial energy request. The commercial buildings are the main consumers of electricity, and play an important role in sustainable cities and societies. The effective energy management in these building is usually influenced by the social, technical, and environmental restraints. These restraints determine the standard of living and comfort. The purpose of this study is to determine the best energy management strategy, to formulate Game theory approach with different environmental strategies and develop various indicators related to energy efficiency and the comfort level of power components. Players which are the residential-commercial sector and environment try to ensure sustainability and comfort. In the recommended method, the closeness coefficient of each policy scenario figured out utilizing Fuzzy TOPSIS and different performance indices have been developed for energy use, taking into account the comfort level ranked. The equilibrium point (RCS2, ES5) is found to identify the most appropriate strategies by using payoff matrix. This result means that renewable energy usage and sustainability strategies are the ideal solutions for the RCS player the environment player, respectively.

1. INTRODUCTION

Energy has an important impact on the socioeconomic development of the country and society. And it is also used for different purposes, such as transportation, industry, and residences. Technological developments have increased the energy demand of every country and as a result, in the near future, energy will be one of the most strategic sectors in terms of the development and progress of countries in the world. As we all know, energy is a principal part of any strategy for economic growth and improving life quality [1]. Energy efficiency can be defined as the effective use of energy without compromising living conditions. In addition, the purpose of the energy management system is to improve energy efficiency. The energy consumption must be minimized without destroying social welfare or economic development, nor reducing quality or performance. As the population grows and living standards improve, energy demand is increasing exponentially, and efforts are made to reconstruct energy conservation opportunities. Therefore, when any organization becomes more cost-competitive in an open market, energy efficiency is always the top priority [2].

Currently, energy costs are increasing at an alarming rate, and interest in environmental responsibility is unprecedentedly high. Newly, various entities have carried out several surveys and found that commercial buildings have 10%-30% energy saving potential. In addition, they account for a large proportion of global energy consumption, with an average of 30%, accounting for one-third of related carbon dioxide emissions. Therefore, when optimizing a sustainable environment, these issues need to be considered to manage commercial energy demand [3], [4].

Energy management and efficiency are the basis for determining national energy policy parameters. Energy management system is a well-organized discipline that is configured according to the efficiency of energy use without reducing output or sacrificing product quality. The energy management system includes five basic steps: review the present state, observe and understand, determine, implement, evaluate and enhance. Within the scope of the country's energy policy application, individual users, apartment and site management, and municipalities are responsible for implementing these steps in RCS. Turkey's energy situation is characterized by its heavy dependence on imported fossil fuels, low energy efficiency and rapid rise in carbon dioxide emissions. Therefore, environmental and energy security risks are increasing rapidly, and this situation is clearly unsustainable. At present, the world and Turkey are facing severe environmental and energy security challenges, and a wise and comprehensive energy policy is required. Turkish policymakers are striving to establish a safe, environmentally friendly and sustainable energy policy in parallel with contemporary global energy policies [5].

Energy use in the residential commercial sector (RCS) is the cornerstone of the sustainability of social life. Satisfying basic human needs can ensure the sustainability of social life. RCS consumes 35% to 40% of the total energy and the share of energy usage under the RCS model is as: space heating 35-45%, water heating 25-30%, cooking 8-12%, electrical appliances 15%. -20% [6], [7]. The effective use of energy and energy saving methods are mostly cheap and easy to apply. Compared with the cost caused by the environmental damage of RCS, it will affect the environmental performance of RCS. The high price of energy inputs, minimizing costs and providing high-quality structures are inevitable for the building industry. Therefore, the energy management system is a key element to increase profitability and productivity by improving energy efficiency.

From the perspective of GT, the research on the multi-criteria decision-making process has attracted widespread attention, such as Min et. al. regarding GT-based power generation maintenance plan (PGMS) in the electricity market [8]. In the study, the author proposes a new method to solve PGMS problem in the electricity market. The PGMS process of the company (Gencos) is designed as a non-cooperative dynamic game, and the optimal strategy configuration of Gencos depends on the Nash equilibrium. The research developed by Lise et al. introduced a static calculation GT model for the Northwest European electricity market and environment. According to this research, explanatory results of opening the European electricity market are given to prove the types of economic and environmental results that the model can produce [9]. Another study was constructed a mixed integer linear programming (MILP) model, which integrates the optimization of energy system and revenue distribution schemes of the building's distributed heating network that the minimum annual total cost of the distributed energy network, generator set configuration, optimal operation strategy and heating pipeline layout can be determined [10].

Recently, the use of artificial intelligence (AI) technology has also increased. The main reason for this increase is that AI has produced multiple solutions that can be effectively applied. In addition, artificial intelligence can be effectively used in decision-making processes and future plans. Competition, uncertainty, determination of effective parameters, formulation of strategies and evaluation of these unknown factors are important factors for predicting and planning the future and generating policies. Many studies related to the application of multi-criteria and multi-objective strategies in the energy sector have been conducted ([11], [12], [13], [14], [15]). Wei et. al. studied the fuzzy comprehensive assessment of district seven heating systems which were analyzed using fuzzy methods. A small number of dimensions are introduced into the calculation; economic, environmental and energy technology factors are comprehensively considered; and the final goodness value is obtained

[16]. Kucukali et. al. studied Turkey's short-term annual total electricity demand with Fuzzy logic. The model they proposed made good estimations and captured the dynamic behaviour of the system from 1970 to 2014 [17]. Altintas et. al. introduced Fuzzy TOPSIS and MCDM analysis for determining a model that explain which the energy strategies using by electric production sector and environment is proper by using [18]. Shakouri et. al. established a simple but appropriate top-down model to foresee the energy demand of Iranian RCS.

In this study, the decision-making process of RCS and the environment and energy management were examined through the GT method [19].

This study aims that determine the best energy management strategies according to RCS sector taking into consideration environment by using Fuzzy TOPSIS and Game Theory. We have two players: RCS and environment. Although the players' goals are conflicting, each players are trying to provide the best strategy in energy policy management. The results presented are related to the energy type, energy efficiency, energy management and sustainable environment of RCS.

2. MATERIALS AND METHODS

In the socioeconomic structure, the assesment of strategies&standards is a highly difficult phase, which has nothing to do with certain judgments and needs to systematically integrate the thinking of decision makers [20]. In an uncertain competitive environment where participants have conflicting goals and strategies, many analysis methods are used in MCDM process to formulate strategies and provide the best suggestions. Deciding which strategy to use is a difficult process and may vary from department to department or according to the ideas of experts and academicians. We decided to use six main parameters: cost, ease of use, efficiency, climate change, pollution and ozone depletion.

In order to construct a correct decision-making process, a hybrid method has been enhanced by integrating expert opinions and various analysis methods. Fuzzy set theory and GT are AI technologies that are widely used in these processes.

Game is a formal description of the strategic situation, while GT is a formal decision making study, in which case many players must make preferences that may affect the others' interests [21]. GT is a very useful tool for checking interactive decision-making, where the results of each player depend on the results of other players, which in turn depend on their strategies. GT is not a method of obtaining solutions to problems that are otherwise unavailable, but strategic thinking is needed in decision-making aimed at solving such problems and helps to see possible outcomes in all situations. In particular, the GT formula introduces time into the decision-making process [22]. In this section, the establishment of GT approach and constitution of Nash equilibrium are given and also Fuzzy TOPSIS method & MCDM with Fuzzy data is performed.

The recommended model consists of two players: the RCS and the environment. Here in, there are four strategies and five strategies for RCS player and environment player, respectively and also there are common eight criteria, as shown in Table 1.

Table 1. Strategies and common criterias

Strategies of RCS		**Strategies of Environment**	
RCS1	Fossil Fuel Usage	**ES1**	Protection Reflex
RCS2	Renewable Energy Usage	**ES2**	Ecological Balance Sheet
RCS3	Energy Recycling	**ES3**	Natural Life Threat
RCS4	Nuclear Energy Usage	**ES4**	Uncertainty
		ES5	Sustainability
Common Criteria			
C1	Productivity	**C5**	Climate Change
C2	Cost	**C6**	Ozone Depletion
C3	User Friendliness	**C7**	Global Warming
C4	Pollution	**C8**	Electricity-Production Resource

After determining the RCS and environmental assessment and analysis strategies and criteria, we need expert opinions. In place of the opinions of experts, we formed a decision-making group consisting of ten academicians, who are experts in these disciplines and members of different universities with different academic positions. Ask experts to fill out a questionnaire. Use this questionnaire to determine the scale of linguistic variables to show the importance an their impact on each criteria and strategies. Linguistic variables are variables and the while linguistic terms which reflect uncertainty, unaccurateness and fuzziness of decision makers are used for its values [23].

Nash equilibrium is a pair of strategies but in this logic, no player can unilaterally change its strategy and achieve better results. If we want to find Nash equilibrium, the items steps have been done: Suppose that you are one of the players and your opponent chooses a specific action, determine the best strategy according to the opponent's actions in the payoff matrix. All steps must be done for each player, and the underlined entry give the Nash equilibrium. If there are multiple points (for example, two) and players choose a different one, there is no guarantee that they will fall into another equilibrium point. In such a case, if the number of equilibrium points is more than one, then Pareto optimality can be used for elimination.

Fuzzy TOPSIS can be used to measure multiple strategies based on selected criteria. This is a very useful method that can help you objectively and systematically evaluate strategies based on multiple criteria [24]. To find the best alternative, closest to the fuzzy positive ideal solution (FNIS) and farthest from the fuzzy negative ideal solution (FNIS) must be chosen. FPIS (FNIS) maximizes the benefit (cost) standard and minimizes the cost (profit) standard [25]. In this section, a group of MCDM algorithm used by Chen et. al. in 1992 is utilized [26].

In many applications of this method, Triangular Fuzzy Numbers (TFNs) is preferable because of its computational simplicity in facilitating representation and information processing in fuzzy systems [24].

Table 2 lists the membership function of each player and its fuzzy number. The range of the membership function is calculated through some statistical data. In other words, these fuzzy numbers are constructed through statistical calculations, and the scales are determined as shown in Table 2. For each decision maker, the questionnaire will ask the smallest, largest and average value of its importance. Taking into account the opinions of all decision makers, the degree of importance value is aggregated through a statistical model, and a scale of all linguistic variables is obtained.

Table 2. Fuzzy linguistic terms and numbers for criterias and strategies

Importance		Fuzzy Numbers
Very Important (VI)	Very Good (VG)	(0.830,1.000,1.000)
Important (I)	Good (G)	(0.650,0.830,0.8525)
Medium Important (MI)	Medium Good (MG)	(0.555,0.650,0.830)
Normal (N)	Medium (M)	(0.3725,0.555,0.650)
Medium Unimportant (MUI)	Medium Bad (MB)	(0.240,0.3725,0.555)
Unimportant (UI)	Bad (B)	(0.175,0.240,0.3725)
No Importance (NI)	Very Bad (VB)	(0.000,0.000,0.240)

Table 3. illustrates the decision makers' responses according to linguistic variables for each player.

Table 3. Decision Makers' evaluations in terms of each criteria of RCS and environment

RCS	DM1	DM2	DM3	DM4	DM5	DM6	DM7	DM8	DM9	DM10
C1	**V I**	**V I**	**V I**	**I**	**I**	**V I**	**N**	**I**	**V I**	**V I**
C2	**I**	**MI**	**V I**	**V I**	**V I**	**V I**	**I**	**V I**	**V I**	**V I**
C3	**I**	**V I**	**I**	**I**	**V I**	**V I**	MUI	**I**	**V I**	**V I**
C4	**V I**	**V I**	**I**	**MI**	**V I**	**I**	**I**	**I**	**V I**	**M I**
C5	**V I**	**N**	**MI**	**N**	**V I**	**V I**	**MI**	**I**	**V I**	**M I**
C6	**V I**	**I**	**MI**	**N**	**V I**	**V I**	**MI**	**I**	**V I**	**M I**
C7	**V I**	**V I**	**MI**	**N**	**V I**	**V I**	**MI**	**I**	**V I**	**M I**
C8	**I**	**V I**	**I**	**MI**	**V I**	**V I**	**I**	**V I**	**V I**	**V I**
Environment	**DM1**	**DM2**	**DM3**	**DM4**	**DM5**	**DM6**	**DM7**	**DM8**	**DM9**	**DM10**
C1	**VG**	**VG**	**G**	**G**	**G**	**VG**	**VG**	**G**	**VG**	**G**
C2	**G**	**G**	**M**	**MG**	**G**	**G**	**MG**	**G**	**G**	**G**
C3	**G**	**G**	**MG**	**M**	**VG**	**MG**	**VG**	**VG**	**G**	**V G**
C4	**VG**	**VG**	**VG**	**VG**	**VG**	**VG**	**G**	**G**	**VG**	**G**
C5	**VG**	**VG**	**VG**	**VG**	**VG**	**VG**	**G**	**G**	**VG**	**G**
C6	**VG**	**VG**	**VG**	**VG**	**VG**	**VG**	**MG**	**G**	**VG**	**G**
C7	**VG**	**VG**	**VG**	**VG**	**VG**	**VG**	**VG**	**G**	**VG**	**G**
C8	**G**	**VG**	**MG**	**M**	**MG**	**MG**	**MG**	**G**	**VG**	**V G**

Suppose that there are K member in the decision group. If the fuzzy rating and importance weight of the k^th^ decision maker about the i^th^ alternative on the j^th^ criteria (eight criteria in our study) are denoted by $\tilde{x}_{ij}^{k} = (a_{ij}^{k}, b_{ij}^{k}, c_{ij}^{k})$ and $\tilde{w}_{ij}^{k} =$

$(w_{j1}^k, w_{j2}^k, w_{j3}^k)$, respectively, where $i = 1, 2, \dots, m$ and $j = 1, 2, \dots, n$, then the fuzzy ratings $\breve{x}_{ij}^k$ of alternatives (i) with respect to each criteria j are given by $\breve{x}_{ij} = (a_{ij}, b_{ij}, c_{ij})$ such that a_{ij} is the minimum, b_{ij} is the weighted average and c_{ij} is the maximum of their values, as in equation (1).

$$a_{ij} = min_k\{a_{ij}^k\}, b_{ij} = \frac{1}{K}\sum_{k=1}^{K} b_{ij}^k \ and\ c_{ij} = max_k\{c_{ij}^k\} \quad (1)$$

The aggregated fuzzy weights $\breve{w}_{ij}$ of each criteria are calculated as $\breve{w}_j^k = (w_{j1}, w_{j2}, w_{j3})$ such that w_{j1} is the minimum, w_{j2} is the weighted average and w_{j3} is the maximum of their value in equation (2).

$$w_{j1} = min_k\{w_{jk1}\}, w_{j2} = \frac{1}{K}\sum_{k=1}^{K} w_{jk2} \ and\ w_{j3} = max_k\{w_{jk3}\} \quad (2)$$

Fuzzy MCDM problems can be stated in equations (3) and (4).

$$D = \begin{matrix} \cdots & C_1 & C_2 & \cdots & C_n \\ A_1 & \breve{x}_{11} & \breve{x}_{12} & \cdots & \breve{x}_{1n} \\ A_2 & \breve{x}_{21} & \breve{x}_{22} & \cdots & \breve{x}_{2n} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ A_m & \breve{x}_{m1} & \breve{x}_{m2} & \cdots & \breve{x}_{mn} \end{matrix} \quad (3)$$

$$\breve{W} = (\breve{w}_1, \breve{w}_2, \dots, \breve{w}_n) \quad (4)$$

where $\breve{x}_{ij}$ for all i, j and $\breve{w}_j$ $i = 1, 2, \dots, m$ and $j = 1,2, \dots, n$ are linguistic variables that can be described by triangular fuzzy numbers; $\breve{x}_{ij} = (a_{ij}, b_{ij}, c_{ij})$ and $\breve{w}_j = (w_{j1}, w_{j2}, w_{j3})$.

The correspondent fuzzy numbers from the perspective of each player according to each criterion are given in Table 4(A) and Table 4(B).

Table 4(A). The fuzzy numbers for RCS

	C1	C2	C3	C4
DM1	(0.830, 1.000, 1.000)	(0.650, 0.830, 0.8525)	(0.650, 0.830, 0.8525)	(0.830, 1.000, 1.000)
DM2	(0.830, 1.000, 1.000)	(0.555, 0.650, 0.830)	(0.830, 1.000, 1.000)	(0.830, 1.000, 1.000)
DM3	(0.830, 1.000, 1.000)	(0.830, 1.000, 1.000)	(0.650, 0.830, 0.8525)	(0.650, 0.830, 0.8525)
DM4	(0.650, 0.830, 0.8525)	(0.830, 1.000, 1.000)	(0.650, 0.830, 0.8525)	(0.555, 0.650, 0.830)
DM5	(0.650, 0.830, 0.8525)	(0.830, 1.000, 1.000)	(0.830, 1.000, 1.000)	(0.830, 1.000, 1.000)
DM6	(0.830, 1.000, 1.000)	(0.830, 1.000, 1.000)	(0.830, 1.000, 1.000)	(0.650, 0.830, 0.8525)
DM7	(0.3725, 0.555, 0.650)	(0.650, 0.830, 0.8525)	(0.240, 0.3725, 0.555)	(0.650, 0.830, 0.8525)
DM8	(0.650, 0.830, 0.8525)	(0.830, 1.000, 1.000)	(0.650, 0.830, 0.8525)	(0.650, 0.830, 0.8525)
DM9	(0.830, 1.000, 1.000)	(0.830, 1.000, 1.000)	(0.830, 1.000, 1.000)	(0.830, 1.000, 1.000)
DM10	(0.830, 1.000, 1.000)	(0.830, 1.000, 1.000)	(0.830, 1.000, 1.000)	(0.555, 0.650, 0.830)
	C5	**C6**	**C7**	**C8**
DM1	(0.830, 1.000, 1.000)	(0.830, 1.000, 1.000)	(0.830, 1.000, 1.000)	(0.650, 0.830, 0.8525)
DM2	(0.3725, 0.555, 0.650)	(0.650, 0.830, 0.8525)	(0.830, 1.000, 1.000)	(0.830, 1.000, 1.000)
DM3	(0.555, 0.650, 0.830)	(0.555, 0.650, 0.830)	(0.555, 0.650, 0.830)	(0.650, 0.830, 0.8525)
DM4	(0.3725, 0.555, 0.650)	(0.3725, 0.555, 0.650)	(0.3725, 0.555, 0.650)	(0.555, 0.650, 0.830)
DM5	(0.830, 1.000, 1.000)	(0.830, 1.000, 1.000)	(0.830, 1.000, 1.000)	(0.830, 1.000, 1.000)
DM6	(0.830, 1.000, 1.000)	(0.830, 1.000, 1.000)	(0.830, 1.000, 1.000)	(0.830, 1.000, 1.000)
DM7	(0.555, 0.650, 0.830)	(0.555, 0.650, 0.830)	(0.555, 0.650, 0.830)	(0.650, 0.830, 0.8525)
DM8	(0.650, 0.830, 0.8525)	(0.650, 0.830, 0.8525)	(0.650, 0.830, 0.8525)	(0.830, 1.000, 1.000)

DM9	(0.830, 1.000, 1.000)	(0.830, 1.000, 1.000)	(0.830, 1.000, 1.000)	(0.830, 1.000, 1.000)
DM10	(0.555, 0.650, 0.830)	(0.555, 0.650, 0.830)	(0.555, 0.650, 0.830)	(0.830, 1.000, 1.000)

Table 4(B). The fuzzy numbers for Environment

	C1	**C2**	**C3**	**C4**
DM1	(0.830, 1.000, 1.000)	(0.650, 0.830, 0.8525)	(0.650, 0.830, 0.8525)	(0.830, 1.000, 1.000)
DM2	(0.830, 1.000, 1.000)	(0.650, 0.830, 0.8525)	(0.650, 0.830, 0.8525)	(0.830, 1.000, 1.000)
DM3	(0.650, 0.830, 0.8525)	(0.3725, 0.555, 0.650)	(0.555, 0.650, 0.830)	(0.830, 1.000, 1.000)
DM4	(0.650, 0.830, 0.8525)	(0.555, 0.650, 0.830)	(0.3725, 0.555, 0.650)	(0.830, 1.000, 1.000)
DM5	(0.650, 0.830, 0.8525)	(0.650, 0.830, 0.8525)	(0.830, 1.000, 1.000)	(0.830, 1.000, 1.000)
DM6	(0.830, 1.000, 1.000)	(0.650, 0.830, 0.8525)	(0.555, 0.650, 0.830)	(0.830, 1.000, 1.000)
DM7	(0.830, 1.000, 1.000)	(0.555, 0.650, 0.830)	(0.830, 1.000, 1.000)	(0.650, 0.830, 0.8525)
DM8	(0.650, 0.830, 0.8525)	(0.650, 0.830, 0.8525)	(0.830, 1.000, 1.000)	(0.650, 0.830, 0.8525)
DM9	(0.830, 1.000, 1.000)	(0.650, 0.830, 0.8525)	(0.650, 0.830, 0.8525)	(0.830, 1.000, 1.000)
DM10	(0.650, 0.830, 0.8525)	(0.650, 0.8300.8525)	(0.830, 1.000, 1.000)	(0.650, 0.830, 0.8525)
	C5	**C6**	**C7**	**C8**
DM1	(0.830, 1.000, 1.000)	(0.830, 1.000, 1.000)	(0.830, 1.000, 1.000)	(0.650, 0.830, 0.8525)
DM2	(0.830, 1.000, 1.000)	(0.830, 1.000, 1.000)	(0.830, 1.000, 1.000)	(0.830, 1.000, 1.000)
DM3	(0.830, 1.000, 1.000)	(0.830, 1.000, 1.000)	(0.830, 1.000, 1.000)	(0.555, 0.650, 0.830)
DM4	(0.830, 1.000, 1.000)	(0.830, 1.000, 1.000)	(0.830, 1.000, 1.000)	(0.3725, 0.555, 0.650)
DM5	(0.830, 1.000, 1.000)	(0.830, 1.000, 1.000)	(0.830, 1.000, 1.000)	(0.555, 0.650, 0.830)
DM6	(0.830, 1.000, 1.000)	(0.830, 1.000, 1.000)	(0.830, 1.000, 1.000)	(0.555, 0.650, 0.830)
DM7	(0.650, 0.830, 0.8525)	(0.555, 0.650, 0.830)	(0.830, 1.000, 1.000)	(0.555, 0.650, 0.830)
DM8	(0.650, 0.830, 0.8525)	(0.650, 0.830, 0.8525)	(0.650, 0.830, 0.8525)	(0.650, 0.830, 0.8525)
DM9	(0.830, 1.000, 1.000)	(0.830, 1.000, 1.000)	(0.830, 1.000, 1.000)	(0.830, 1.000, 1.000)
DM10	(0.650, 0.830, 0.8525)	(0.650, 0.830, 0.8525)	(0.650, 0.830, 0.8525)	(0.830, 1.000, 1.000)

After using the linquistic variable evaluation criteria, with the help of equations (1) and (2), we obtain a normalized fuzzy weight matrix, which represents the importance of the evaluation criteria. Table 5 give the TFN form and the weights. It can be easily seen that criteria's importance are different. Cost (C2) is the most important criteria with the defuzzification value of 0.82867 for RCS and followed by Domestic resource usage (C8) (0.823) and pollution (C4) (0.80567) criterias.

Table 5. Fuzzy weight matrix

	RCS				**Environment**			
Criteria	**a**	**b**	**c**	**weight**	**A**	**B**	**C**	**weight**
C1	0.3725	0.9045	1.000	0.759	0.650	0.915	1.000	0.855
C2	0.555	0.931	1.000	0.82867	0.3725	0.7665	0.8525	0.66383

C3	0.240	0.86925	1.000	0.7031	0.3725	0.8345	1.000	0.73567
C4	0.555	0.862	1.000	0.80567	0.650	0.949	1.000	0.866
C5	0.3725	0.789	1.000	0.7205	0.650	0.949	1.000	0.866
C6	0.3725	0.8165	1.000	0.72967	0.555	0.931	1.000	0.829
C7	0.3725	0.8335	1.000	0.73533	0.650	0.966	1.000	0.872
C8	0.555	0.914	1.000	0.823	0.3725	0.7815	1.000	0.718

To transform various criteria scales into a comparable scale, the linear scale transformation is used and then the normalized fuzzy decision matrix can be represented by $\check{R}$, which is a $m \times n$ matrix in equation (5).

$$\check{R} = \left[\check{r}_{ij}\right]_{m\times n} \quad (5)$$

where $i = 1, 2, \ldots, m$ and $j = 1, 2, \ldots, n$.

$$\check{r}_{ij} = \left(\frac{a_{ij}}{c_j^*}, \frac{b_{ij}}{c_j^*}, \frac{c_{ij}}{c_j^*}\right), c_j^* = max_i\{c_{ij}\} \quad \text{(Benefit)} \quad (6)$$

$$\check{r}_{ij} = \left(\frac{\bar{a}_j}{c_{ij}}, \frac{\bar{a}_j}{b_{ij}}, \frac{\bar{a}_j}{a_{ij}}\right), \bar{a}_j = min_i\{a_{ij}\} \quad \text{(Cost)} \quad (7)$$

By multiplying the weights of the evaluation criteria and the normalized fuzzy decision matrix, the weighted normalized fuzzy decision matrix $\check{V}$ is obtained in equation (8).

$$\check{V} = \left[\check{v}_{ij}\right]_{m\times n} = \left[\check{r}_{ij}\right]_{m\times n} \times \check{w}_j, i = 1, 2, \ldots, m \text{ and } j = 1, 2, \ldots, n. \quad (8)$$

Now, we analyze the strategy compared with the competitor's strategy. If we focus on the first strategy, Table 6 gives the evaluation of the RCS strategy based on C1.

Table 6. RCS’s evaluation according to C1 (ES1 Case)

	Linguistic variables				**Correspondent Fuzzy Numbers**			
C1	**RCS1**	**RCS2**	**RCS3**	**RCS4**	**RCS1**	**RCS2**	**RCS3**	**RCS4**
DM1	VI	VI	VI	VI	(0.830, 1.000, 1.000)	(0.830, 1.000, 1.000)	(0.830, 1.000, 1.000)	(0.830, 1.000, 1.000)
DM2	NI	I	I	UI	(0.000, 0.000, 0.240)	(0.650, 0.830, 0.8525)	(0.650, 0.830, 0.8525)	(0.175, 0.240, 0.3725)
DM3	VI	MUI	MI	I	(0.830, 1.000, 1.000)	(0.240, 0.3725, 0.555)	(0.555, 0.650, 0.830)	(0.650, 0.830, 0.8525)
DM4	I	MI	VI	I	(0.650, 0.830, 0.8525)	(0.555, 0.650, 0.830)	(0.830, 1.000, 1.000)	(0.650, 0.830, 0.8525)
DM5	MI	MI	I	VI	(0.555, 0.650, 0.830)	(0.555, 0.650, 0.830)	(0.650, 0.830, 0.8525)	(0.830, 1.000, 1.000)
DM6	UI	VI	VI	VI	(0.175, 0.240, 0.3725)	(0.830, 1.000, 1.000)	(0.830, 1.000, 1.000)	(0.830, 1.000, 1.000)
DM7	UI	MUI	MI	MI	(0.175, 0.240, 0.3725)	(0.240, 0.3725, 0.555)	(0.555, 0.650, 0.830)	(0.555, 0.650, 0.830)
DM8	MI	MI	I	VI	(0.555, 0.650, 0.830)	(0.555, 0.650, 0.830)	(0.650, 0.830, 0.8525)	(0.830, 1.000, 1.000)
DM9	MUI	MI	MI	UI	(0.240, 0.3725, 0.555)	(0.555, 0.650, 0.830)	(0.555, 0.650, 0.830)	(0.175, 0.240, 0.3725)
DM10	N	I	VI	UI	(0.3725, 0.555, 0.650)	(0.650, 0.830, 0.8525)	(0.830, 1.000, 1.000)	(0.175, 0.240, 0.3725)

The evaluation of RCS and environmental strategy is carried out separately according to each standard. Stated in other words, this methodology is applicable to all combinations of player’s strategies. Table 6 (ES1 Case) is only an example of this evaluation. Table 7 illustrates the (RCS’s strategies) fuzzy decision matrix of all of the criteria (ES1 Case). Again, the methodology is applied for all of the combinations.

Table 7. RCS's strategies fuzzy decision matrix: ES1 case

	C1	C2	C3	C4
RCS11	(0.000, 0.55375, 1.000)	(0.175, 0.41625, 0.8525)	(0.175, 0.593, 0.8525)	(0.000, 0.2585, 0.8525)
RCS21	(0.240, 0.7005, 1.000)	(0.175, 0.43775, 0.8525)	(0.240, 0.62975, 0.8525)	(0.240, 0.86925, 1.000)
RCS31	(0.555, 0.844, 1.000)	(0.000, 0.52175, 1.000)	(0.240, 0.66475, 1.000)	(0.555, 0.879, 1.000)
RCS41	(0.175, 0.703, 1.000)	(0.000, 0.3585, 0.8525)	(0.000, 0.49225, 0.8525)	(0.000, 0.5295, 1.000)
	C5	**C6**	**C7**	**C8**
RCS11	(0.000, 0.203, 0.8525)	(0.000, 0.24025, 0.8525)	(0.000, 0.22375, 0.8525)	(0.000, 0.572, 1.000)
RCS21	(0.240, 0.90325, 1.000)	(0.240, 0.90325, 1.000)	(0.240, 0.90325, 1.000)	(0.555, 0.881, 1.000)
RCS31	(0.3725, 0.8695, 1.000)	(0.3725, 0.8865, 1.000)	(0.555, 0.896, 1.000)	(0.555, 0.914, 1.000)
RCS41	(0.000, 0.67525, 1.000)	(0.000, 0.66575, 1.000)	(0.000, 0.64025, 1.000)	(0.000, 0.318, 1.000)

Table 8 illustrates (RCS's strategies) the normalized fuzzy decision matrix of all of the criteria (ES_1 Case). Again, methodology is applied to all other combinations.

Table 8. RCS's strategies normalized fuzzy decision matrix: ES1 case

	C1	C2	C3	C4
RCS11	(0.000, 0.55375, 1.000)	(0.175, 0.41625, 0.8525)	(0.175, 0.593, 0.8525)	(0.000, 0.2585, 0.8525)
RCS21	(0.240, 0.7005, 1.000)	(0.175, 0.43775, 0.8525)	(0.240, 0.62975, 0.8525)	(0.240, 0.86925, 1.000)
RCS31	(0.555, 0.844, 1.000)	(0.000, 0.52175, 1.000)	(0.240, 0.66475, 1.000)	(0.555, 0.879, 1.000)
RCS41	(0.175, 0.703, 1.000)	(0.000, 0.3585, 0.8525)	(0.000, 0.49225, 0.8525)	(0.000, 0.5295, 1.000)
	C5	**C6**	**C7**	**C8**
RCS11	(0.000, 0.203, 0.8525)	(0.000, 0.24025, 0.8525)	(0.000, 0.22375, 0.8525)	(0.000, 0.572, 1.000)
RCS21	(0.240, 0.90325, 1.000)	(0.240, 0.90325, 1.000)	(0.240, 0.90325, 1.000)	(0.555, 0.881, 1.000)
RCS31	(0.3725, 0.8695, 1.000)	(0.3725, 0.8865, 1.000)	(0.555, 0.896, 1.000)	(0.555, 0.914, 1.000)
RCS41	(0.000, 0.67525, 1.000)	(0.000, 0.66575, 1.000)	(0.000, 0.64025, 1.000)	(0.000, 0.318, 1.000)

It can be defined that The FPIS and FNIS of the alternatives are shown as equation (9) and (10).

$$A^{+} = (\check{v}_1^{+}, \check{v}_2^{+}, \dots, \check{v}_n^{+}), \quad \text{where} \quad \check{v}_j^{+} = max_i\{v_{ij3}\}$$

$$i = 1, 2, \ \dots, m \text{ and } j = 1, 2, \dots, n. \qquad (9)$$

$$A^{-} = (\check{v}_1^{-}, \check{v}_2^{-}, \dots, \check{v}_n^{-}), \quad \text{where} \quad \check{v}_j^{-} = min_i\{v_{ij1}\}$$

$$i = 1, 2, \ \dots, m \text{ and } j = 1, 2, \dots, n. \qquad (10)$$

Applying equations (11) and (12), the distance of each weighted alternative to FPIS and FNIS can be obtained. Table 9 shows RCS' ideal solutions for ES1.

Table 9. RCS' ideal solutions: ES1 case

	C1	C2	C3	C4	C5	C6	C7	C8
Positive	(1, 1, 1)	(1, 1, 1)	(1, 1, 1)	(1, 1, 1)	(1, 1, 1)	(1, 1, 1)	(1, 1, 1)	(1, 1, 1)
Negative	(0, 0, 0)	(0, 0, 0)	(0, 0, 0)	(0, 0, 0)	(0, 0, 0)	(0, 0, 0)	(0, 0, 0)	(0, 0, 0)

$$d_i^{+} = \sum_{j=1}^{n} d_v\left(\check{v}_{ij}, \check{v}_j^{+}\right) \quad i = 1, 2, \dots m \qquad (11)$$

$$d_i^{-} = \sum_{j=1}^{n} d_v\left(\check{v}_{ij}, \check{v}_j^{-}\right) \quad i = 1, 2, \dots m \qquad (12)$$

where $d_v(a,b)$ is the distance measurement between the two fuzzy numbers a and b.

RCS' ideal solutions are given according to the distances from FPIS and FNIS are given in Table 10, 11, respectively.

Table 10. The distances from FPIS

	C1	C2	C3	C4	C5	C6	C7	C8	
RCS11	0.645273	0.635623	0.625644	0.73615	0.758743	0.745635	0.749119	0.639716	5.535902
RCS21	0.566698	0.629266	0.609566	0.52096	0.551288	0.547144	0.544754	0.415033	4.38471
RCS31	0.477926	0.649219	0.596195	0.423293	0.529246	0.522176	0.48075	0.410656	4.089462
RCS41	0.579214	0.698959	0.670588	0.657132	0.637261	0.634644	0.637046	0.707855	5.2227

Table 11. The distances from FNIS

	C1	C2	C3	C4	C5	C6	C7	C8	
RCS11	0.645722	0.543559	0.575682	0.508727	0.500803	0.505053	0.503831	0.651493	4.434871
RCS21	0.68543	0.548418	0.58587	0.725529	0.710839	0.719235	0.724521	0.762294	5.462137
RCS31	0.736098	0.64186	0.667634	0.745876	0.704723	0.717213	0.730407	0.773041	5.716851
RCS41	0.685217	0.528568	0.55071	0.634646	0.654177	0.657135	0.654416	0.601242	4.966113

The closeness coefficient CC_i of the i^{th} alternative represents the distances to the FPIS and the FNIS and calculated by using equation (13).

$$CC_i = \frac{d_i^-}{d_i^- + d_i^+} \quad i = 1, 2, \dots, m \tag{13}$$

According to their relative closeness to the ideal solution, the alternatives are sorted. The higher value of CC_i, the better the alternative method.

If we want to evaluate Table 12(A) and Table 12(B), suppose that environment plays its 3rd, 4th and 5th, RCS2 will be the best strategy for Residential and Commercial Sector. From the perspective of environment, if the Residential and Commercial sector plays its 3rd, 4th and 5th strategies, environment will play its first strategy with CC values of 0.608841, 0.557774, and 0.484413.

Table 12(A). RCS's strategies' CCs for all ESs

		Environment (Player 2)									
		ES1		ES2		ES3		ES4		ES5	
		IC	Rank	IC	Rank	IC	Rank	IC	Rank	IC	Rank
RCS (Player 1)	RCS1	0.444787	1	0.433757	1	0.435725	1	0.446815	1	0.432765	1
	RCS2	0.554709	3	0.562293	3	0.567466	4	0.564188	4	0.57129	4
	RCS3	0.582977	4	0.569723	4	0.552281	3	0.557672	3	0.559062	3

RCS4	0.487408	2	0.489334	2	0.477954	2	0.475877	2	0.484352	2

Table 12(B). Environment strategies' CCs for all RCSs

		RCS (Player1)							
		RCS1		RCS2		RCS3		RCS4	
		IC	Rank	IC	Rank	IC	Rank	IC	Rank
Environment (Player 2)	ES11	0.426769	2	0.537668	1	0.541202	1	0.461229	1
	ES21	0.429012	4	0.597585	3	0.563646	5	0.466353	2
	ES31	0.431045	5	0.604637	4	0.545658	2	0.48403	4
	ES41	0.428937	3	0.553762	2	0.549266	3	0.466575	3
	ES51	0.420371	1	0.608841	5	0.557774	4	0.484413	5

To construct the Nash equilibrium point of the game, the first step is to find the best response of the player's RCS. In other words, for each possible strategy of the environmental player, we determine the best response of the RCS. For example, if the environment player prefers ES1, then the best response of RCS is to play RCS3. We emphasize the results of this strategy, as shown in Table 13. Next, we perform the same operation on all strategies of environmental player. The second step is to find the best response for environmental player. Nash equilibrium is defined as a pair of strategies in which all players respond best to the strategies of other player at the same time. This is equivalent to saying that if two outcomes are emphasized, a pair of strategies in the game is in equilibrium. The equilibrium point is (RCS2, ES5).

Table 13. Payoff matrix

	ES1	ES2	ES3	ES4	ES5
R C S 1	(0.444787, 0.426769)	(0.433757, 0.429012)	(0.435725, 0.431045)	(0.446815, 0.428937)	(0.432765, 0.420371)
R C S 2	(0.554709, 0.537668)	(0.562293, 0.597585)	(0.567466, 0.604637)	(0.564188, 0.553762)	(0.57129, 0.608841)
R C S 3	(0.582977, 0.541202)	(0.569723, 0.563646)	(0.552281, 0.545658)	(0.557672, 0.549266)	(0.559062, 0.557774)
R C S 4	(0.487408, 0.461229)	(0.489334, 0.466353)	(0.477954, 0.48403)	(0.475877, 0.466575)	(0.484352, 0.484413)

3. CONCLUSION

This research determines energy and environmental policies through the decision-making process of energy management. The methods include hybrid methods, including Fuzzy TOPSIS and GT analysis methods. The RCS and the environment can be seen as opponents, they use different methods to achieve their goals and common criteria. By evaluating all the key factors, the best profit strategy for players can be found. The result of the game pay-off matrix shows that the Nash equilibrium [(RCS2, ES5) , (0.57129, 0.608841)]. This result means that the RCSs' use of energy triggers the environment's strategy. First and foremost, the environment creates its protection reflex. An acceptable way to achieve the best balance point between the environment and the residential commercial sector is to use renewable energy and habitual reflection to protect the balance of the environment. Each fuel type has different effects on the environment that is used by the residential and commercial sector. Choosing energy resources, effectively using energy and minimizing the residential commercial sector will be effective ways to improve sustainability. Global warming, climate change, and pollution are caused by leaving the balance point.

The correct analysis and MCDM process is an important issue for reducing energy costs and constructing and protecting a sustainable environment. This method will help to systematically evaluate all factors. By expanding the script, this method can be used with many players to plan future energy policies. Energy-intensive industries can benefit from its policy management from this approach.

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