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Research paper

CO_2 emissions integrated fuzzy model: A case of seven emerging economies

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ABSTRACT

This paper proposes a new model to study carbon emission issues in seven emerging (E7) economies (China, Mexico, Turkey, Russia, Brazil, Indonesia and India). It employs weighted Quantum Spherical fuzzy DEMATEL model with golden cut using 18 years data, which was ranked for carbon emission evaluation via Quantum Spherical fuzzy TOPSIS method. The data includes macroeconomic variables for the period from 2003 to 2020. Paper observes that (i) CO_2 emissions from fossil fuels is the most significant factor distressing the carbon emission problem of E7 economies. It suggests that these countries need to explore alternatives to fossil fuels to handle the carbon emission problem. (ii) The CO_2 emission problem in energy production can be minimized by renewable energy and nuclear energy, suggesting some financial incentives to the investors in energy explorations areas. (iii) It is also observed that due to high volatility of CO_2 emissions, a negative market factor exists in consumer sentiment in consumption of oil and petroleum products. This can be compensated via energy consumption fiscal policy in taxation and encourage of extractive industries and producers of petroleum products, as well as the uneven spatial development to have a significant impact on the reduction of CO_2 emission. The paper gives recommendation that E7 countries need to find alternatives to fossil fuels in order to deal effectively with the carbon emission problem.

1. Introduction

The objective is to shed the light on projects that should be prioritized by all groups that are involved in the energy system of China and E7 countries based on the discussions with the participants of this research. The main research question is that global CO_2 emissions from fossil fuels is the most significant factor regarding the carbon emission problem of E7 economies. This paper also fills the gap in economic modeling and energy research: E7 countries ranking for carbon emission evaluation with the help of Quantum Spherical fuzzy TOPSIS and ranking of successful E7 countries to manage carbon emission problem. The energy cooperation between E7 economies calls upon the analysis of recent energy production and consumption of CO_2 emissions in Emerging Economies. Therefore, it is significant to introduce management of energy resources.

Carbon emission issues are a significant concern in the seven emerging (E7) economies, including China, India, Indonesia, Russia, Mexico, Brazil, and Turkey. These countries are home to almost half of the world's population and account for more than half of global economic growth. While economic growth is necessary for development, it has resulted in increased carbon emissions, leading to environmental degradation and climate change. To address this issue, these countries are adopting the green economy paradigm, which aims to use resources rationally and reduce carbon emissions. Studies have shown that there is cointegration between energy consumption, economic growth, and CO_2 emissions in Brazil, India, and Russia, but not in Indonesia (Romero-Ávila, 2008; Karakaya et al., 2017; Klenert et al., 2018).

The paper uses the macroeconomic variables for the period from 2003 to 2020 because this period is optimal one for Integrated Fuzzy Model:

Global CO_2 emissions from fossil fuels,
Annual change in CO_2 emissions,

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Consumption-based (trade-adjusted) emissions,
Decoupling CO_2 emissions from economic growth,
GDP in current prices.

Much research is included the questions of analysis of CO_2 emissions: in South American countries (Robalino-López et al., 2016), in Asia (Rodríguez and Pena-Boquete, 2017), in industrialized countries (Awaworyi Churchill et al., 2018; Bhattacharya et al., 2020), in emerging economies (Awaworyi Churchill et al., 2020; Bhattacharya et al., 2018; Parker and Liddle, 2017). But these papers do not analyze CO_2 emissions in Emerging Economies for the period of 2003–2022. They believe that growing energy demand in E7 economies comes mostly from heavy industry and infrastructure sectors. They also attempt to show that individual consumption matters what is also proved by International Energy Agency.

The research purposes were identified within the development study. Development study stands for the 'development processes and structures in particular parts of the world. There are no limits of social disciplines that fall with the development research. Therefore, politics as a social science suit to the development research. Energy development consists of actors, structures and dynamics. Development studies is closely related to the historical knowledge. The core focus of the research is on E7 economies energy cooperation and on CO_2 emissions problem.

The high volatility of CO_2 emissions has created a negative market factor that affects consumer sentiment towards the consumption of oil and petroleum products. This is due to the increased awareness and concern about the impact of fossil fuels on the environment, particularly with regards to climate change. Consumers are now more likely to seek out alternatives to traditional oil and gas products, such as renewable energy sources and electric vehicles. As a result, companies in the oil and gas industry are facing increasing pressure to adapt to these changing consumer preferences and invest in cleaner, more sustainable technologies.

The main novelty of this study is to identify the most efficient and effective strategies to minimize carbon emission with an original methodology. On the other hand, it is also possible to mention some superiorities of the proposed fuzzy decision-making model by comparing with the previous ones. Firstly, in this framework, a hybrid decision-making model is created by using different techniques in both stages. In other words, criteria weights are not assumed as equal. This situation has a positive impact on the objectivity of the results. Another important superiority of the proposed model is considering Spherical fuzzy sets. Because they include both membership, non-membership and hesitancy, it can be possible to perform more effective analysis. This issue helps to reach more reliable results. DEMATEL methodology provides opportunity both to weight criteria and make causality analysis among the items. This situation is accepted as a significant advantage of this approach in comparison with other similar decision-making approaches.

This paper fills the gap in research of carbon emission in E7 economies pointed in the research (Parker and Bhatti, 2020; Tsagkanos and Siriopoulos, 2015; Naeem et al., 2021; Tsagkanos et al., 2022) and investigate the connectedness with carbon emissions examining asymmetric adjustment behavior. Moreover, the main evaluation is made by using fuzzy decision-making methodology. Within this context, a new model is suggested that has three different stages. Firstly, quantum mass function with golden ratios makes two quantum spherical fuzzy sets. Secondly, five different criteria are selected with the help of a detailed literature review. Quantum Spherical fuzzy DEMATEL with golden cut is used for measuring the relative importance of the criteria for the carbon emissions. In the third stage, E7 countries are ranked for carbon emission evaluation with the help of Quantum Spherical fuzzy TOPSIS. With the help of the analysis results, it can be possible to generate appropriate strategies for E7 economies to minimize carbon emission problem.

The paper has five sections. Literature review is the second part. The data and methods are explained in the third part. The results are in the fourth part. The discussions are shared in the fifth part. The sixth part is conclusions.

2. Literature review

These consequences such as high level of air pollution and energy dependency have made the E7 economies government reconsider the current energy policy and build a new energy system. E7 economies recent economic growth has been based on fundamental economic forces such as capital flow to the country in the form of foreign investments and a growing production of outputs that is reflected in export. To develop energy efficiency, E7 economies should prepare the fundamental basic of laws and regulations (Chiemchaisri et al. 2012; Gardner et al. 1993; Gliske et al., 2020; Jin et al., 2020).

Another study was introduced by the experts who found that carbon emissions in E7 economies analysis cannot be based only on correlation analysis but also on regression. At the end of the study, they highlighted the importance of advanced technologies. Furthermore, technological developments should be accompanied by the energy saving policies. Over the past years, E7 economies have fully demonstrated several important relations between GDP indicator and growing energy consumption, between growing energy consumption and growing carbon. Apart from these paired associations, one more an artificial pair was created by E7 economies. By setting high energy prices in the country, in the short run energy consumption will be increased, while in the long run decreased (Santiago et al., 2021).

Energy efficiency means the most rational use of energy and energy savings (Liu and Wang, 2018; Zhai et al., 2017; Ozili, 2018; Ozimek, 2020; Abualigah et al., 2018a; Phoumin and Kimura, 2014; Rana et al., 2020; Abualigah et al., 2018b; Schmidt et al., 2019; Pham et al., 2020). Although domestic scholars have noted the importance of renewable energy cooperation in carbon emissions decrease, which is embodied in:

1. Although the phenomenon of disorderly resource renewable energy waste has aroused attention from various aspects (Raza et al., 2019);
2. Lack of effective research on the sustainable development approach of renewable energy;
3. Lack of theoretical analysis on the spillover effect of renewable energy in decaying mining areas (Wang et al., 2020).
4. Lack of research on different modes of transfer of dominant factors in recessive renewable energy areas (Xu et al., 2019; Yuan and Xi, 2020);
5. Lack of research on the obstacles to the transfer of the dominant factors to renewable energy (Wang and Jun, 2020; Bai et al., 2020; Zhang et al., 2020a,b)

Due to the novelty of the topic, this study is exploratory. This purpose of this research is to investigate energy cooperation between E7 economies; identify energy trends; generate new fields for further research. Political and economic sides of the research require a qualitative approach that helps to make claims based on respondents' answers on introduced questions. The research focuses on the E7 economies energy cooperation as a significant phenomenon in bilateral cooperation, prepares open-ended questions, validates the accuracy of the research findings, makes interpretation of participants' answers, and creates possible statements.

Table 1
GDP in current prices (annual changes), %.

Country	Mexico	Turkey	China	Russia	Brazil	Indonesia	India
2003	−0.06	0.33	0.13	0.25	0.08	0.20	0.16
2004	0.07	0.28	0.18	0.37	0.19	0.09	0.16
2005	0.12	0.24	0.17	0.29	0.34	0.11	0.17
2006	0.11	0.09	0.20	0.30	0.23	0.28	0.14
2007	0.08	0.24	0.29	0.31	0.27	0.19	0.27
2008	0.06	0.13	0.29	0.28	0.22	0.20	0.10
2009	−0.19	−0.16	0.11	−0.26	−0.01	0.04	−0.02
2010	0.17	0.19	0.19	0.24	0.30	0.29	0.29
2011	0.12	0.08	0.24	0.25	0.18	0.18	0.14
2012	0.02	0.05	0.13	0.07	−0.06	0.03	−0.01
2013	0.06	0.09	0.13	0.05	0.00	0.00	0.03
2014	0.03	−0.02	0.08	−0.09	−0.01	−0.03	0.07
2015	−0.11	−0.08	0.05	−0.34	−0.26	−0.04	0.04
2016	−0.08	0.01	0.02	−0.06	0.00	0.08	0.07
2017	0.08	−0.01	0.10	0.22	0.14	0.09	0.15
2018	0.05	−0.09	0.13	0.05	−0.07	0.03	0.07
2019	0.04	−0.03	0.03	0.02	−0.03	0.07	0.04
2020	−0.14	−0.06	0.03	−0.12	−0.22	−0.05	−0.08

3. The data and the model

3.1. Data analysis

Paper uses the data for the period from 2003 to 2020 because this time frame is optimal one for proposed models (Dinçer and Yüksel, 2018). The environmental database is uploaded from Oxford Economics (2022). The paper uses collecting and aggregation of multidimensional statistical data (Big Data), input–output tables, dynamic series of inflation processes for goods and services and wages data for various working specialties. This data is deposited at Mendeley Data (Mikhaylov, 2022) and shown at Table 1:

Global CO_2 emissions from fossil fuels,
Annual change in CO_2 emissions,
Consumption-based (trade-adjusted) emissions,
Decoupling CO_2 emissions from economic growth,
GDP in current prices.

3.2. The model - quantum spherical fuzzy sets with golden cut

In developing the model, we use quantum mechanics which is being used in solving decision-making problems effectively in various areas of business and economics. This approach of model building can identify the probabilities with respect to the different conditions (Wang et al., 2021) which can help to minimize uncertainty bias in this process. The proposed model is used in 3 stages:

(i) Employment of quantum mass function with golden ratios,
(ii) Appling the DEMATEL approach for deep learning about the factors influencing phenomena,
(iii) Appling the TOPSIS which is used to rank different alternatives and building optimum decision matrix via quantum spherical fuzzy.

To begin with the first step, let us consider equations (1) to (3) below which give information about the quantum mass function and phase angle. In these equations, $|Q(|u>)| = \varphi^2$ refers to the amplitude result for the probability of event $|u>$. On the other hand, in Eq. (2), ς explains the set of collective exhaustive events. Additionally, θ^2 shows the phase angle of event and $|\varphi_1|^2$ demonstrates the belief degree (Afradi and Ebrahimabadi, 2021).

$$Q\left(|u\rangle\right) = \varphi e^{j\theta} \tag{1}$$

$$|\varsigma\rangle = \{|u_1\rangle, |u_2\rangle, \ldots, |u_n\rangle\} \tag{2}$$

$$\sum_{|u\rangle \subseteq |\varsigma\rangle} |Q(|u\rangle)| = 1 \tag{3}$$

Spherical fuzzy sets $(\tilde{A}_S)$ *in* (4) can be considered for the purpose of increasing the effectiveness of the results. Within this framework, the limitation of this extension is that the square sum of the membership μ, non-membership ν and hesitation π parameters is between 0 and 1. Equations (4) and (5) identify the details of these sets (Kutlu Gündoğdu and Kahraman, 2019).

$$\tilde{A}_S = \left\{ \langle u, (\mu_{\tilde{A}_S}(u), v_{\tilde{A}_S}(u), h_{\tilde{A}_S}(u)) | u \in U \right\} \tag{4}$$

$$0 \le \mu^2_{\tilde{A}_S}(u) + v^2_{\tilde{A}_S}(u) + h^2_{\tilde{A}_S}(u) \le 1, \forall_u \in U \tag{5}$$

The probability of quantum theory can be implemented with Spherical fuzzy sets. Eq. (6) defines this situation where $\varsigma_{\mu_{\tilde{A}_S}}$, $\varsigma_{v_{\tilde{A}_S}}$, and $\varsigma_{h_{\tilde{A}_S}}$ represent the membership, non-membership hesitant degrees (Bharill et al., 2019).

$$|\varsigma_{\tilde{A}_S}\rangle = \left\{ \langle u, (\varsigma_{\mu_{\tilde{A}_S}}(u), \varsigma_{v_{\tilde{A}_S}}(u), \varsigma_{h_{\tilde{A}_S}}(u)) | u \in 2^{|\varsigma_{\tilde{A}_S}\rangle} \right\} \tag{6}$$

Moreover, the Quantum Spherical fuzzy numbers ς can be computed as in Eqs. (7) and (8). In this context, ς_μ, ς_v, and ς_h indicate the amplitudes of the degrees. Furthermore, α, γ, and β demonstrate the set of θ phase angles.

$$\varsigma = \left[\varsigma_\mu . e^{j2\pi.\alpha}, \varsigma_v . e^{j2\pi.\gamma}, \varsigma_h . e^{j2\pi.\beta}\right] \tag{7}$$

$$\varphi^2 = \left|\varsigma_\mu\left(|u_i\rangle\right)\right| \tag{8}$$

In this study, for the sake of model building, we considered golden ratio (G) which is taken into consideration to increase the accuracy of the findings. Equations (9) and (10) define the details of this ratio. In these equations, a and b refer to the large and small quantities (Noori et al., 2020).

$$G = \frac{a}{b} \tag{9}$$

$$G = \frac{1 + \sqrt{5}}{2} = 1.618\ldots \tag{10}$$

The amplitude of non-membership and hesitancy degrees is given in Eqs. (11) and (12).

$$\varsigma_v = \frac{\varsigma_\mu}{G} \tag{11}$$

$$\varsigma_h = 1 - \varsigma_\mu - \varsigma_v \tag{12}$$

Eq. (13) indicates the phase angle (a) of the quantum spherical fuzzy sets.

$$\alpha = \left|\varsigma_\mu\left(|u_i\rangle\right)\right| \tag{13}$$

The phase angle of non-member degrees γ and hesitancy degrees β is defined in Eqs. (14) and (15).

$$\gamma = \frac{\alpha}{G} \tag{14}$$

$$\beta = 1 - \alpha - \gamma \tag{15}$$

X_1 and X_2 represent two universes. Also, $\tilde{A}_\varsigma = (\varsigma_{\mu_{\tilde{A}}} e^{j2\pi.\alpha_{\tilde{A}}}, \varsigma_{v_{\tilde{A}}} e^{j2\pi.\gamma_{\tilde{A}}}, \varsigma_{h_{\tilde{A}}} e^{j2\pi.\beta_{\tilde{A}}})$ and $\tilde{B}_\varsigma = (\varsigma_{\mu_{\tilde{B}}}.e^{j2\pi.\alpha_{\tilde{B}}}, \varsigma_{v_{\tilde{B}}}.e^{j2\pi.\gamma_{\tilde{B}}}, \varsigma_{h_{\tilde{B}}}.e^{j2\pi.\beta_{\tilde{B}}})$ show two quantum spherical fuzzy sets. Equations (16)–(19) identify the operations.

$$\lambda * \tilde{A}_\varsigma = \Bigg\{ \left(1-\left(1-\varsigma_{\mu_{\tilde{A}}}{}^2\right)^\lambda\right)^{\frac{1}{2}} e^{j2\pi.\left(1-\left(1-\left(\frac{\alpha_{\tilde{A}}}{2\pi}\right)^2\right)^\lambda\right)^{\frac{1}{2}}}, \varsigma_{v_{\tilde{A}}}{}^\lambda e^{j2\pi.\left(\frac{\gamma_{\tilde{A}}}{2\pi}\right)^\lambda}, \Bigg(\left(1-\varsigma_{h_{\tilde{A}}}{}^2\right)^\lambda - (1- \varsigma_{\mu_{\tilde{A}}}{}^2 - \varsigma_{h_{\tilde{A}}}{}^2\Big)^\lambda\Bigg)^{\frac{1}{2}} e^{j2\pi.\left(\left(1-\left(\frac{\beta_{\tilde{A}}}{2\pi}\right)^2\right)^\lambda - \left(1-\left(\frac{\alpha_{\tilde{A}}}{2\pi}\right)^2-\left(\frac{\beta_{\tilde{A}}}{2\pi}\right)^2\right)^\lambda\right)^{\frac{1}{2}}} \Bigg\}, \tag{16}$$

$\lambda > 0$

Quantum spherical fuzzy set is defined by a state vector in a Hilbert space, and its membership degree is calculated by the inner product of the state vector and a quantum state that represents a fuzzy set.

$$\tilde{A}_\varsigma^\lambda = \Bigg\{ \varsigma_{\mu_{\tilde{A}}}{}^\lambda e^{j2\pi.\left(\frac{\alpha_{\tilde{A}}}{2\pi}\right)^\lambda}, \left(1-\left(1-\varsigma_{v_{\tilde{A}}}{}^2\right)^\lambda\right)^{\frac{1}{2}}, e^{j2\pi.\left(1-\left(1-\left(\frac{\gamma_{\tilde{A}}}{2\pi}\right)^2\right)^\lambda\right)^{\frac{1}{2}}} \Bigg(\left(1-\varsigma_{v_{\tilde{A}}}{}^2\right)^\lambda - (1- \varsigma_{v_{\tilde{A}}}{}^2 - \varsigma_{h_{\tilde{A}}}{}^2\Big)^\lambda\Bigg)^{\frac{1}{2}} e^{j2\pi.\left(\left(1-\left(\frac{\gamma_{\tilde{A}}}{2\pi}\right)^2\right)^\lambda - \left(1-\left(\frac{\gamma_{\tilde{A}}}{2\pi}\right)^2-\left(\frac{\beta_{\tilde{A}}}{2\pi}\right)^2\right)^\lambda\right)^{\frac{1}{2}}} \Bigg\}, \tag{17}$$

$\lambda > 0$

Quantum spherical fuzzy sets have several applications in various fields, including decision-making, pattern recognition, and image processing.

$$\tilde{A}_\varsigma \oplus \tilde{B}_\varsigma = \Bigg\{ \Big(\varsigma_{\mu_{\tilde{A}}}{}^2 + \varsigma_{\mu_{\tilde{B}}}{}^2 - \varsigma_{\mu_{\tilde{A}}}{}^2 \varsigma_{\mu_{\tilde{B}}}{}^2\Big)^{\frac{1}{2}} e^{j2\pi.\left(\left(\frac{\alpha_{\tilde{A}}}{2\pi}\right)^2+\left(\frac{\alpha_{\tilde{B}}}{2\pi}\right)^2-\left(\frac{\alpha_{\tilde{A}}}{2\pi}\right)^2\left(\frac{\alpha_{\tilde{B}}}{2\pi}\right)^2\right)^{\frac{1}{2}}}, \varsigma_{v_{\tilde{A}}} \varsigma_{v_{\tilde{B}}} e^{j2\pi.\left(\left(\frac{\gamma_{\tilde{A}}}{2\pi}\right)\left(\frac{\gamma_{\tilde{B}}}{2\pi}\right)\right)}, \Big(\left(1-\varsigma_{\mu_{\tilde{B}}}{}^2\right) \varsigma_{h_{\tilde{A}}}{}^2 + (1- \varsigma_{\mu_{\tilde{A}}}{}^2\Big) \varsigma_{h_{\tilde{B}}}{}^2 - \varsigma_{h_{\tilde{A}}}{}^2 \varsigma_{h_{\tilde{B}}}{}^2\Big)^{\frac{1}{2}} e^{j2\pi.\left(\left(1-\left(\frac{\alpha_{\tilde{B}}}{2\pi}\right)^2\right)\left(\frac{\beta_{\tilde{A}}}{2\pi}\right)^2+\left(1-\left(\frac{\alpha_{\tilde{A}}}{2\pi}\right)^2\right)\left(\frac{\beta_{\tilde{B}}}{2\pi}\right)^2-\left(\frac{\beta_{\tilde{A}}}{2\pi}\right)^2\left(\frac{\beta_{\tilde{B}}}{2\pi}\right)^2\right)^{\frac{1}{2}}} \Bigg\} \tag{18}$$

Quantum spherical fuzzy sets can represent complex information and provide a more accurate representation of uncertainty than classical fuzzy sets.

$$\tilde{A}_\varsigma \otimes \tilde{B}_\varsigma = \Bigg\{ \varsigma_{\mu_{\tilde{A}}} \varsigma_{\mu_{\tilde{B}}} e^{j2\pi.\left(\frac{\alpha_{\tilde{A}}}{2\pi}\right)\left(\frac{\alpha_{\tilde{B}}}{2\pi}\right)}, \Big(\varsigma_{v_{\tilde{A}}}{}^2 + \varsigma_{v_{\tilde{B}}}{}^2 - \varsigma_{v_{\tilde{A}}}{}^2 \varsigma_{v_{\tilde{B}}}{}^2\Big)^{\frac{1}{2}} e^{j2\pi.\left(\left(\frac{\gamma_{\tilde{A}}}{2\pi}\right)^2+\left(\frac{\gamma_{\tilde{B}}}{2\pi}\right)^2-\left(\frac{\gamma_{\tilde{A}}}{2\pi}\right)^2\left(\frac{\gamma_{\tilde{B}}}{2\pi}\right)^2\right)^{\frac{1}{2}}}, \Big(\left(1-\varsigma_{v_{\tilde{B}}}{}^2\right) \varsigma_{h_{\tilde{A}}}{}^2 + \left(1-\varsigma_{v_{\tilde{A}}}{}^2\right) \varsigma_{h_{\tilde{B}}}{}^2 - \varsigma_{h_{\tilde{A}}}{}^2 \varsigma_{h_{\tilde{B}}}{}^2\Big)^{\frac{1}{2}} e^{j2\pi.\left(\left(1-\left(\frac{\gamma_{\tilde{B}}}{2\pi}\right)^2\right)\left(\frac{\beta_{\tilde{A}}}{2\pi}\right)^2+\left(1-\left(\frac{\gamma_{\tilde{A}}}{2\pi}\right)^2\right)\left(\frac{\beta_{\tilde{B}}}{2\pi}\right)^2-\left(\frac{\beta_{\tilde{A}}}{2\pi}\right)^2\left(\frac{\beta_{\tilde{B}}}{2\pi}\right)^2\right)^{\frac{1}{2}}} \Bigg\} \tag{19}$$

3.3. The extension to DEMATEL

Decision Making and Trial Evaluation Laboratory (DEMATEL) approach is considered to find the most significant factors among many different ones. With the help of this technique, the causal relationship between the items can also be identified. This situation is accepted as a significant strength of this methodology (Dinçer and Yüksel, 2018). In this study, DEMATEL is implemented to the quantum spherical fuzzy sets. For this purpose, firstly, linguistic evaluations are obtained for constructing the relation matrix. Secondly, quantum Spherical fuzzy relation matrix is created as in Eq. (20) (Bhuiyan et al., 2022).

$$\varsigma_k = \begin{bmatrix} 0 & \varsigma_{12} & \cdots & \cdots & \varsigma_{1n} \\ \varsigma_{21} & 0 & \cdots & \cdots & \varsigma_{2n} \\ \vdots & \vdots & \ddots & \cdots & \cdots \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ \varsigma_{n1} & \varsigma_{n2} & \cdots & \cdots & 0 \end{bmatrix} \tag{20}$$

Eq. (21) demonstrates the calculation of the aggregated values ς of the decision makers.

$$\varsigma = \Bigg\{ \left[1-\prod_{i=1}^{k}\left(1-\varsigma_{\mu_i}{}^2\right)^{\frac{1}{k}}\right]^{\frac{1}{2}} e^{2\pi.\left[1-\prod_{i=1}^{k}\left(1-\left(\frac{\alpha_i}{2\pi}\right)^2\right)^{\frac{1}{k}}\right]^{\frac{1}{2}}}, \prod_{i=1}^{k} \varsigma_{v_i}{}^{\frac{1}{k}} e^{2\pi.\prod_{i=1}^{k}\left(\frac{\gamma_i}{2\pi}\right)^{\frac{1}{k}}}, \left[\prod_{i=1}^{k}\left(1-\varsigma_{\mu_i}{}^2\right)^{\frac{1}{k}} - \prod_{i=1}^{k}\left(1-\varsigma_{\mu_i}{}^2-\varsigma_{h_i}{}^2\right)^{\frac{1}{k}}\right]^{\frac{1}{2}} e^{2\pi.\left[\prod_{i=1}^{k}\left(1-\left(\frac{\alpha_i}{2\pi}\right)^2\right)^{\frac{1}{k}}-\prod_{i=1}^{k}\left(1-\left(\frac{\alpha_i}{2\pi}\right)^2-\left(\frac{\beta_i}{2\pi}\right)^2\right)^{\frac{1}{k}}\right]^{\frac{1}{2}}} \Bigg\} \tag{21}$$

The aggregated values ς of the decision makers represent their preferences for each alternative. The aggregated value is calculated by aggregating the individual values assigned by each decision maker to each criterion. There are different methods to calculate the aggregated values, including the weighted sum model, the weighted product model, and the technique for order preference by similarity to ideal solution (TOPSIS).

Thirdly, the defuzzified values $Def\,\varsigma$ are calculated with Eq. (22)

$$Def\,\varsigma_i = \varsigma_{\mu_i} + \varsigma_{h_i}\left(\frac{\varsigma_{\mu_i}}{\varsigma_{\mu_i} + \varsigma_{v_i}}\right) + \left(\frac{\alpha_i}{2\pi}\right) + \left(\frac{\gamma_i}{2\pi}\right)\left(\frac{\left(\frac{\alpha_i}{2\pi}\right)}{\left(\frac{\alpha_i}{2\pi}\right) + \left(\frac{\beta_i}{2\pi}\right)}\right) \tag{22}$$

The fourth step is related to the normalization process as detailed in Eqs. (23) and (24) (Yuan et al., 2020).

$$B = \frac{\varsigma}{max_{1\le i\le n} \sum_{j=1}^{n} \varsigma_{ij}} \tag{23}$$

$$where,\ 0 \le b_{ij} \le 1 \tag{24}$$

Total relation matrix is constructed with Eq. (25).

$$\lim_{k\to\infty}\left(B + B^2 + \cdots + B^k\right) = B(I - B)^{-1} \tag{25}$$

Eqs. (26) and (27) define the computations of total cause and effects. The cause factors $D = \left[d_{ij}\right]_{n\times 1}$ are listed with the sums of rows as the effect factors $E = \left[e_{ij}\right]_{1\times n}$ are demonstrated in the sums of columns.

$$D = \left[\sum_{j=1}^{n} e_{ij}\right]_{nx1} \tag{26}$$

$$E = \left[\sum_{i=1}^{n} e_{ij}\right]_{1xn} \tag{27}$$

The totals of these values are used to calculate the weights. Additionally, the difference of these values is considered to identify causal relationship. Eq. (28) identifies the threshold value that is used for the generation of the impact relation map.

$$\alpha = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n}\left[e_{ij}\right]}{N} \tag{28}$$

3.4. The extension of TOPSIS

TOPSIS is used to rank different alternatives. The main difference of this technique in comparison with other ones is that both positive and negative values are considered. Linguistic evaluations are obtained for constructing the decision matrix in the first stage. Secondly, Quantum spherical fuzzy decision matrix is identified by using the linguistic evaluations as in Eq. (29) (Delen et al., 2020).

$$X_k = \begin{bmatrix} 0 & X_{12} & \cdots & \cdots & X_{1m} \\ X_{21} & 0 & \cdots & \cdots & X_{2m} \\ \vdots & \vdots & \ddots & \cdots & \cdots \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ X_{n1} & X_{n2} & \cdots & \cdots & 0 \end{bmatrix} \tag{29}$$

Thirdly, the defuzzification process is applied with the help of the score function. Fourthly, normalized values are computed as in Eq. (30) (Kou et al., 2021)

$$r_{ij} = \frac{X_{ij}}{\sqrt{\sum_{i=1}^{m} X_{ij}^2}}. \tag{30}$$

Eq. (31) shows the weighted values.

$$v_{ij} = w_{ij} \times r_{ij}. \tag{31}$$

In the following step, thhe positive (A^+) and negative (A^-) ideal solutions are computed as in Eqs. (32) and (33)

$$A^+ = \left\{v_{1j}, v_{2j}, \ldots, v_{mj}\right\} = \left\{\max v_{1j}\ for\ \forall j\ n\right\}, \tag{32}$$

$$A^- = \left\{v_{1j}, v_{2j}, \ldots, v_{mj}\right\} = \left\{\min v_{1j}\ for\ \forall j\ \in n\right\}. \tag{33}$$

Seventhly, the distances to the best (D_i^+) and worst alternatives (D_i^-) are computed as in Eqs. (34) and (35).

$$D_i^+ = \sqrt{\sum_{j=1}^{n}\left(v_{ij} - A_j^+\right)^2}, \tag{34}$$

$$D_i^- = \sqrt{\sum_{j=1}^{n}\left(v_{ij} - A_j^-\right)^2}. \tag{35}$$

Eq. (36) is used to calculate the relative closeness to the ideal solutions (RC_i).

$$RC_i = \frac{D_i^-}{D_i^+ + D_i^-}. \tag{36}$$

4. Analysis results

In this stage of the analysis, an extended method is applied for weighting and constructing the influence directions of the selected 5 indicators entitled Global CO_2 emissions from fossil fuels (criterion 1), Annual change in CO_2 emissions (criterion 2), Consumption-based (trade-adjusted) emissions (criterion 3), Decoupling CO_2 emissions from economic growth (criterion 4), GDP in current prices (criterion 5). Quantum Spherical fuzzy DEMATEL with golden cut is used for measuring the relative importance of the criteria for the carbon emissions. Accordingly, the linguistic evaluations of decision makers are collected for the criteria from three decision makers. These people are experts with at least fifteen-year experience in the field of energy industry. Table 2 gives information about the scales.

The evaluation results are given in Table 3.

In the following step, the average values of quantum spherical fuzzy numbers are calculated. Table 4 gives information about the results.

To calculate the average value of quantum spherical fuzzy numbers for a criterion, we first calculate the centroid of each quantum spherical fuzzy number assigned by the decision makers for that criterion. Then, we calculate the weighted average of the centroids using the assigned weights for the decision makers. At the following step, the score function values of the criteria are computed as in Table 5.

After that, the normalized relation matrix is generated as Table 6.

Later, the total relation matrix and the directions are defined in Table 7.

Table 7 indicates that annual change in CO_2 emissions (criterion 2) and GDP in current prices (criterion 5) have an impact on the other criteria. In addition to this issue, consumption-based (trade-adjusted) emissions (criterion 3) has an influence on only decoupling CO_2 emissions from economic growth (criterion 4). At the final step, the influence degrees and the weights of the criteria are given in Table 8.

Table 8 demonstrates that global CO_2 emissions from fossil fuels (criterion 1) is the most significant factor with respect to carbon emission problem of E7 economies. Similarly, decoupling CO_2 emissions from economic growth (criterion 4) has also a high weight in this framework. In the following stage, the performance of emerging economies is ranked with the respect to the criteria of carbon emissions. For this purpose, the linguistic evaluations of

Table 2
Linguistic scales and golden cut-based quantum spherical fuzzy numbers.

Linguistic scales for criteria	Linguistic scales for alternatives	Possibility degrees	QSFNs
No influence (n)	Weakest (w)	0.40	$\left[\sqrt{0.16}e^{j2\pi.0.4}, \sqrt{0.10}e^{j2\pi.0.25}, \sqrt{0.74}e^{j2\pi.0.35}\right]$
somewhat influence (s)	Poor (p)	0.45	$\left[\sqrt{0.20}e^{j2\pi.0.45}, \sqrt{0.13}e^{j2\pi.0.28}, \sqrt{0.67}e^{j2\pi.0.27}\right]$
medium influence (m)	Fair (f)	0.50	$\left[\sqrt{0.25}e^{j2\pi.0.50}, \sqrt{0.15}e^{j2\pi.0.31}, \sqrt{0.60}e^{j2\pi.0.19}\right]$
high influence (h)	Good (g)	0.55	$\left[\sqrt{0.30}e^{j2\pi.0.55}, \sqrt{0.19}e^{j2\pi.0.34}, \sqrt{0.51}e^{j2\pi.0.11}\right]$
very high influence (vh)	Best (b)	0.60	$\left[\sqrt{0.36}e^{j2\pi.0.6}, \sqrt{0.22}e^{j2\pi.0.37}, \sqrt{0.42}e^{j2\pi.0.03}\right]$

Table 3
Linguistic evaluations of Decision Makers for the criteria.

	Decision maker 1				
	C1	C2	C3	C4	C5
C1		H	S	S	VH
C2	VH		S	VH	S
C3	H	S		S	S
C4	VH	S	VH		H
C5	S	H	S	VH	
	Decision maker 2				
	C1	C2	C3	C4	C5
C1		H	S	VH	VH
C2	VH		S	VH	S
C3	H	S		S	S
C4	VH	S	VH		VH
C5	S	H	H	VH	
	Decision maker 3				
	C1	C2	C3	C4	C5
C1		S	S	H	VH
C2	S		H	VH	S
C3	H	S		S	S
C4	VH	S	VH		H
C5	S	H	S	S	

Table 4
Average values of quantum spherical fuzzy numbers for the criteria.

	C1	C2	C3	C4	C5
C1		$\left[\sqrt{0.27}e^{j2\pi.0.51}, \sqrt{0.16}e^{j2\pi.0.31}, \sqrt{0.60}e^{j2\pi.0.22}\right]$	$\left[\sqrt{0.20}e^{j2\pi.0.45}, \sqrt{0.13}e^{j2\pi.0.28}, \sqrt{0.67}e^{j2\pi.0.27}\right]$	$\left[\sqrt{0.30}e^{j2\pi.0.55}, \sqrt{0.19}e^{j2\pi.0.34}, \sqrt{0.51}e^{j2\pi.0.11}\right]$	$\left[\sqrt{0.36}e^{j2\pi.0.60}, \sqrt{0.22}e^{j2\pi.0.37}, \sqrt{0.42}e^{j2\pi.0.03}\right]$
C2	$\left[\sqrt{0.32}e^{j2\pi.0.56}, \sqrt{0.18}e^{j2\pi.0.34}, \sqrt{0.52}e^{j2\pi.0.15}\right]$		$\left[\sqrt{0.24}e^{j2\pi.0.48}, \sqrt{0.14}e^{j2\pi.0.30}, \sqrt{0.62}e^{j2\pi.0.22}\right]$	$\left[\sqrt{0.36}e^{j2\pi.0.60}, \sqrt{0.22}e^{j2\pi.0.37}, \sqrt{0.42}e^{j2\pi.0.03}\right]$	$\left[\sqrt{0.20}e^{j2\pi.0.45}, \sqrt{0.13}e^{j2\pi.0.28}, \sqrt{0.67}e^{j2\pi.0.27}\right]$
C3	$\left[\sqrt{0.30}e^{j2\pi.0.55}, \sqrt{0.19}e^{j2\pi.0.34}, \sqrt{0.51}e^{j2\pi.0.11}\right]$	$\left[\sqrt{0.20}e^{j2\pi.0.45}, \sqrt{0.13}e^{j2\pi.0.28}, \sqrt{0.67}e^{j2\pi.0.27}\right]$		$\left[\sqrt{0.20}e^{j2\pi.0.45}, \sqrt{0.13}e^{j2\pi.0.28}, \sqrt{0.67}e^{j2\pi.0.27}\right]$	$\left[\sqrt{0.20}e^{j2\pi.0.45}, \sqrt{0.13}e^{j2\pi.0.28}, \sqrt{0.67}e^{j2\pi.0.27}\right]$
C4	$\left[\sqrt{0.36}e^{j2\pi.0.60}, \sqrt{0.22}e^{j2\pi.0.37}, \sqrt{0.42}e^{j2\pi.0.03}\right]$	$\left[\sqrt{0.20}e^{j2\pi.0.45}, \sqrt{0.13}e^{j2\pi.0.28}, \sqrt{0.67}e^{j2\pi.0.27}\right]$	$\left[\sqrt{0.36}e^{j2\pi.0.60}, \sqrt{0.22}e^{j2\pi.0.37}, \sqrt{0.42}e^{j2\pi.0.03}\right]$		$\left[\sqrt{0.32}e^{j2\pi.0.56}, \sqrt{0.18}e^{j2\pi.0.34}, \sqrt{0.52}e^{j2\pi.0.15}\right]$
C5	$\left[\sqrt{0.20}e^{j2\pi.0.45}, \sqrt{0.13}e^{j2\pi.0.28}, \sqrt{0.67}e^{j2\pi.0.27}\right]$	$\left[\sqrt{0.30}e^{j2\pi.0.55}, \sqrt{0.19}e^{j2\pi.0.34}, \sqrt{0.51}e^{j2\pi.0.11}\right]$	$\left[\sqrt{0.24}e^{j2\pi.0.48}, \sqrt{0.14}e^{j2\pi.0.30}, \sqrt{0.62}e^{j2\pi.0.22}\right]$	$\left[\sqrt{0.32}e^{j2\pi.0.56}, \sqrt{0.18}e^{j2\pi.0.34}, \sqrt{0.52}e^{j2\pi.0.15}\right]$	

decision makers are collected for the country alternatives. Table 9 shows the alternatives of emerging economies.

Table 10 gives information about the linguistic evaluations by the decision makers.

In the next step, the average values are computed for the alternatives. The results are given in Table 11.

The alternatives calculation of the weighted average of the centroids using the assigned weights for the decision makers. Next, the score function of the alternatives is calculated by using Eq. (22) as in Table 12.

The decision matrix is also normalized, and the results are given in Table 13 and Fig. 1.

Fig. 1. Score function for global CO_2 emissions from fossil fuels (criterion 1), annual change in CO_2 emissions (criterion 2), consumption-based (trade-adjusted) emissions (criterion 3), decoupling CO_2 emissions from economic growth (criterion 4), GDP in current prices (criterion 5).

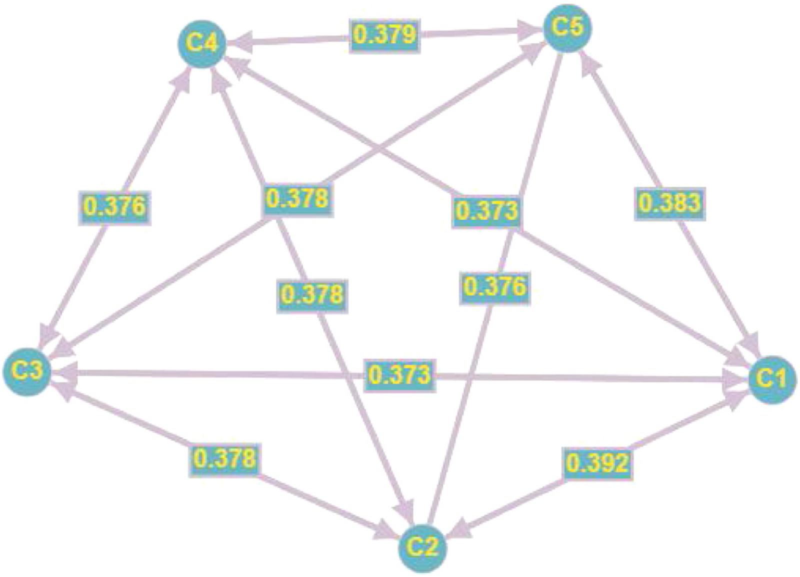

Fig. 2. Normalized decision function between global CO_2 emissions from fossil fuels (criterion 1), annual change in CO_2 emissions (criterion 2), consumption-based (trade-adjusted) emissions (criterion 3), decoupling CO_2 emissions from economic growth (criterion 4), GDP in current prices (criterion 5).

Table 5
Score function of the criteria for quantum spherical fuzzy sets.

	C1	C2	C3	C4	C5
C1	0.000	1.263	1.236	1.285	1.236
C2	1.300	0.000	1.263	1.236	1.236
C3	1.236	1.236	0.000	1.236	1.236
C4	1.236	1.236	1.236	0.000	1.245
C5	1.236	1.236	1.263	1.300	0.000

Table 6
Normalized relation matrix.

	C1	C2	C3	C4	C5
C1	0.000	0.251	0.245	0.255	0.245
C2	0.258	0.000	0.251	0.245	0.245
C3	0.245	0.245	0.000	0.245	0.245
C4	0.245	0.245	0.245	0.000	0.247
C5	0.245	0.245	0.251	0.258	0.000

Fig. 3. Weighted decision function between global CO_2 emissions from fossil fuels (criterion 1), annual change in CO_2 emissions (criterion 2), consumption-based (trade-adjusted) emissions (criterion 3), decoupling CO_2 emissions from economic growth (criterion 4), GDP in current prices (criterion 5).

Table 7
Total relation Matrix and the impact directions.

	C1	C2	C3	C4	C5	Impact directions
C1	26.351	26.394	26.502	26.760	26.317	C1→(C2,C3,C4)
C2	26.624	26.261	26.573	26.821	26.384	C2→(C1,C3,C4,C5)
C3	26.232	26.076	25.989	26.434	26.003	C3→(C4)
C4	26.271	26.115	26.225	26.277	26.043	C4→(N/A)
C5	26.613	26.455	26.570	26.827	26.184	C5→(C1,C2,C3,C4)

The weighted decision matrix is indicated in Table 14 (see Fig. 2).

Finally, the ranking results are shown in Table 15 (see Fig. 3). Table 15 demonstrates that China is the most successful E7 country to manage carbon emission problem. India is also another important country in this framework.

5. Discussions

It is not hard to explain why energy efficiency and conservation are the most popular topics to emerge in the context of growing energy consumption and why it is vital for today's E7 economies and its future. The following literature review reflects the current concerns over the asymmetric correlation between energy reduction and stable economic growth in E7 economies.

The discussion on efficiency should start first with its importance that is highlighted in the official documents. According to the Russian State program on Energy efficiency and Energy sector development, energy efficiency is an effective way for industries and the entire economy to function in the most efficient way.

Another evaluation is also made by using fuzzy decision-making methodology. Based on previous research (Narayanamoorthy et al., 2019), a new model is suggested that has two different stages. Firstly, five different criteria are selected with the help of a detailed literature review that are global CO_2 emissions from fossil fuels (criterion 1), annual change in CO_2 emissions (criterion 2), consumption-based (trade-adjusted) emissions (criterion 3), decoupling CO_2 emissions from economic growth (criterion 4), GDP in current prices (criterion 5). Quantum Spherical fuzzy DEMATEL with golden cut is used for measuring the relative importance of the criteria for the carbon emissions. It is concluded that global CO_2 emissions from fossil fuels (criterion 1) is the most significant factor regarding the carbon emission problem of E7 economies. Additionally, decoupling CO_2 emissions from economic growth (criterion 4) is also another important item in this framework. Secondly, E7 countries are ranked for carbon emission evaluation with the help of Quantum Spherical fuzzy TOPSIS. It is concluded that China is the most successful E7 country to manage carbon emission problem. India is also another important country in this framework.

The production/consumption of oil in E7 countries shows that oil production in Russia is almost equal to oil consumption in China. Whereas the Chinese domestic oil production is slightly higher than Russian oil consumption. Second, China is the second largest oil consumer in the world after the USA. The following first table indicates that even though Chinese crude oil import has been increased from 2015 to 2018, domestic crude oil production showed an upward significantly the role of vertically integrated projects is introduced. As stated by the participants vertically integrated company controls the entire supply chain. However, vertically integrated project is a vertically controlled, i.e., controlled by high-level officials (Lohrmann and Luukka, 2018).

China is promoting renewable energy and is at an early stage of transitioning from fossil energy to renewable energy. E7 economies launched the idea of an energy revolution with the aim of developing a clean, low-carbon, safe and efficient energy system by 2050 (Abualigah and Khader, 2017; Tsang et al., 2018). It has become obvious that the E7 economies energy companies are an example of the coalescence of state and business. The findings indicate that in the context of the management of strategic resources such types of energy businesses are inevitable (Khalid

Table 8
Influence Degrees and Weights of the Criteria.

	D	E	D+E	D−E	Weighting results	Weighting priorities
C1	132.325	132.091	264.416	0.234	0.2005	1
C2	132.663	131.300	263.963	1.363	0.2002	3
C3	130.734	131.860	262.594	−1.126	0.1991	5
C4	130.930	133.119	264.049	−2.189	0.2002	2
C5	132.649	130.931	263.579	1.718	0.1999	4

Table 9
Selected country alternatives of emerging economies for the carbon emissions.

Alternatives
Turkey (A1)
China (A2)
Mexico (A3)
Brazil (A4)
India (A5)
Russia (A6)
Indonesia (A7)

Table 10
Linguistic evaluations of Decision Makers for the alternatives.

	Decision maker 1				
	C1	C2	C3	C4	C5
A1	P	F	B	B	F
A2	B	F	B	B	B
A3	F	P	P	P	P
A4	P	F	B	B	P
A5	B	G	P	P	B
A6	P	B	P	B	F
A7	P	P	B	F	P
	Decision maker 2				
	C1	C2	C3	C4	C5
A1	P	P	B	B	F
A2	P	B	B	B	B
A3	F	P	P	F	P
A4	P	F	B	G	F
A5	B	G	F	F	G
A6	P	B	G	G	F
A7	P	P	B	F	G
	Decision maker 3				
	C1	C2	C3	C4	C5
A1	P	F	B	B	F
A2	B	G	B	B	B
A3	F	F	P	P	P
A4	P	G	B	B	P
A5	F	G	P	F	B
A6	G	B	F	G	F
A7	P	P	G	F	G

et al., 2020). However, during the analysis of estimated amounts of investments for the gas deal implementation, following assumption can be drawn (Lahimiri and Bekiros, 2019; Tang et al., 2019; Zhu et al., 2020).

6. Conclusion

E7 countries need to find alternatives to fossil fuels in order to deal effectively with the asymmetric carbon emission problem. In this context, it is important to consider clean energy sources. Thanks to the use of renewable energy alternatives, the carbon emission problem in energy production will be minimized. However, the initial cost of these energy projects is very high. In order to eliminate this disadvantage, the state should provide some incentives to these investors. In this context, low-interest loans will contribute to renewable energy investors in gaining a cost advantage. In addition, the use of nuclear energy also helps to reduce the carbon emission problem. For this reason, nuclear energy can also be considered as an alternative to fossil fuels. In order to increase nuclear energy investments, it is important to know the technology for this type of energy. This will contribute to the increase of nuclear energy investments. Thus, the carbon emission problem will be minimized.

Renewable energy sources, such as solar, wind, hydro, and geothermal power, offer a viable alternative to fossil fuels. These sources of energy are abundant, widely available, and environmentally friendly. Many of these countries have significant potential for renewable energy generation, such as India's solar power potential, China's wind power potential, and Brazil's hydropower potential. To transition to renewable energy, these countries need to invest in infrastructure, technology, and research and development. Policies that promote renewable energy, such as feed-in tariffs, tax incentives, and renewable energy targets, can also help accelerate the transition. Additionally, international cooperation and collaboration can play a crucial role in sharing knowledge, resources, and technology to facilitate the adoption of renewable energy.

This paper gives the direction of the future studies like emission trading and carbon market performance effects in developed countries. The main limitation of the proposed approach is that the proposed model has term period from 2003 to 2020. The time frame less 10 years is not optimal one for proposed models.

CRediT authorship contribution statement

Hasan Dinçer: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Writing – original draft. **Serhat Yüksel:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Writing – original draft. **Alexey Mikhaylov:** Project administration, Writing – original draft, Writing – review & editing. **S.M. Muyeen:** Validation, Visualization. **Tsangyao Chang:** Supervision. **Sergey Barykin:** Resources. **Olga Kalinina:** Software.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Availability of data and materials

In this study, data available at Mendeley Data: Mikhaylov, A. (2022). Carbon emissions, Mendeley Data, V1 doi:.

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Table 11
Average values of quantum spherical fuzzy numbers for the alternatives.

	C1	C2	C3	C4	C5
A1	$\begin{bmatrix}\sqrt{0.20e^{j2\pi.0.45}},\\ \sqrt{0.13e^{j2\pi.0.28}},\\ \sqrt{0.67e^{j2\pi.0.27}}\end{bmatrix}$	$\begin{bmatrix}\sqrt{0.24e^{j2\pi.0.48}},\\ \sqrt{0.14e^{j2\pi.0.30}},\\ \sqrt{0.62e^{j2\pi.0.22}}\end{bmatrix}$	$\begin{bmatrix}\sqrt{0.36e^{j2\pi.0.60}},\\ \sqrt{0.22e^{j2\pi.0.37}},\\ \sqrt{0.42e^{j2\pi.0.03}}\end{bmatrix}$	$\begin{bmatrix}\sqrt{0.36e^{j2\pi.0.60}},\\ \sqrt{0.22e^{j2\pi.0.37}},\\ \sqrt{0.42e^{j2\pi.0.03}}\end{bmatrix}$	$\begin{bmatrix}\sqrt{0.25e^{j2\pi.0.50}},\\ \sqrt{0.15e^{j2\pi.0.31}},\\ \sqrt{0.60e^{j2\pi.0.19}}\end{bmatrix}$
A2	$\begin{bmatrix}\sqrt{0.32e^{j2\pi.0.57}},\\ \sqrt{0.20e^{j2\pi.0.35}},\\ \sqrt{0.48e^{j2\pi.0.09}}\end{bmatrix}$	$\begin{bmatrix}\sqrt{0.32e^{j2\pi.0.57}},\\ \sqrt{0.20e^{j2\pi.0.35}},\\ \sqrt{0.48e^{j2\pi.0.09}}\end{bmatrix}$	$\begin{bmatrix}\sqrt{0.36e^{j2\pi.0.60}},\\ \sqrt{0.22e^{j2\pi.0.37}},\\ \sqrt{0.42e^{j2\pi.0.03}}\end{bmatrix}$	$\begin{bmatrix}\sqrt{0.36e^{j2\pi.0.60}},\\ \sqrt{0.22e^{j2\pi.0.37}},\\ \sqrt{0.42e^{j2\pi.0.03}}\end{bmatrix}$	$\begin{bmatrix}\sqrt{0.36e^{j2\pi.0.60}},\\ \sqrt{0.22e^{j2\pi.0.37}},\\ \sqrt{0.42e^{j2\pi.0.03}}\end{bmatrix}$
A3	$\begin{bmatrix}\sqrt{0.25e^{j2\pi.0.50}},\\ \sqrt{0.15e^{j2\pi.0.31}},\\ \sqrt{0.60e^{j2\pi.0.19}}\end{bmatrix}$	$\begin{bmatrix}\sqrt{0.22e^{j2\pi.0.47}},\\ \sqrt{0.13e^{j2\pi.0.29}},\\ \sqrt{0.65e^{j2\pi.0.25}}\end{bmatrix}$	$\begin{bmatrix}\sqrt{0.20e^{j2\pi.0.45}},\\ \sqrt{0.13e^{j2\pi.0.28}},\\ \sqrt{0.67e^{j2\pi.0.27}}\end{bmatrix}$	$\begin{bmatrix}\sqrt{0.22e^{j2\pi.0.47}},\\ \sqrt{0.13e^{j2\pi.0.29}},\\ \sqrt{0.65e^{j2\pi.0.25}}\end{bmatrix}$	$\begin{bmatrix}\sqrt{0.20e^{j2\pi.0.45}},\\ \sqrt{0.13e^{j2\pi.0.28}},\\ \sqrt{0.67e^{j2\pi.0.27}}\end{bmatrix}$
A4	$\begin{bmatrix}\sqrt{0.20e^{j2\pi.0.45}},\\ \sqrt{0.13e^{j2\pi.0.28}},\\ \sqrt{0.67e^{j2\pi.0.27}}\end{bmatrix}$	$\begin{bmatrix}\sqrt{0.27e^{j2\pi.0.52}},\\ \sqrt{0.16e^{j2\pi.0.32}},\\ \sqrt{0.57e^{j2\pi.0.18}}\end{bmatrix}$	$\begin{bmatrix}\sqrt{0.36e^{j2\pi.0.60}},\\ \sqrt{0.22e^{j2\pi.0.37}},\\ \sqrt{0.42e^{j2\pi.0.03}}\end{bmatrix}$	$\begin{bmatrix}\sqrt{0.34e^{j2\pi.0.58}},\\ \sqrt{0.21e^{j2\pi.0.36}},\\ \sqrt{0.45e^{j2\pi.0.07}}\end{bmatrix}$	$\begin{bmatrix}\sqrt{0.22e^{j2\pi.0.47}},\\ \sqrt{0.13e^{j2\pi.0.29}},\\ \sqrt{0.65e^{j2\pi.0.25}}\end{bmatrix}$
A5	$\begin{bmatrix}\sqrt{0.33e^{j2\pi.0.57}},\\ \sqrt{0.20e^{j2\pi.0.35}},\\ \sqrt{0.49e^{j2\pi.0.11}}\end{bmatrix}$	$\begin{bmatrix}\sqrt{0.30e^{j2\pi.0.55}},\\ \sqrt{0.19e^{j2\pi.0.34}},\\ \sqrt{0.51e^{j2\pi.0.11}}\end{bmatrix}$	$\begin{bmatrix}\sqrt{0.22e^{j2\pi.0.47}},\\ \sqrt{0.13e^{j2\pi.0.29}},\\ \sqrt{0.65e^{j2\pi.0.25}}\end{bmatrix}$	$\begin{bmatrix}\sqrt{0.24e^{j2\pi.0.48}},\\ \sqrt{0.14e^{j2\pi.0.30}},\\ \sqrt{0.62e^{j2\pi.0.22}}\end{bmatrix}$	$\begin{bmatrix}\sqrt{0.34e^{j2\pi.0.58}},\\ \sqrt{0.21e^{j2\pi.0.36}},\\ \sqrt{0.45e^{j2\pi.0.07}}\end{bmatrix}$
A6	$\begin{bmatrix}\sqrt{0.24e^{j2\pi.0.48}},\\ \sqrt{0.14e^{j2\pi.0.30}},\\ \sqrt{0.62e^{j2\pi.0.22}}\end{bmatrix}$	$\begin{bmatrix}\sqrt{0.36e^{j2\pi.0.60}},\\ \sqrt{0.22e^{j2\pi.0.37}},\\ \sqrt{0.42e^{j2\pi.0.03}}\end{bmatrix}$	$\begin{bmatrix}\sqrt{0.26e^{j2\pi.0.50}},\\ \sqrt{0.15e^{j2\pi.0.31}},\\ \sqrt{0.60e^{j2\pi.0.20}}\end{bmatrix}$	$\begin{bmatrix}\sqrt{0.32e^{j2\pi.0.57}},\\ \sqrt{0.20e^{j2\pi.0.35}},\\ \sqrt{0.48e^{j2\pi.0.09}}\end{bmatrix}$	$\begin{bmatrix}\sqrt{0.25e^{j2\pi.0.50}},\\ \sqrt{0.15e^{j2\pi.0.31}},\\ \sqrt{0.60e^{j2\pi.0.19}}\end{bmatrix}$
A7	$\begin{bmatrix}\sqrt{0.20e^{j2\pi.0.45}},\\ \sqrt{0.13e^{j2\pi.0.28}},\\ \sqrt{0.67e^{j2\pi.0.27}}\end{bmatrix}$	$\begin{bmatrix}\sqrt{0.20e^{j2\pi.0.45}},\\ \sqrt{0.13e^{j2\pi.0.28}},\\ \sqrt{0.67e^{j2\pi.0.27}}\end{bmatrix}$	$\begin{bmatrix}\sqrt{0.34e^{j2\pi.0.58}},\\ \sqrt{0.21e^{j2\pi.0.36}},\\ \sqrt{0.45e^{j2\pi.0.07}}\end{bmatrix}$	$\begin{bmatrix}\sqrt{0.25e^{j2\pi.0.50}},\\ \sqrt{0.15e^{j2\pi.0.31}},\\ \sqrt{0.60e^{j2\pi.0.19}}\end{bmatrix}$	$\begin{bmatrix}\sqrt{0.27e^{j2\pi.0.52}},\\ \sqrt{0.16e^{j2\pi.0.32}},\\ \sqrt{0.57e^{j2\pi.0.18}}\end{bmatrix}$

Table 12
Score function of the alternatives for quantum spherical fuzzy sets.

Criteria/alternatives	C1	C2	C3	C4	C5
A1	1.236	1.243	1.236	1.236	1.236
A2	1.300	1.259	1.236	1.236	1.236
A3	1.236	1.243	1.236	1.243	1.236
A4	1.236	1.243	1.236	1.247	1.243
A5	1.269	1.236	1.243	1.243	1.247
A6	1.263	1.236	1.256	1.245	1.236
A7	1.236	1.236	1.247	1.236	1.263

Table 13
Normalized decision matrix.

Criteria/alternatives	C1	C2	C3	C4	C5
A1	0.373	0.378	0.376	0.377	0.376
A2	0.392	0.383	0.376	0.377	0.376
A3	0.373	0.378	0.376	0.379	0.376
A4	0.373	0.378	0.376	0.380	0.378
A5	0.383	0.376	0.378	0.379	0.379
A6	0.381	0.376	0.382	0.379	0.376
A7	0.373	0.376	0.380	0.377	0.384

Table 14
Weighted decision matrix.

Criteria/alternatives	C1	C2	C3	C4	C5
A1	0.075	0.076	0.075	0.075	0.075
A2	0.079	0.077	0.075	0.075	0.075
A3	0.075	0.076	0.075	0.076	0.075
A4	0.075	0.076	0.075	0.076	0.076
A5	0.077	0.075	0.075	0.076	0.076
A6	0.076	0.075	0.076	0.076	0.075
A7	0.075	0.075	0.076	0.075	0.077

Table 15
Ranking results.

Alternatives	D+	D+	RCi	Ranking
A1	0.005	0.000	0.080	7
A2	0.002	0.004	0.660	1
A3	0.005	0.001	0.113	6
A4	0.004	0.001	0.169	5
A5	0.003	0.002	0.451	2
A6	0.003	0.002	0.401	3
A7	0.004	0.002	0.293	4

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