Fuzzy-based multi-criteria decision analysis of environmental regulation and green economic efficiency in a post-COVID-19 scenario: the case of China

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Abstract

The COVID-19 pandemic outbreak posed serious threats not only to global health but also to the worldwide development regime. The experts, economists, policymakers, and the governments expressed their pledges and determinations to adapt and mitigate climate change. Policymakers and governments have started adopting green growth and development strategies. The progress moves further to achieve green economic efficiency (GEE) to achieve economic, social, and environmental development. One of the major challenges has been promulgating and strictly implementing environmental regulations and policies vis-à-vis green growth and development. China, having the second largest economy, has started its voyage to achieve GEE. However, there are multiple challenges on the way to the green economy. The objective of the present study is to analyze environmental regulation and GEE in China using fuzzy-based multi-criteria decision analysis. To serve this purpose, the study identifies 5 alternative strategies to achieve GEE while considering 10 criteria and 48 sub-criteria in the context of environmental regulations in China. The Fuzzy Analytical Hierarchy Process (AHP) has been employed to rank criteria and sub-criteria to the goal. The Fuzzy Vlekrerijumsko KOMpromisno Rangiranje (VIKOR) method has been used to rank the alternative strategies of GEE. The proposed model unveiled resource efficiency and green purchasing as the best strategy to achieve GEE in the Chinese economy followed by local production. The study provides a comprehensive insight into the green development process to achieve GEE in the Chinese economy in the post-COVID-19 world.

Keywords Environmental regulation · Green economic efficiency · Green economy · Post-COVID-19 · Fuzzy AHP · Fuzzy VIKOR

Introduction

In the wake of the Paris agreement and the global consensus on Sustainable Development Goals (SDGs) in 2015, the global economies have been focusing on the formulation and implementation of adaption and mitigation strategies (Ahmed et al. 2020a). However, economic development and environmental protection being contradictory objectives have become a major concern, especially for developing countries (Liu et al. 2020). Unprecedented rapid growth in developing economies

required resource inputs resulting in significant ecological damage (Miao et al. 2017). Promulgation and enforcement of environmental regulations have fundamental importance for eco-efficiency to balance the economic value and environmental consequences (Liu et al. 2020). The economists, policymakers, and economic decision-makers are convinced that the greening of economies is not a “drag on growth” but a new “engine of growth” (UNEP 2011). It provides a great opportunity and motivates the policymakers and the governments to enable conditions to stimulate transitions to a green economy.

Green Economic Initiative (GEI) was founded by the United Nations Environment Programme (UNEP) in 2008; it was aimed to improve “human well-being and social equity, while significantly reducing environmental risks and ecological scarcities” (UNEP 2011) and the green economy was defined as “one which is a low carbon, resource-efficient, and socially inclusive” (UNEP 2011). The concept of GEE is

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multi-dimensional and multi-faceted. It must be examined from the perspectives of a multi-criteria decision framework. As the economic efficiency is not only limited to GTI, its scope is beyond it, extending to every socio-economic activity in the economy. Recently, green economic efficiency (GEE) has attracted the attention of researchers and analysts. A recent study by Liu et al. (2020) traced out the causal relationships among environmental regulation, green technological innovation (GTI), and their interaction term on eco-efficiency in China. The study explores the impact of GDI on eco-efficiency under multiple environmental regulations to adjust and obtain the more marginal benefit of green technology. Based on the economic-social-resource-environment perspective, Wang et al. (2019) examine GEE in the Yangtze River Delta (YRD) using spatiotemporal evolution and influencing factors. The study unveiled that overall spatial pattern has emerged higher efficiency in the West but lower efficiency in the East. The biggest direct effect on local GEE and spatial spillover effects on nearby areas was found in terms of the proportion of tertiary industry. Though the study was primarily focused on environmental regulation, GTI and eco-efficiency yet did not cover the overall dynamics of environmental regulation and green economic efficiency (GEE) in China.

Global efforts were underway to combat the menace of climate change. It was considered to be a global climate challenge in the pre-COVID-19 world. The COVID-19 pandemic outbreak changed the overall scenario and diverted the attention of the policymakers and the governments toward an emergent and unprecedented global health crisis posed by a novel coronavirus. COVID-19 appeared as a development challenge for all countries, accentuating the case for a global development paradigm. The pandemic has implications across global value chains, digitalization, debt, and climate change (Oldekop et al. 2020). Efforts have been put to enhance the energy landscape and reduce air pollutions (Solangi et al. 2018). Global oil market crash and COVID-19 pandemic exerted economic and social issues that need to be addressed through thoughtful policy design (Henry et al. 2020). There is a dire need to be persistent in the efforts of mitigation and adaptation of climate change. Though the pandemic has affected the growth and development trajectories of the economy, yet an economic recovery tilted toward green stimulus and reduction in traditional fuel investment would add the positive outcomes in avoiding future global warming (Forster et al. 2020). The Chinese economy, being first hit by the COVID-19 pandemic, is focusing on economic recovery. The focus is on the stimulation of investment in infrastructure to facilitate renewable energy, intercity transport, and electric vehicle charging stations. Moreover, the Chinese government, in post-COVID-19 recovery, is focusing on five work streams—food, water and energy, urban climate adoption, circular economy, energy storage (Thorpe 2020). All of

these areas are pivotal to achieve environmental regulation and GEE criteria and alternative strategies.

The objective of the paper is to assess and prioritize alternative strategies to achieve GEE in China in a post-COVID-19 scenario. This study prioritizes 5 alternative strategies under 10 criteria and 48 sub-criteria in total. These criteria and sub-criteria are distilled through extensive literature review in environmental regulation and policy formulations for green economic development and green economic efficiency achievement in the Chinese economy. This study is a comprehensive analysis based on the fuzzy-based multi-criteria decision analysis. Firstly, the identified criteria and sub-criteria for green economic efficiency are assessed and ranked using the Fuzzy Analytical Hierarchy Process (AHP). Secondly, green economic efficiency strategies are evaluated and prioritized using the Fuzzy VIKOR¹ method. Rankings of each criterion and sub-criteria are found based on Fuzzy AHP estimations. This ranking clarifies the important criteria and sub-criteria significant for green economic efficiency. Moreover, the Fuzzy VIKOR analysis provides the ranking of GEE alternative strategies in the context of prioritized criteria and sub-criteria for the Chinese economy. The fuzzy-based multi-criteria decision analysis for environmental regulation for green economic efficiency would provide guidelines in the post-COVID-19 scenario.

Proposed criteria, sub-criteria, and alternative strategies to green economic efficiency

The present study focuses on the examination and prioritization of strategies to GEE in China based on the fuzzy-based multi-criteria decision analysis of environmental regulations for GEE. Environmental regulation is an important fulcrum for the transition to green industrial growth (Feng and Chen 2018). The recent study provides a profound understanding by arguing that moderate environmental regulation can help reduce the damaging influence of green technological innovation (Liu et al. 2020). The primary focus of this study is to identify, assess, and prioritize the criteria and sub-criteria for alternative GEE strategies in China. This research determines a profound insight to achieve GEE in the post-COVID-19. To serve this purpose, the authors have carried out an extensive literature review to identify criteria and sub-criteria for GEE in China. The study finalized 10 major criteria including Socio-Economic Development Policies, Green Growth Agenda promulgated by the government, Green Industrial Development (GID), Environmental Regulations, Resource Efficiency, Technological Initiatives and Innovation (TII), Green

¹ VIKOR is an acronym for a Serbian term “Vlekrerijumsko KOmpromisno Rangiranje” which implies “multi-criteria optimization and compromise solution” in English (Shumaiza et al. 2019).

Energy Production and Consumption Practices, Blue-Green Infrastructure Development, Pollution Control, and Waste Management, and Labor Policies. The sub-criteria for each criterion with a brief description are presented in Table 1.

Green economic efficiency strategies

The present study identifies 5 GE strategies. The alternative strategies and their brief descriptions are summarized in Table 2.

Since globally, many countries have traditional environmental regulations and economic efficiency system, which negatively impacts the environment, such as global warming, climate change, air pollution, and human health (such as COVID-19). In this regard, it is important to transform the old-style environmental and economic efficiencies into a sustainable environmental and economic efficiency system. In this study, a comprehensive literature review was analyzed to identify the most relevant GEE criteria, sub-criteria, and strategies. Thus, 10 GEE criteria, 48 sub-criteria, and 5 significant strategies have been identified in the context of China. This study used a fuzzy-based multi-criteria decision model, i.e., Fuzzy AHP and Fuzzy VIKOR, to evaluate this decision-making problem. This is the first study that analyzed GEE criteria, sub-criteria, and strategies using a fuzzy decision model. This research would assist the government and decision-makers in implementing environmental regulation and GEE in obtaining green development in China. This would also help boost Chinese economy in the post-COVID-19 scenario.

Proposed fuzzy multi-criteria decision analysis

The objective of this study is to select, analyze, and rank the GEE criteria, sub-criteria, and alternative strategies in the context of Chinese economy. In this regard, the fuzzy-based multi-criteria decision analysis, i.e., AHP and VIKOR methods, has been used to solve this multi-faceted decision-making problem. The AHP and VIKOR are the most utilized and suitable approaches to MCDA. Figure 1 shows the proposed fuzzy decision model. The sub-sections provided Fuzzy AHP and Fuzzy VIKOR methods to evaluate the proposed decision-making problem.

Fuzzy AHP method

The AHP method was proposed by Saaty in the 1970s (Saaty 1990; Wang et al. 2020). This approach is very famous and useful in analyzing and prioritizing any decision-making problem. The AHP method has four hierarchical stages: goal, criteria, sub-criteria, and alternatives (Solangi et al. 2019b). This study used the Fuzzy AHP technique to obtain more reliable and robust results. Because fuzzy set theory helps in

minimizing any human error and ambiguity during decision-making. In this study, the fuzzy-based pairwise comparison matrix has been operated as triangular fuzzy numbers (TFNs) to evaluate the GEE criteria and sub-criteria for environmental sustainability in China. The linguistic terms based on TFNs are shown in Table 3 (Kaganski et al. 2018).

The following steps have been used to compute the inconsistency ratio of the fuzzy pairwise comparison matrix, which is proposed by Gogus and Boucher (1998).

Step 1. Convert a triangular fuzzy matrix into two independent matrices:

$$X_i = (l_i, m_i, u_i) \quad (1)$$

Next, the first triangular fuzzy matrix is established with the middle fuzzy triangular matrix:

$$X_m = [x_{ijm}] \quad (2)$$

Here, the second triangular fuzzy matrix is established by a geometric mean approach for the upper and lower bounds of the TFNs:

$$X_g = [\sqrt{x_{iju}x_{ijl}}] \quad (3)$$

Step 2. Establish the weight vector based on the Saaty method and computation of lambda max.

Step 3. Establish the consistency index (CI) for each matrix:

$$CI_m = \frac{\lambda_{max}^m - n}{n-1} \quad (4)$$

$$CI_g = \frac{\lambda_{max}^g - n}{n-1} \quad (5)$$

Step 4. Establish the consistency ratio (CR) for each matrix. For CR, the consistency index (CI) of each matrix is divided by its random index (RI).

$$CR_m = \frac{CI_m}{RI_m} \quad (6)$$

$$CR_g = \frac{CI_g}{RI_g} \quad (7)$$

The fuzzy matrices are to be considered valid if the values of CR_m and CR_g are smaller than 0.10. However, if the value surpasses 0.10, then it will be considered inconsistent. The RI scale is shown in Table 4. The RI scale of the current study is proposed by Gogus and Boucher (Zhou et al. 2019).

Fuzzy VIKOR method

The VIKOR method was proposed by Opricovic in 1980 (Opricovic and Tzeng 2007). This approach mainly focuses

Table 1 Criteria and sub-criteria and strategies to green economic efficiency

Code	Criteria	Sub-criteria	Code	Brief description
A1	Socio-Economic Development Policies	Sustainable Development Initiative (SDI)	A11	SDI policy regimes can stimulate the process of green development and increase GEE. Improvement in the community's quality of life attracts a stronger workforce (Hou et al. 2019). Moreover, the increase in the local production of goods and services is also significant to achieve the objective (ICMA 2019). The Chinese government has initiated Agenda 2030 for the adoption and implementation of SDGs in China (Yu et al. 2020). In addition to this, the Chinese government has introduced a new policy paradigm of “ecological civilization” (Tracy et al. 2017).
		Green Civil Society (GCS) Initiative(s)	A12	The emergence of the green public sphere in the economic growth and development process plays a pivotal role in environmental protection (Yang and Calhoun 2007). The GCS has been growing fast and playing its positive role in combating environmental degradation and climate change (Fengshi 2009; Yang and Calhoun 2007).
		Ensuring Stakeholder Participation	A13	The participation of stakeholders and their role in developing a stable modern society is indispensable (Laurisz 2019). Stakeholder participation is beneficial in sustainable development (Weng et al. 2015; Zhuang 2017).
		Gender Mainstreaming	A14	The objectives of sustainable development cannot be achieved until the mainstreaming of gender into economic development policies and projects. The development should offer more equal opportunities for both men and women in development (Bohong et al. 2016).
		Sectoral and Regional Development Initiatives	A15	Sectoral and regional development initiatives need to be introduced to ensure sustainable and green development in the economy. Though the Chinese economy has shown tremendous growth, yet initiatives are required to address the regional development strategy among the Eastern, Central, and Western regions in China (Chu et al. 2018; Weng et al. 2015).
		Social Inclusion in Green Economy	A16	In addition to the adoption of green stimulus for industries, investment in green projects, and other development initiatives, social inclusion indispensable in achieving the green economy objectives (IIED 2020; Weng et al. 2015).
B2	Green Growth Agenda	Inclusive and Collaborative Planning	B21	Inclusive and collaborative planning is fundamental to the development process (Ahmed et al. 2020b; Ali et al. 2019). In addition to this, communicative planning could help avoid conflicts during the development process (Wang and Wang 2020).
		Promote Green Growth Patterns (GGPs)	B22	The promotion of GGPs is pivotal for green economy efficiency. The Chinese government has been focusing on adopting GGPs (Weng et al. 2015).
		Simulate Green Investment	B23	Green investment is critical for GEE. If the Chinese government attracts the green inward FDI and invests in foreign technology-intensive industries, it will be helpful to obtain green technology spillovers and stimulate green innovation (Luo et al. 2021).
		Government Investment Incentives (GIIs)	B24	It is essential to provide direct government funding and tax incentives to promote green technology innovation. Moreover, it is also important to introduce some tax incentives to support green technology initiatives (Guo et al. 2018).
		Sustainable Special Economic Zone (SSEZs) Development	B25	The establishment of SSEZs is fundamental for setting up an eco-friendly industrial base in the economy. Apart from the other factors in developing SSEZs, sustainability issues under the Zone 3.0 paradigm are indispensable to achieve SDGs (Ahmed et al. 2020b).
C3	Green Industrial Development	Green Product Innovation (GPI)	C31	GPI refers to the product innovation that fulfills environmental requirements through innovation in design, development, and production through the product life cycle (Feng and Chen 2018). It plays a pivotal role in setting the green growth trajectory of the economy. In GPI, mostly, the focus is on the reduction of energy consumption (Chan et al. 2016; Feng and Chen 2018).
		Green Craft Innovation (GCI)	C32	

Table 1 (continued)

Code	Criteria	Sub-criteria	Code	Brief description
				GCI refers to the “innovation of production technology and technological equipment in the production process” (Feng and Chen 2018). It is believed that the increase in technical transformation investment of the total output value increases the GCI ability in the economy (Feng and Chen 2018).
		Green Innovation Initiative (GII) for Green Industrial Growth (GIG)	C33	It is beneficial to decouple economic growth from the use and consumption of natural resources and energy. Moreover, it is also important to provide more value with better economic and ecological efficiency. The government’s support is indispensable in encouraging green innovation for GIG (UNIDO 2010). Green innovation is also important in realizing sustainable development (Luo et al. 2021).
		Industrial Specialization	C34	Industrial specialization is conducive to economic growth (Ma et al. 2019).
		Industrial Diversity	C35	Industrial diversity is also an important factor in promoting innovation and productivity (Ma et al. 2019).
		Industrial Competition	C36	Industrial competition is conducive to improving capital productivity (Ma et al. 2019).
D4	Environmental Regulations	Administrative Environmental Regulations (AERs)	D41	The AERs refer to the mandatory environmental laws, regulations, and policies promulgated and enacted by the government and government’s environmental protection agencies. The Chinese government has introduced multiple AERs to ensure environmental protection (Feng and Chen 2018).
		Market-based Environmental Regulations (MERs)	D42	MERs refer to sewage charges, subsidies, and tradable permits to prevent environmental damage and reduce pollution. The Chinese government has also introduced multiple MERs to protect the environment (Feng and Chen 2018).
		Monitoring and Evaluation System Development	D43	Monitoring and evaluating system development are critical in setting growth and development. The Chinese government has focused on “strengthening cross-departmental coordination of environmental monitoring and local management system” (Weng et al. 2015).
		Public Participation in Environmental Regulation and Compliance	D44	Public participation environmental regulations are introduced to ensure public participation in environmental regulation activities through understanding information and compliance with environmental regulations (Feng and Chen 2018).
		Land/Planning laws	D45	Land use policies are a fundamental part of the policy mix to achieve economic, environmental, and social goals. Land use policies must ensure the cooperation between stakeholders at the local, regional, and national levels (OECD 2020).
E5	Resource Efficiency	Minimization of Environmental Risk	E51	Minimization of environmental risks is one of the key objectives of the governments. It is critical to minimize the environmental risks posed by the industries, companies, and other business units in the economy. The Chinese government has introduced multiple policy instruments to manage environmental risks (Weng et al. 2015).
		Sustainable Public Procurement (SPP)	E52	The SPP is a driver for resource efficiency (Green Growth 2018)
		Reducing Waste through Industrial Symbiosis	E53	Resource efficiency can be obtained through a reduction in waste through industrial symbiosis. It has been achieved in Japan (Green Growth 2018).
		Reduce Resources and Energy Consumption	E54	In the wake of the Paris agreement and the global community’s consensus on SDGs in 2015, global efforts are underway to reduce resource and energy consumption and control carbon emissions. In the last 20 years, the Chinese government has put forward serious efforts to reduce energy intensity (Liao and Wang 2019).
		Efficient Land Use	E55	Efficient use of land is important. The Chinese government has introduced multiple projects to ensure efficient land use (Weng et al. 2015).
F6	Technological Initiatives and Innovation	Direct Government Funding and Tax Incentives	F61	Technological progress increases energy efficiency, reduces energy consumption, and has rebound effects and helps in energy saving (Liao

Table 1 (continued)

Code	Criteria	Sub-criteria	Code	Brief description
				and Wang 2019). It is vital to introduce direct government funding and tax incentives to promote technological initiatives and innovation programs.
		Intellectual Property Laws	F62	Protection of intellectual property rights is the critical element to stimulation technological progress and innovation. Promulgation of intellectual property laws and their implementation paves the way for technological innovation. The Chinese government has been focusing on this issue and continuously introduced intellectual property laws and regulations (Prud'homme and Zhang 2019).
		Research and Development (R&D)	F63	Promotion of R&D is fundamental in achieving a green economy (Weng et al. 2015).
		Green Technology Innovation	F64	Green innovation is pivotal for the transition to green industrial growth (Cao et al. 2019).
		Marketization Innovation	F65	Marketization innovation is also important. The intervention policies from the central/provincial governments independently stimulate the adoption of marketization innovation (Zhu and Zhang 2019).
G7	Green Energy Production and Consumption Practices	Green Energy Initiative	G71	In the wake of the Paris agreement, governments worldwide have introduced green energy initiatives to reduce energy consumption and shift their energy mix from traditional to renewable energy sources (Kul et al. 2020). The Chinese economy has done impressively well in green energy production and consumption (Liao and Wang 2019).
		Energy-Saving Technology Adoption	G72	In addition to the production and consumption of clean energy, it is also vital to reduce energy consumption through energy-saving technology adoption (Hesselink and Chappin 2019).
		Green Energy Transmission and Distribution System	G73	Efficient transmission and distribution of green energy are important. The Chinese government has put forward reform plans for the electric power system to reduce power transmission barriers (GTR 2018).
H8	Blue-Green Infrastructure Development	Blue Infrastructure Development	H81	Blue-green infrastructure (BGI) is increasingly attracting attention as an alternative to conventional water management. The efforts are underway to effective Blue infrastructure development in China (Liu et al. 2019).
		Green Stormwater Management System Development	H82	Green stormwater management system development is fundamental in managing infrastructure development (Liu et al. 2019).
		Recycling Infrastructure	H83	Recycling infrastructure is critical for green economic development. The Chinese government aims to increase the recycling rates for residence and to build basic trash sortation systems. The government is also considering charging waste management fees for residential and commercial waster in major cities (CLP 2020).
		Transport Infrastructure	H84	Transport infrastructure and its efficient use are critical for economic efficiency (Ma et al. 2019).
		Green Buildings	H85	The development and promotion of green buildings are significant in achieving SDGs. Chinese green building industry is growing fast (Fu et al. 2020) and will play a pivotal role in obtaining GEE. Moreover, urban green infrastructure has been given special attention in urban development planning and projects in China (Z. Zhu et al. 2019a).
I9	Pollution Control and Waste Management	Air Pollution Control	I91	Environmental protection laws are important for green economic development. The Chinese government formulated and enacted the “Air Pollution Prevention and Control Law of the PRC” (Guo et al. 2018).
		Wastewater Management	I92	Treatment of wastewater influent, sewage treatment, and water recycling are also important to pollution control and resource management. The Chinese government has put forward policy interventions to ensure sustainable water quality, maximizing energy recovery, efficient resource recycling, and environmental friendliness (Qu et al. 2019).
		Solid Waste Management (SWM)	I93	SWM is one of the challenges for governments and societies. Efforts are needed to reach a zero-waste economy. It can be obtained through innovative technologies to reduce waste streams, increasing recycling

Table 1 (continued)

Code	Criteria	Sub-criteria	Code	Brief description
				rates, transforming W2E without relying on incineration (Ali Shah et al. 2020).
		Shared and Circular Economy Promotion	I94	The concept of a shared and circular economy has got attention all over the globe. The Chinese government has taken initiatives to adopt and promote a shared and circular economy in the country (Pesce et al. 2020; Zhu et al. 2019b).
J10	Labor Policies	Skill Development	J101	Labor policies need to ensure investment in skills required for a sustainable and low-carbon economy (ILO 2011).
		Occupational Safety and Health (OSH)	J102	Insurance of occupational safety and health is also fundamental on the way to sustainable development (ILO 2011).
		SME Development	J103	The development of SMEs can help ensure green jobs due to the labor-intensive (Ali 2013) and the environmentally friendly nature of SMEs (ILO 2011).
		Green Jobs	J104	Sustainable development encompasses economic growth, sustaining environmental quality, and improving human health, social justice, and employment (Pociovălișteanu et al. 2015). Green jobs refer to “the transformation of economies, enterprises, workplaces and labor market into a sustainable, low-carbon economy providing decent work” (ILO 2015).

on ranking the set of alternatives with conflicting criteria to obtain compromise solutions. This approach will help decision-makers reach a mutual consensus (Liu et al. 2013). This study utilized a fuzzy-based VIKOR method to obtain more significant and reliable findings, even with less

information, vague, and uncertain. The fuzzy set theory was developed by Zedah who proposed it in 1965 (Solangi et al. 2019a). There are several triangular fuzzy numbers (TFNs) that can be used for various purposes based on the decision-making problem (Shukla et al. 2014).

Table 2 Green economic efficiency alternative strategies

Code	Strategy	Brief description
S1	Green economic development strategy	The economies are industrializing by going green, using smart and innovation-driven ideas (Cao et al. 2019). Economic growth and development are the primary objectives to achieve. In the green economy, like traditional economic development, strategies are adapted for growth and development that improve environmental outcomes (ICMA 2019).
S2	Resource efficiency and green purchasing strategy	The green economic development strategies focus on production supply. Resource efficiency and green purchasing are broader strategies that address the consumption side of the green economy. These strategies harness the community’s purchasing power, demand for energy, resources, water, and green products (ICMA 2019).
S3	Local production and utilization strategy	Local production and utilization strategy is another alternative to green development strategy. It encourages an increase in community wealth by producing and consuming locally. It promotes regional self-reliance and economic security. It also eliminates the environmental impacts linked to transportation and logistics (ICMA 2019; OECD 2012).
S4	Waste stream management strategy	This strategy primarily focuses on the adoption of aggressive solid waste management programs. It focuses on reducing the costs and negative externalities related to waste disposal. The local governments can do impressively by creating jobs and reducing the cost of doing business. However, for this purpose to achieve, innovative technologies need to be introduced for a reduction in the waste stream, an increase in recycling, and transforming W2E (ICMA 2019).
S5	Green infrastructure strategy	Green infrastructure development strategy is another alternative to achieve GEE (John et al. 2019). Comprehensive and inclusive land use policy decisions can significantly help inefficient resource use, maintain environmental quality, and create economic activity. Moreover, local governments can positively impact the green economy by using their authority in planning and implementing. The local governments can help improve the quality of life for the residents and improve the local business environment (ICMA 2019).

Fig. 1 The proposed fuzzy-based multi-criteria decision model

The followings are the key steps of the Fuzzy VIKOR method:

Step 1. Create a decision matrix

In this study, 48 sub-criteria and 5 alternatives are ranked based on the Fuzzy VIKOR method. Table 5 shows the type of criterion and weight assigned to each criterion.

The TFN scale of this study is presented in Table 6.

The alternatives in terms of various criteria are evaluated, and the results of the decision matrix are shown in Appendix 2 Table 22.

Step 2. Determine the positive ideal solution and negative ideal solution

Positive and negative ideal solutions of each criterion can be obtained as follows.

If the criterion is positive, the positive ideal solution ($\tilde{f}^*$) and negative ideal solution ($\tilde{f}^\circ$) can be obtained using the following relations:

$$\tilde{f}_j^* = \max_i \tilde{f}_{ij} \quad i = 1, 2, \dots, n \quad (8)$$

Table 3 TFN scale

Code	Linguistic terms	TFNs
1	Equally dominant	(1, 1, 1)
2	Equally to average dominant	(1, 2, 3)
3	Averagely dominant	(2, 3, 4)
4	Averagely to strongly dominant	(3, 4, 5)
5	Strongly dominant	(4, 5, 6)
6	Strongly to very strongly dominant	(5, 6, 7)
7	Very strongly dominant	(6, 7, 8)
8	Very strongly to extremely dominant	(7, 8, 9)
9	Extremely dominant	(9, 9, 9)

Table 4 RI scale

n	RI_m	RI_g
1	0	1
2	0	2
3	0.4890	0.1796
4	0.7937	0.2627
5	1.0720	0.3597
6	1.1996	0.3818
7	1.2874	0.4090
8	1.3410	0.4164
9	1.3793	0.4348
10	1.4095	0.4455

Table 5 Characteristics of criteria

Number	Name	Type	Weight
1	A11	Benefit	(0.021, 0.021, 0.021)
2	A12	Benefit	(0.021, 0.021, 0.021)
3	A13	Benefit	(0.021, 0.021, 0.021)
4	A14	Benefit	(0.021, 0.021, 0.021)
5	A15	Benefit	(0.021, 0.021, 0.021)
6	A16	Benefit	(0.021, 0.021, 0.021)
7	B21	Benefit	(0.021, 0.021, 0.021)
8	B22	Benefit	(0.021, 0.021, 0.021)
9	B23	Benefit	(0.021, 0.021, 0.021)
10	B24	Benefit	(0.021, 0.021, 0.021)
11	B25	Benefit	(0.021, 0.021, 0.021)
12	C31	Benefit	(0.021, 0.021, 0.021)
13	C32	Benefit	(0.021, 0.021, 0.021)
14	C33	Benefit	(0.021, 0.021, 0.021)
15	C34	Benefit	(0.021, 0.021, 0.021)
16	C35	Benefit	(0.021, 0.021, 0.021)
17	C36	Benefit	(0.021, 0.021, 0.021)
18	D41	Benefit	(0.021, 0.021, 0.021)
19	D42	Benefit	(0.021, 0.021, 0.021)
20	D43	Benefit	(0.021, 0.021, 0.021)
21	D44	Benefit	(0.021, 0.021, 0.021)
22	D45	Benefit	(0.021, 0.021, 0.021)
23	E51	Benefit	(0.021, 0.021, 0.021)
24	E52	Benefit	(0.021, 0.021, 0.021)
25	E53	Benefit	(0.021, 0.021, 0.021)
26	E54	Benefit	(0.021, 0.021, 0.021)
27	E55	Benefit	(0.021, 0.021, 0.021)
28	F61	Benefit	(0.021, 0.021, 0.021)
29	F62	Benefit	(0.021, 0.021, 0.021)
30	F63	Benefit	(0.021, 0.021, 0.021)
31	F64	Benefit	(0.021, 0.021, 0.021)
32	F65	Benefit	(0.021, 0.021, 0.021)
33	G71	Benefit	(0.021, 0.021, 0.021)
34	G72	Benefit	(0.021, 0.021, 0.021)
35	G73	Benefit	(0.021, 0.021, 0.021)
36	H81	Benefit	(0.021, 0.021, 0.021)
37	H82	Benefit	(0.021, 0.021, 0.021)
38	H83	Benefit	(0.021, 0.021, 0.021)
39	H84	Benefit	(0.021, 0.021, 0.021)
40	H85	Benefit	(0.021, 0.021, 0.021)
41	I91	Benefit	(0.021, 0.021, 0.021)
42	I92	Benefit	(0.021, 0.021, 0.021)
43	I93	Benefit	(0.021, 0.021, 0.021)
44	I94	Benefit	(0.021, 0.021, 0.021)
45	J101	Benefit	(0.021, 0.021, 0.021)
46	J102	Benefit	(0.021, 0.021, 0.021)
47	J103	Benefit	(0.021, 0.021, 0.021)
48	J104	Benefit	(0.021, 0.021, 0.021)

Table 6 TFN scale

Code	Linguistic terms	TFNs
1	Very low	(0, 0, 0.25)
2	Low	(0, 0.25, 0.5)
3	Medium	(0.25, 0.5, 0.75)
4	High	(0.5, 0.75, 1)
5	Very high	(0.75, 1, 1)

$$\tilde{f}_j^{\circ} = \min_i \tilde{f}_{ij} \quad i = 1, 2, \dots, n \quad (9)$$

If the criterion is negative, the positive ideal solution ($\tilde{f}^*$) and negative ideal solution ($\tilde{f}^{\circ}$) can be obtained using the following relations:

$$\tilde{f}_j^* = \max_i \tilde{f}_{ij} \quad i = 1, 2, \dots, n \quad (10)$$

$$\tilde{f}_j^{\circ} = \min_i \tilde{f}_{ij} \quad i = 1, 2, \dots, n \quad (11)$$

Step 3. Compute the normalized decision matrix

Based on the positive and negative ideal solutions, a normalized decision matrix can be calculated by the following relation:

$$\tilde{d}_{ij} = \left(\tilde{f}_j^* \ominus \tilde{f}_{ij} \right) / \left(r_j^* - l_j^{\circ} \right) \text{Positive ideal solution} \quad (12)$$

$$\tilde{d}_{ij} = \left(\tilde{f}_{ij} \ominus \tilde{f}_j^{\circ} \right) / \left(r_j^{\circ} - l_j^* \right) \text{Negative ideal solution} \quad (13)$$

where

$$\tilde{f}_j^* = \left(l_j^*, m_j^*, r_j^* \right)$$

$$\tilde{f}_j^{\circ} = \left(l_j^{\circ}, m_j^{\circ}, r_j^{\circ} \right)$$

Appendix 2 Table 23 shows the normalized values of the evaluation matrix.

Step 4. Compute the values $\tilde{S}_i$ and $\tilde{R}_i$:

First, the normalized matrix is transformed into a weighted normalized decision matrix, and then the values $\tilde{S}_i$ and $\tilde{R}_i$ can be calculated as follows:

$$\text{If } \tilde{R}_i = \left(R_i^l, R_i^m, R_i^r \right) \text{ and } \tilde{s}_i = \left(s_i^l, s_i^m, s_i^r \right)$$

$$\tilde{S}_i = \sum_{j=1}^J \left(\tilde{w}_j \otimes \tilde{d}_{ij} \right) \quad (14)$$

Table 7 The final ranking of GEE criteria

Code	Criteria	Weight	Rank
A1	Socio-Economic Development Policies	0.161	1
B2	Green Growth Agenda	0.120	3
C3	Green Industrial Development	0.124	2
D4	Environmental Regulations	0.113	4
E5	Resource Efficiency	0.106	5
F6	Technological Initiatives and Innovation	0.094	6
G7	Green Energy Production and Consumption Practices	0.086	7
H8	Blue-Green Infrastructure Development	0.076	8
I9	Pollution Control and Waste Management	0.067	9
J10	Labor Policies	0.052	10

$$\tilde{R}_i = \max_j (\tilde{w}_j \otimes \tilde{d}_{ij}) \quad (15)$$

The variable v representing the maximum group utility is equal to 0.5 in this study.

The fuzzy numbers S , R , and Q can be transformed into crisp numbers using the following formula.

If $\tilde{A} = (l, m, r)$ ($\tilde{A}$ is expressed as a fuzzy number)

$$\text{Crisp}(\tilde{A}) = \frac{2m + l + r}{4} \quad (17)$$

Appendix 2 Table 24 shows the fuzzy values S , R , and Q .

Step 5. Calculate the VIKOR index (Q)

The value of Q can be calculated as follows.

If $\tilde{Q}_i = (Q_i^l, Q_i^m, Q_i^r)$

$$\tilde{Q}_i = v \frac{(\tilde{s}_i \ominus \tilde{s}^*)}{s^{\circ r} - s^{*l}} \oplus (1-v) \frac{(\tilde{R}_i \ominus \tilde{R}^*)}{R^{\circ r} - R^{*l}} \quad (16)$$

where

$$\tilde{s}^* = \min_i \tilde{s}_i$$

$$s^{\circ r} = \max_i s_i^r$$

$$\tilde{R}^* = \min_i \tilde{R}_i$$

$$R^{\circ r} = \max_i R_i^r$$

Step 6. Proposing a compromise solution

In this step, a decision is made based on the values R , S , and Q for the alternatives sorted in descending order. Two conditions need to be made a decision, and a set of compromise solutions can be proposed following these two conditions.

Condition 1. Acceptable advantage: $Q(A^{(2)}) - Q(A^{(1)}) \geq 1/(m-1)$ where $A^{(1)}$ is the alternative with the first position and $A^{(2)}$ is the alternative with the second position in the ranking list by Q . m is a number of alternatives.

Fig. 2 Weight and ranking of Socio-Economic Development Policies (A1)

Fig. 3 Weight and ranking of Green Growth Agenda (B2)

Condition 2. Acceptable stability in decision-making: The alternative $A^{(1)}$ must also be the best ranked by S or/and R.

If one of the conditions is not satisfied, then a set of compromise solutions is proposed, which consists of the following:

Solution 1. Alternatives $A^{(1)}, A^{(2)}, \dots, A^{(M)}$ if Condition 1 is not satisfied; Alternative $A^{(M)}$ is determined by $Q(A^{(M)}) - Q(A^{(1)}) < 1/(m-1)$ for maximum M (the positions of these alternatives are “in closeness”).

Solution 2. Alternatives $A^{(1)}$ and $A^{(2)}$ if only condition 2 is not satisfied.

Solution 3. The alternative with the minimum Q value will be selected as the best Alternative if both conditions are satisfied.

Experts for Fuzzy AHP and Fuzzy VIKOR approach

It is one of the tough jobs to assess the GEE criteria. The weights assigned by inexperienced individuals are always unimportant and useless in making decisions (Solangi et al. 2019c). Therefore, this research consulted with six

professional and experienced experts to assign weights of GEE criteria, sub-criteria, and alternative strategies using Fuzzy AHP and Fuzzy VIKOR methods. These experts belong to academia, research institute, economist, and ecologist. All the responses of experts were gathered by webmail service to analyze the obtained data using Fuzzy AHP method and Fuzzy VIKOR methodologies. Thus, the findings of this research would help in identifying the most suitable GEE criteria, sub-criteria, and strategy in the context of China.

Results and discussion

In this section, the findings of 10 GEE criteria, 48 sub-criteria, and 5 strategies have been analyzed and ranked using Fuzzy AHP and Fuzzy VIKOR approaches. The GEE criteria and sub-criteria have been evaluated using the Fuzzy AHP method, whereas the Fuzzy VIKOR approach has been used to analyze the GEE strategies. These assessed GEE criteria and strategies are considered to be very crucial for the development and implementation of environmental regulation and GEE in the country. Therefore, the detailed findings are provided in the below sub-sections.

Fig. 4 Weight and ranking of Green Industrial Development (C3)

Fig. 5 Weight and ranking of Environmental Regulations (D4)

The results of GEE criteria

This section determines 10 GEE criteria using the Fuzzy AHP method. Table 7 provides the final prioritizing order of GEE criteria. It can be seen that the Socio-Economic Development Policies (A1) is the most relevant GEE criteria with a weight of 0.161 (16.10%) to achieve sustainable environmental regulation and economic efficiency goals. The Green Industrial Development (C3) obtained the second highest weight of 0.124 (12.40%). The Green Growth Agenda (B2) received third importance with a weight of 0.120 (12%) from the overall 10 GEE criteria. The Blue-Green Infrastructure Development (H8), Pollution Control and Waste Management (I9), and Labor Policies (J10) are considered to be the least significant GEE criteria. Overall, the results present that all these criteria are vital for adopting sustainable environmental regulation and GEE criteria in China. The fuzzy pairwise comparison matrix of the AHP method for GEE criteria and sub-criteria are provided in Appendix 1 Tables 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21.

The results of GEE sub-criteria

In the above section, the GEE criteria were analyzed and ranked using the Fuzzy AHP method. So, in this section, it further obtained the GEE sub-criteria ranking based on each

criterion. Figure 2 shows the final prioritizing order of GEE sub-criteria with respect to Socio-Economic Development Policies (A1). According to the findings, the Sustainable Development Initiative (A11) is the priority GEE sub-criteria with a weight of 0.186 (18.60%). The Green Civil Society Initiative(s) (A12) is a second significant GEE sub-criteria with a weight of 0.184 (18.40%). Furthermore, the Gender Mainstreaming (A14) and Sectoral and Regional Development Initiatives (A15) are recognized as the third important GEE sub-criterion with the same weight of 0.171 (17.10%). Ensuring Stakeholder Participation (A13) and Social Inclusion in Green Economy (A16) has obtained the lowest weight of 0.168 (16.80%) and 0.120 (12%). The analysis reveals that all these sub-criteria are very important for developing environmental regulation and GEE in China.

Figure 3 shows the weight and ranking of GEE sub-criteria with respect to the Green Growth Agenda (B2). It can be seen that the Simulate Green Investment (B23) is the significant GEE sub-criteria with a weight of 0.219 (21.90%). The Government Investment Incentives (B24) is the subsequent vital GEE sub-criteria with a weight of 0.218 (21.80%). The Inclusive and Collaborative Planning (B21) and Promote Green Growth Patterns (B22) are the third significant GEE sub-criteria with an equal weight of 0.211 (21.10%), respectively. The Sustainable Special Economic Zone Development (B25) obtained the lowest weight of 0.141 (14.10%). It is

Fig. 6 Weight and ranking of Resource Efficiency (E5)

Fig. 7 Weight and ranking of Technological Initiatives and Innovation (F6)

identified that all these 5 GEE sub-criteria are vital under the B2 category.

Figure 4 shows the weight and ranking of GEE sub-criteria under Green Industrial Development (C3). Under this category, the Green Innovation Initiative for Green Industrial Growth (C33) ranked the first crucial GEE sub-criteria with a weight of 0.189 (18.90%). The Green Product Innovation (C31) obtained the second highest importance with a weight of 0.185 (18.50%). The Industrial Specialization (C34) received third vital GEE sub-criteria with a weight of 0.184 (18.40%). The green Craft Innovation (C32), Industrial Diversity (C35), and Industrial Competition (C36) are moderate to least important sub-criterion to attain the environmental regulation and GEE alternative strategies.

Figure 5 shows the weight and ranking of GEE sub-criteria under Environmental Regulations (D4). Under this sub-criterion, the ranking indicates that the Administrative Environmental Regulations (D41) received the highest weight of 0.273 (27.30%). The Monitoring and Evaluation System Development (D43) obtained the second highest weight of 0.218 (21.80%). The Market-based Environmental Regulations (D42) got third important GEE sub-criteria with a weight of 0.203 (20.30%). Public Participation in Environmental Regulation and Compliance (D44) and Land/Planning laws (D45) achieved the lowest weight scores under the D4 category.

It is imperative to mention that the analyzed GEE sub-criterion is very significant to implement sustainable environmental regulation and the GEE system in the country.

Figure 6 presents the weight and ranking of the GEE sub-criterion with respect to Resource Efficiency (E5). It shows that the Minimization of Environmental Risk (E51) obtained the first ranked GEE sub-criteria under the E5 category with a weight of 0.279 (27.90%). Reducing Waste through Industrial Symbiosis (E53) achieved the second highest weight of 0.224 (22.40%). The Sustainable Public Procurement (E52), Reduce Resources and Energy Consumption (E54), and Efficient Land Use (E55) obtained the third, fourth, and fifth ranks, respectively.

Figure 7 displays the weight and ranking of the GEE sub-criterion under Technological Initiatives and Innovation (F6). The Direct Government Funding and Tax Incentives (F61) were reported as the highest ranked GEE sub-criteria with a weight of 0.229 (22.90%). The Intellectual Property Laws (F62) achieved the second highest weight of 0.216 (21.60%). Research and Development (R&D) (F63) is considered to be the third important GEE sub-criteria with a weight of 0.210 (21%). The Green Technology Innovation (F64) and Marketization Innovation (F65) were reported to be the least vital GEE sub-criterion with a weight of 0.201 (20.10%) and 0.144 (14.40%).

Fig. 8 Weight and ranking of Green Energy Production and Consumption Practices (G7)

Fig. 9 Weight and ranking of Blue-Green Infrastructure Development (H8)

Figure 8 displays the weight and ranking of GEE sub-criteria with respect to Green Energy Production and Consumption Practices (G7). The analysis reveals that the Green Energy Initiative (G71) received the highest weight of 0.449 (44.90%), followed by Energy-Saving Technology Adoption (G72) and Green Energy Transmission and Distribution System (G73) with a weight of 0.321 (32.10%) and 0.230 (23%).

Figure 9 depicts the weight and ranking of GEE sub-criteria under Blue-Green Infrastructure Development (H8). The findings show that the Blue Infrastructure Development (H81) and Recycling Infrastructure (H83) attained the priority order with an equal weight of 0.219 (21.90%). The Transport Infrastructure (H84) is considered the second vital GEE sub-criteria with a weight of 0.214 (21.40%). The Green Stormwater Management System Development (H82) was the third crucial GEE sub-criteria with a weight of 0.200 (20%). The Green Buildings (H85) is considered the least vital sub-criteria with a weight of 0.148 (14.80%).

Figure 10 presents the weight and ranking of GEE sub-criteria with respect to the Pollution Control and Waste Management (I9). The results recommend that the Air Pollution Control (I91) is the most significant GEE sub-criteria with a weight of 0.300 (30%). Wastewater Management (I92) appeared as the second vital sub-criteria with a weight of 0.264 (26.40%). The Shared and Circular

Economy Promotion (I94) and Solid Waste Management (I93) recognized as third and fourth vital GEE sub-criterion with a weight of 0.247 (24.70%) and 0.188 (18.80%).

Figure 11 shows the weight and ranking of GEE sub-criteria under Labor Policies (J10). The results indicate that Skill Development (J101) is the top-ranked GEE sub-criteria with a weight of 0.277 (27.70%). The SME Development (J103) appeared as the second important sub-criteria with a weight of 0.254 (25.40%). The Green Jobs (J104) and Occupational Safety and Health (J102) have been identified as third and fourth vital GEE sub-criterion with a weight of 0.242 (24.20%) and 0.228 (22.80%). Therefore, it is determined that most of the sub-criteria under the J10 category are very significant for achieving sustainable environmental regulation and GEE goals in the country.

Results of overall GEE sub-criteria

This sub-section finally determines the overall ranking of GEE sub-criteria with respect to the decision-making goal of the study. The overall weight of sub-criteria has been obtained through multiplying the initial weights of sub-criteria to their respective GEE criteria. Table 8 shows the overall weight and ranking of GEE sub-criteria. The findings reveal that Green Energy Initiative (G71) and Energy-Saving Technology Adoption (G72) are the most significant sub-criteria among

Fig. 10 Weight and ranking of Pollution Control and Waste Management (I9)

Fig. 11 Weight and ranking of Labor Policies (J10)

all 48 GEE sub-criteria. The G71 and G72 sub-criteria reported the highest final weights of 0.0507 (5.07%) and 0.0362 (3.62%). These GEE sub-criteria belong to the Green Energy Production and Consumption Practices (G7). The Sustainable Development Initiative (A11) followed by Green Civil Society Initiative(s) (A12), Gender Mainstreaming (A14), and Sectoral and Regional Development Initiatives (A15) are the next vital GEE sub-criterion. These sub-criteria A11, A12, A14, and A15 belong to the Socio-Economic Development Policies (A1) category. The remaining GEE sub-criteria have been prioritized as follows: A13 < B23 < B24 < J101 < G73 < B21 < B22 < J103 < C33 < H81 < C31 < C34 < I91 < J104 < H84 < C32 < J102 < H82 < I92 < F61 < A16 < I94 < F62 < D41 < F63 < C35 < F64 < B25 < H85 < C36 < D43 < E51 < I93 < D42 < F65 < D44 < E53 < E52 < E54 < D45 < E55. Finally, the findings show that all GE sub-criteria are suitable to be applied for the achievement of sustainable environmental regulation and GEE system in China.

Results of Fuzzy VIKOR (GEE alternative strategies)

In this section, the ranking of 5 GE alternative strategies has been evaluated using the Fuzzy VIKOR methodology. A group analyzed 6 experts to form group decision-making at the end. The fuzzy decision matrix, fuzzy positive and negative ideal values, fuzzy normalized decision matrix, and the fuzzy values S , R , and Q are presented in [Appendix 2](#) of this paper. All criteria of this study were considered as benefit criteria.

In the adoption of the Fuzzy VIKOR approach, the strategy with lowest Q value has been considered as an optimal alternative. The obtained fuzzy values of S , R , and Q are presented in [Table 9](#). Moreover, the final ranking based on the Q value is shown in [Table 10](#). The findings of the Fuzzy VIKOR method indicate that resource efficiency and green purchasing strategy (S2) is the most suitable alternative for sustainable development in China. Local production and utilization strategy (S3)

is the second important alternative to follow sustainable environmental regulation and GEE in China. The green economic development strategy (S1) is considered as a third vital alternative of the study. The waste stream management strategy (S4) and green infrastructure strategy (S5) are the least significant alternatives. It is identified that all these strategies are very crucial for the sustainable economic, social, and environmental development of the country.

The Fuzzy AHP and Fuzzy VIKOR methods have been applied systematically to determine the environmental regulation and GEE criteria problem in the context of Chinese economy. This process will serve the country to achieve green development phase. Moreover, this research will help the government and decision-makers to select and evaluate the feasible GEE criteria and alternative strategies for the sustainable development of the country.

Discussion

This research aims to select, assess, and rank the essential GEE criteria, sub-criteria, and alternative strategies for the implementation of sustainable economic, social, and environmental development in China. This decision-making problem comprehensively provides the comprehension to accomplish environmental regulation and GEE in the post-COVID-19 situation. This process has been done using a fuzzy-based multi-criteria analysis. In this regard, the fuzzy-based AHP and VIKOR methods have been used to analyze and rank the GEE criteria and alternative strategies. The evaluation process in the real-life example is complicated and uncertain. Thus, this research used the fuzzy set theory to reduce uncertainty, shortcoming, and fuzziness during the decision-making process.

The ranking of GEE criteria and sub-criteria are presented in [Figs. 2, 3, 4, 5, 6, 7, 8, 9, and 10](#). The global weights of sub-criteria are shown in [Table 8](#). Among 10 GEE criteria, Socio-Economic Development Policies (A1), Green Industrial

Table 8 The overall weight and ranking of GEE sub-criteria with respect to the decision goal of the study

Code	GEE sub-criteria	Weight	Rank
A11	Sustainable Development Initiative	0.0299	3
A12	Green Civil Society Initiative(s)	0.0296	4
A13	Ensuring Stakeholder Participation	0.0270	6
A14	Gender Mainstreaming	0.0275	5
A15	Sectoral and Regional Development Initiatives	0.0275	5
A16	Social Inclusion in Green Economy	0.0193	25
B21	Inclusive and Collaborative Planning	0.0253	11
B22	Promote Green Growth Patterns	0.0253	11
B23	Simulate Green Investment	0.0262	7
B24	Government Investment Incentives (GIIs)	0.0261	8
B25	Sustainable Special Economic Zone Development	0.0169	32
C31	Green Product Innovation (GPI)	0.0229	15
C32	Green Craft Innovation (GCI)	0.0221	20
C33	Green Innovation Initiative (GII) for Green Industrial Growth (GIG)	0.0234	13
C34	Industrial Specialization	0.0228	16
C35	Industrial Diversity	0.0179	30
C36	Industrial Competition	0.0146	34
D41	Administrative Environmental Regulations (AERs)	0.0182	28
D42	Market-based Environmental Regulations (MERs)	0.0136	38
D43	Monitoring and Evaluation System Development	0.0146	35
D44	Public Participation in Environmental Regulation and Compliance	0.0119	40
D45	Land/Planning Laws	0.0085	44
E51	Minimization of Environmental Risk	0.0145	36
E52	Sustainable Public Procurement	0.0105	42
E53	Reducing Waste through Industrial Symbiosis	0.0116	41
E54	Reduce Resources and Energy Consumption	0.0086	43
E55	Efficient Land Use	0.0066	45
F61	Direct Government Funding and Tax Incentives	0.0196	24
F62	Intellectual Property Laws	0.0185	27
F63	Research and Development (R&D)	0.0180	29
F64	Green Technology Innovation	0.0172	31
F65	Marketization Innovation	0.0123	39
G71	Green Energy Initiative	0.0507	1
G72	Energy-Saving Technology Adoption	0.0362	2
G73	Green Energy Transmission and Distribution System	0.0259	10
H81	Blue Infrastructure Development	0.0232	14
H82	Green Storm water Management System Development	0.0212	22
H83	Recycling Infrastructure	0.0232	14
H84	Transport Infrastructure	0.0226	19
H85	Green Buildings	0.0156	33
I91	Air Pollution Control	0.0228	17
I92	Wastewater Management	0.0200	23
I93	Solid Waste Management	0.0142	37
I94	Shared and Circular Economy Promotion	0.0187	26
J101	Skill Development	0.0260	9
J102	Occupational Safety and Health (OSH)	0.0214	21
J103	SME Development	0.0238	12
J104	Green Jobs	0.0227	18

Table 9 Crisp values and ranking of alternatives based on S , R , and Q

	Crisp value of R	Rank in R	Crisp value of S	Rank in S	Crisp value of Q	Rank in Q
S1	0.01	4	0.155	3	0.085	3
S2	0.006	1	0.093	1	0.001	1
S3	0.007	2	0.124	2	0.034	2
S4	0.009	3	0.204	4	0.091	4
S5	0.011	5	0.216	5	0.114	5

Development (C3), and Green Growth Agenda (B2) are the most important criteria for the adoption and boosting up of the sustainable environmental regulation and GEE in China. Furthermore, the final ranking of sub-criteria shows that Green Energy (G71), Energy-Saving Technology Adoption (G72), and Sustainable Development Initiative (A11) are the most significant criteria. After obtaining the findings of criteria and sub-criteria using the Fuzzy AHP approach, this research uses the Fuzzy VIKOR method to analyze and rank the various strategies. This method indicates that resource efficiency and green purchasing (S2) is the most suitable strategy for developing environmental regulation and GEE in the country. The local production and utilization (S3) and green economic development (S1) are the second and third vital GEE alternative strategies.

There are various previous researches on the transformation of environmental regulation and GEE. Such as transition to green industrial growth (Feng and Chen 2018), environmental regulation can decrease the harmful influence of green technological innovation (Liu et al. 2020), and environmental regulation, industrial innovation, and green development in the context Chinese manufacturing (Yuan and Xiang 2018). Furthermore, the economic growth, and energy regulation, and environmental degradation for OECD countries (Lorente and Álvarez-Herranz 2016). However, this research is the very first attempt in the context of China. Moreover, none of the authors has used fuzzy-based multi-criteria analysis to solve this multi-faceted decision-making problem. This study uses Fuzzy AHP and Fuzzy VIKOR methods to determine this decision-making problem. This research is unique in terms of identifying, evaluating, and ranking environmental regulation and GEE criteria, sub-criteria, and strategies. The

proposed research framework determined the 10 criteria, 48 sub-criteria, and 5 strategies. To the best of the author's knowledge, none of the studies utilized composed these important criteria for the evaluation process. The proposed fuzzy multi-criteria analysis framework of this research is a very supportive tool for the government, decision-makers, and stakeholders for sustainable economic and environmental development.

Conclusion

The transition to a green economy and the achievement of GEE are the objectives of governments all over the globe. Achievement of GEE in an economy may depend on specifics of an economy's development, patterns of development, the structure of the economy, structure of environmental regulations, and their implementation in the economy. Moreover, the COVID-19 outbreak diverted the consideration of the governments toward an unparalleled worldwide health crisis posed by a novel coronavirus. The Chinese economy is the first country, which is hit by the COVID-19 pandemic, focusing on economic retrieval. In addition to this, multiple socio-cultural-economic-environmental-institutional factors may have their insinuations of the eco-efficient and GEE of the economy. Like other economies, the Chinese economy has started focusing on green economic development and GEE to achieve SDGs. The present study is a pioneer attempt to examine and prioritize GEE alternative strategies in the context of environmental regulations. This study is a fuzzy-based multi-criteria decision analysis in the context of environmental regulations and GEE in China. This study assesses and

Table 10 Final alternatives (strategies) ranking according to the lowest Q values

Code	Strategy	Crisp value of Q	Rank final
S1	Green economic development	0.085	3
S2	Resource efficiency and green purchasing	0.001	1
S3	Local production and utilization	0.034	2
S4	Waste stream management	0.091	4
S5	Green infrastructure	0.114	5

prioritizes 5 alternative strategies for GEE in China while identifying 10 criteria and their respective sub-criteria.

The mostly used multi-criteria tool of Fuzzy AHP has been employed to assess and prioritize the criteria and sub-criteria. The Fuzzy VIKOR has been used to evaluate and rank the 5 alternative GEE strategies. The developed criteria, sub-criteria, and strategies are qualitative; therefore, it is difficult to analyze and obtain accurate results. Thus, fuzzy-based multi-criteria analysis has been utilized to analyze this decision-making problem. The Fuzzy AHP and Fuzzy VIKOR methods allow an expert to use quantitative terms using a TFN scale. The TFNs can help deal with uncertain and subjective data for reducing ambiguity and uncertainty during the evaluation process. The empirical results of Fuzzy AHP show that Socio-Economic Development

Policies (A1) are the most vital criteria to initiate green economic development and GEE for the achievement of SDGs in China. The final ranking of sub-criteria shows that Green Energy (G71) is the most significant in overall sub-criteria. The Fuzzy VIKOR approach shows that resource efficiency and green purchasing (S2) is the most crucial strategy in transiting to the green economy in China. It is determined that the proposed fuzzy decision analysis framework is critical in adopting GEE criteria and strategies in the context of China. Therefore, the governments and decision-makers can apply this model to assess and rank the GEE criteria and alternative strategies for sustainable economic, environmental, and social development in the post-COVID-19 scenario.

Appendix 1. The Fuzzy AHP results

Table 11 Fuzzy pairwise comparison with respect to the decision-making goal of the study

	A1	B2	C3	D4	E5	F6	G7	H8	I9	J10
A1	(1.000, 1.000, 1.000)	(1.000, 1.944, 4.000)	(1.000, 2.038, 4.000)	(1.000, 2.181, 4.000)	(1.000, 2.883, 5.000)	(1.000, 2.797, 6.000)	(1.000, 2.696, 5.000)	(2.000, 3.268, 6.000)	(1.000, 3.358, 6.000)	(2.000, 3.597, 6.000)
B2	(0.250, 0.514, 1.000)	(1.000, 1.000, 1.000)	(1.000, 1.000, 1.000)	(1.000, 1.122, 3.000)	(1.000, 1.347, 4.000)	(1.000, 1.998, 3.000)	(1.000, 1.413, 3.000)	(1.000, 1.905, 4.000)	(1.000, 1.347, 4.000)	(1.000, 1.259, 3.000)
C3	(0.250, 0.491, 1.000)	(1.000, 1.000, 1.000)	(1.000, 1.000, 1.000)	(1.000, 1.122, 3.000)	(1.000, 1.780, 3.000)	(1.000, 1.586, 3.000)	(1.000, 1.619, 4.000)	(1.000, 1.697, 4.000)	(1.000, 1.512, 4.000)	(1.000, 2.181, 4.000)
D4	(0.250, 0.459, 1.000)	(0.333, 0.891, 1.000)	(0.333, 0.891, 1.000)	(1.000, 1.000, 1.000)	(1.000, 1.000, 1.000)	(1.000, 2.038, 4.000)	(1.000, 1.259, 3.000)	(1.000, 1.259, 3.000)	(1.000, 1.905, 4.000)	(1.000, 1.697, 4.000)
E5	(0.200, 0.347, 1.000)	(0.250, 0.742, 1.000)	(0.333, 0.562, 1.000)	(1.000, 1.000, 1.000)	(1.000, 1.000, 1.000)	(1.000, 1.259, 3.000)	(1.000, 1.586, 3.000)	(1.000, 1.259, 3.000)	(1.000, 1.586, 3.000)	(1.000, 1.905, 4.000)
F6	(0.167, 0.358, 1.000)	(0.333, 0.501, 1.000)	(0.333, 0.631, 1.000)	(0.250, 0.491, 1.000)	(0.333, 0.794, 1.000)	(1.000, 1.000, 1.000)	(1.000, 1.122, 3.000)	(1.000, 1.586, 3.000)	(1.000, 1.413, 3.000)	(1.000, 1.413, 3.000)
G7	(0.200, 0.371, 1.000)	(0.333, 0.708, 1.000)	(0.250, 0.618, 1.000)	(0.333, 0.794, 1.000)	(0.333, 0.631, 1.000)	(0.333, 0.891, 1.000)	(1.000, 1.000, 1.000)	(1.000, 1.122, 3.000)	(1.000, 1.259, 3.000)	(1.000, 1.259, 3.000)
H8	(0.167, 0.306, 0.500)	(0.250, 0.525, 1.000)	(0.250, 0.589, 1.000)	(0.333, 0.794, 1.000)	(0.333, 0.794, 1.000)	(0.333, 0.631, 1.000)	(0.333, 0.891, 1.000)	(1.000, 1.000, 1.000)	(1.000, 1.259, 3.000)	(1.000, 1.586, 3.000)
I9	(0.167, 0.298, 1.000)	(0.250, 0.742, 1.000)	(0.250, 0.661, 1.000)	(0.250, 0.525, 1.000)	(0.333, 0.631, 1.000)	(0.333, 0.708, 1.000)	(0.333, 0.794, 1.000)	(0.333, 0.794, 1.000)	(1.000, 1.000, 1.000)	(1.000, 1.259, 3.000)
J10	(0.167, 0.278, 0.500)	(0.333, 0.794, 1.000)	(0.250, 0.459, 1.000)	(0.250, 0.589, 1.000)	(0.250, 0.525, 1.000)	(0.333, 0.708, 1.000)	(0.333, 0.794, 1.000)	(0.333, 0.631, 1.000)	(0.333, 0.794, 1.000)	(1.000, 1.000, 1.000)

Table 12 Fuzzy pairwise comparison with respect to Socio-Economic Development Policies (A1)

	A11	A12	A13	A14	A15	A16
A11	(1.000, 1.000, 1.000)	(0.333, 1.201, 4.000)	(1.000, 1.619, 4.000)	(1.000, 1.442, 4.000)	(0.333, 1.348, 4.000)	(1.000, 2.492, 6.000)
A12	(0.250, 0.833, 3.003)	(1.000, 1.000, 1.000)	(1.000, 1.618, 4.000)	(0.333, 1.201, 4.000)	(0.333, 1.513, 5.000)	(1.000, 2.288, 5.000)
A13	(0.250, 0.618, 1.000)	(0.250, 0.618, 1.000)	(1.000, 1.000, 1.000)	(0.333, 1.000, 3.000)	(0.250, 1.048, 3.000)	(1.000, 2.182, 4.000)
A14	(0.250, 0.693, 1.000)	(0.250, 0.833, 3.003)	(0.333, 1.000, 3.003)	(1.000, 1.000, 1.000)	(0.250, 1.122, 4.000)	(1.000, 1.816, 4.000)
A15	(0.250, 0.742, 3.003)	(0.200, 0.661, 3.003)	(0.333, 0.954, 4.000)	(0.250, 0.891, 4.000)	(1.000, 1.000, 1.000)	(1.000, 1.512, 4.000)
A16	(0.167, 0.401, 1.000)	(0.200, 0.437, 1.000)	(0.250, 0.458, 1.000)	(0.250, 0.551, 1.000)	(0.250, 0.661, 1.000)	(1.000, 1.000, 1.000)

Table 13 Fuzzy pairwise comparison with respect to Green Growth Agenda (B2)

	B21	B22	B23	B24	B25
B21	(1.000, 1.000, 1.000)	(0.250, 0.934, 3.000)	(0.250, 0.833, 4.000)	(0.250, 0.890, 4.000)	(1.000, 2.290, 5.000)
B22	(0.333, 1.071, 4.000)	(1.000, 1.000, 1.000)	(0.200, 0.794, 1.000)	(0.250, 0.694, 3.000)	(1.000, 2.620, 4.000)
B23	(0.250, 1.200, 4.000)	(1.000, 1.259, 5.000)	(1.000, 1.000, 1.000)	(1.000, 1.122, 3.000)	(1.000, 2.448, 4.000)
B24	(0.250, 1.124, 4.000)	(0.333, 1.441, 4.000)	(0.333, 0.891, 1.000)	(1.000, 1.000, 1.000)	(1.000, 2.450, 5.000)
B25	(0.200, 0.437, 1.000)	(0.250, 0.382, 1.000)	(0.250, 0.408, 1.000)	(0.200, 0.408, 1.000)	(1.000, 1.000, 1.000)

Table 14 Fuzzy pairwise comparison with respect to Green Industrial Development (C3)

	C31	C32	C33	C34	C35	C36
C31	(1.000, 1.000, 1.000)	(0.250, 1.260, 4.000)	(0.250, 0.891, 4.000)	(0.250, 0.891, 4.000)	(1.000, 1.781, 5.000)	(1.000, 2.289, 5.000)
C32	(0.250, 0.794, 4.000)	(1.000, 1.000, 1.000)	(0.250, 0.742, 1.000)	(0.250, 0.833, 3.000)	(1.000, 1.816, 4.000)	(1.000, 2.181, 4.000)
C33	(0.250, 1.122, 4.000)	(1.000, 1.348, 4.000)	(1.000, 1.000, 1.000)	(1.000, 1.348, 4.000)	(1.000, 1.905, 4.000)	(1.000, 2.288, 4.000)
C34	(0.250, 1.122, 4.000)	(0.333, 1.200, 4.000)	(0.250, 0.742, 1.000)	(1.000, 1.000, 1.000)	(1.000, 1.816, 4.000)	(1.000, 2.138, 5.000)
C35	(0.200, 0.561, 1.000)	(0.250, 0.551, 1.000)	(0.250, 0.525, 1.000)	(0.250, 0.551, 1.000)	(1.000, 1.000, 1.000)	(1.000, 1.347, 4.000)
C36	(0.200, 0.437, 1.000)	(0.250, 0.459, 1.000)	(0.250, 0.437, 1.000)	(0.200, 0.468, 1.000)	(0.250, 0.742, 1.000)	(1.000, 1.000, 1.000)

Table 15 Fuzzy pairwise comparison with respect to Environmental Regulations (D4)

	D41	D42	D43	D44	D45
D41	(1.000, 1.000, 1.000)	(1.000, 1.697, 4.000)	(1.000, 2.038, 4.000)	(1.000, 2.181, 4.000)	(1.000, 2.620, 4.000)
D42	(0.250, 0.589, 1.000)	(1.000, 1.000, 1.000)	(0.333, 1.122, 3.000)	(1.000, 1.000, 1.000)	(1.000, 1.348, 4.000)
D43	(0.250, 0.491, 1.000)	(0.333, 0.891, 3.003)	(1.000, 1.000, 1.000)	(1.000, 1.780, 3.000)	(1.000, 1.347, 4.000)
D44	(0.250, 0.459, 1.000)	(1.000, 1.000, 1.000)	(0.333, 0.562, 1.000)	(1.000, 1.000, 1.000)	(1.000, 1.201, 4.000)
D45	(0.250, 0.382, 1.000)	(0.250, 0.742, 1.000)	(0.250, 0.742, 1.000)	(0.250, 0.833, 1.000)	(1.000, 1.000, 1.000)

Table 16 Fuzzy pairwise comparison with respect to Resource Efficiency (E5)

	E51	E52	E53	E54	E55
E51	(1.000, 1.000, 1.000)	(1.000, 2.181, 4.000)	(1.000, 2.038, 4.000)	(1.000, 2.450, 5.000)	(1.000, 2.288, 4.000)
E52	(0.250, 0.459, 1.000)	(1.000, 1.000, 1.000)	(0.333, 0.891, 1.000)	(1.000, 1.259, 3.000)	(1.000, 1.347, 4.000)
E53	(0.250, 0.491, 1.000)	(1.000, 1.122, 3.003)	(1.000, 1.000, 1.000)	(1.000, 1.201, 4.000)	(1.000, 1.697, 4.000)
E54	(0.200, 0.408, 1.000)	(0.333, 0.794, 1.000)	(0.250, 0.833, 1.000)	(1.000, 1.000, 1.000)	(1.000, 1.122, 3.000)
E55	(0.250, 0.437, 1.000)	(0.250, 0.742, 1.000)	(0.250, 0.589, 1.000)	(0.333, 0.891, 1.000)	(1.000, 1.000, 1.000)

Table 17 Fuzzy pairwise comparison with respect to Technological Initiatives and Innovation (F6)

	F61	F62	F63	F64	F65
F61	(1.000, 1.000, 1.000)	(1.000, 1.512, 4.000)	(0.333, 1.441, 4.000)	(0.333, 1.441, 4.000)	(1.000, 2.039, 4.000)
F62	(0.250, 0.661, 1.000)	(1.000, 1.000, 1.000)	(1.000, 1.201, 4.000)	(0.333, 1.000, 3.000)	(1.000, 2.290, 4.000)
F63	(0.250, 0.694, 3.003)	(0.250, 0.833, 1.000)	(1.000, 1.000, 1.000)	(1.000, 1.259, 3.000)	(1.000, 1.905, 4.000)
F64	(0.250, 0.694, 3.003)	(0.333, 1.000, 3.003)	(0.333, 0.794, 1.000)	(1.000, 1.000, 1.000)	(1.000, 1.201, 4.000)
F65	(0.250, 0.490, 1.000)	(0.250, 0.437, 1.000)	(0.250, 0.525, 1.000)	(0.250, 0.833, 1.000)	(1.000, 1.000, 1.000)

Table 18 Fuzzy pairwise comparison under Green Energy Production and Consumption Practices (G7)

	G71	G72	G73
G71	(1.000, 1.000, 1.000)	(1.000, 1.698, 4.000)	(1.000, 2.377, 6.000)
G72	(0.250, 0.589, 1.000)	(1.000, 1.000, 1.000)	(1.000, 1.122, 3.000)
G73	(0.167, 0.421, 1.000)	(0.333, 0.891, 1.000)	(1.000, 1.000, 1.000)

Table 19 Fuzzy pairwise comparison with respect to Blue-Green Infrastructure Development (H8)

	H81	H82	H83	H84	H85
H81	(1.000, 1.000, 1.000)	(1.000, 1.442, 4.000)	(0.250, 1.070, 4.000)	(0.250, 0.954, 4.000)	(1.000, 2.289, 5.000)
H82	(0.250, 0.693, 1.000)	(1.000, 1.000, 1.000)	(0.250, 0.742, 1.000)	(0.250, 0.833, 3.000)	(1.000, 1.817, 4.000)
H83	(0.250, 0.935, 4.000)	(1.000, 1.348, 4.000)	(1.000, 1.000, 1.000)	(0.333, 1.201, 4.000)	(1.000, 2.288, 4.000)
H84	(0.250, 1.048, 4.000)	(0.333, 1.200, 4.000)	(0.250, 0.833, 3.003)	(1.000, 1.000, 1.000)	(1.000, 2.038, 4.000)
H85	(0.200, 0.437, 1.000)	(0.250, 0.550, 1.000)	(0.250, 0.437, 1.000)	(0.250, 0.491, 1.000)	(1.000, 1.000, 1.000)

Table 20 Fuzzy pairwise comparison with respect to Pollution Control and Waste Management (I9)

	I91	I92	I93	I94
I91	(1.000, 1.000, 1.000)	(0.333, 1.512, 5.000)	(1.000, 1.998, 3.000)	(1.000, 1.817, 4.000)
I92	(0.200, 0.661, 3.003)	(1.000, 1.000, 1.000)	(1.000, 1.122, 3.000)	(0.250, 1.259, 4.000)
I93	(0.333, 0.501, 1.000)	(0.333, 0.891, 1.000)	(1.000, 1.000, 1.000)	(0.333, 0.891, 1.000)
I94	(0.250, 0.550, 1.000)	(0.250, 0.794, 4.000)	(1.000, 1.122, 3.003)	(1.000, 1.000, 1.000)

Table 21 Fuzzy pairwise comparison with respect to Labor Policies (J10)

	J101	J102	J103	J104
J101	(1.000, 1.000, 1.000)	(1.000, 1.697, 4.000)	(0.333, 1.543, 4.000)	(0.333, 1.347, 4.000)
J102	(0.250, 0.589, 1.000)	(1.000, 1.000, 1.000)	(0.250, 0.833, 1.000)	(0.250, 1.177, 3.000)
J103	(0.250, 0.648, 3.003)	(1.000, 1.200, 4.000)	(1.000, 1.000, 1.000)	(1.000, 1.122, 3.000)
J104	(0.250, 0.742, 3.003)	(0.333, 0.850, 4.000)	(0.333, 0.891, 1.000)	(1.000, 1.000, 1.000)

Appendix- 2: The Fuzzy VIKOR results

Table 22 Fuzzy decision matrix

	A11	A12	A13	A14	A15	A16	B21	B22	B23	B24	B25	C31
S1	(0.083, 0.208, 0.458)	(0.167, 0.250, 0.500)	(0.167, 0.333, 0.583)	(0.167, 0.333, 0.583)	(0.208, 0.375, 0.625)	(0.167, 0.292, 0.542)	(0.125, 0.250, 0.500)	(0.167, 0.292, 0.542)	(0.083, 0.292, 0.542)	(0.208, 0.417, 0.667)	(0.125, 0.250, 0.500)	(0.250, 0.417, 0.667)
S2	(0.042, 0.292, 0.542)	(0.042, 0.167, 0.417)	(0.125, 0.333, 0.583)	(0.167, 0.417, 0.667)	(0.167, 0.417, 0.667)	(0.125, 0.375, 0.625)	(0.125, 0.292, 0.542)	(0.083, 0.208, 0.458)	(0.125, 0.333, 0.583)	(0.125, 0.333, 0.583)	(0.083, 0.333, 0.583)	(0.167, 0.375, 0.625)
S3	(0.167, 0.375, 0.625)	(0.083, 0.333, 0.583)	(0.042, 0.250, 0.500)	(0.042, 0.250, 0.500)	(0.125, 0.375, 0.625)	(0.083, 0.292, 0.542)	(0.083, 0.292, 0.542)	(0.083, 0.208, 0.458)	(0.042, 0.125, 0.375)	(0.125, 0.333, 0.583)	(0.125, 0.333, 0.583)	(0.125, 0.292, 0.542)
S4	(0.125, 0.292, 0.542)	(0.042, 0.125, 0.375)	(0.083, 0.208, 0.458)	(0.042, 0.167, 0.417)	(0.042, 0.250, 0.500)	(0.167, 0.375, 0.625)	(0.208, 0.417, 0.667)	(0.042, 0.208, 0.458)	(0.042, 0.125, 0.375)	(0.000, 0.167, 0.417)	(0.083, 0.208, 0.458)	(0.083, 0.250, 0.500)
S5	(0.000, 0.125, 0.375)	(0.000, 0.167, 0.417)	(0.083, 0.250, 0.500)	(0.042, 0.208, 0.458)	(0.125, 0.292, 0.542)	(0.083, 0.167, 0.417)	(0.250, 0.458, 0.708)	(0.083, 0.167, 0.417)	(0.083, 0.292, 0.542)	(0.083, 0.167, 0.417)	(0.083, 0.250, 0.500)	(0.167, 0.333, 0.583)
E54	E55	F61	F62	F63	F64	F65	G71	G72	G73	H81	H82	H83
(0.125, 0.250, 0.500)	(0.083, 0.208, 0.458)	(0.125, 0.250, 0.500)	(0.000, 0.167, 0.417)	(0.250, 0.417, 0.667)	(0.125, 0.292, 0.542)	(0.250, 0.458, 0.708)	(0.042, 0.208, 0.458)	(0.167, 0.333, 0.583)	(0.083, 0.250, 0.500)	(0.125, 0.333, 0.583)	(0.000, 0.083, 0.333)	(0.208, 0.375, 0.625)
(0.042, 0.208, 0.458)	(0.083, 0.333, 0.583)	(0.042, 0.250, 0.500)	(0.125, 0.292, 0.542)	(0.083, 0.292, 0.542)	(0.083, 0.250, 0.500)	(0.208, 0.458, 0.708)	(0.125, 0.333, 0.583)	(0.125, 0.333, 0.583)	(0.083, 0.292, 0.542)	(0.167, 0.417, 0.667)	(0.208, 0.375, 0.625)	(0.167, 0.375, 0.625)
(0.083, 0.250, 0.500)	(0.125, 0.375, 0.625)	(0.167, 0.333, 0.583)	(0.083, 0.167, 0.417)	(0.125, 0.333, 0.583)	(0.167, 0.375, 0.625)	(0.167, 0.417, 0.667)	(0.125, 0.292, 0.542)	(0.083, 0.292, 0.542)	(0.167, 0.375, 0.625)	(0.167, 0.417, 0.667)	(0.125, 0.250, 0.500)	(0.167, 0.417, 0.667)
(0.042, 0.250, 0.500)	(0.208, 0.375, 0.625)	(0.083, 0.250, 0.500)	(0.000, 0.125, 0.375)	(0.042, 0.250, 0.500)	(0.083, 0.208, 0.458)	(0.125, 0.375, 0.625)	(0.125, 0.250, 0.500)	(0.167, 0.417, 0.667)	(0.125, 0.333, 0.583)	(0.083, 0.250, 0.500)	(0.042, 0.167, 0.417)	(0.083, 0.292, 0.542)
(0.167, 0.333, 0.583)	(0.000, 0.125, 0.375)	(0.083, 0.292, 0.542)	(0.083, 0.250, 0.500)	(0.042, 0.167, 0.417)	(0.083, 0.250, 0.500)	(0.042, 0.083, 0.333)	(0.083, 0.250, 0.500)	(0.125, 0.250, 0.500)	(0.042, 0.167, 0.417)	(0.000, 0.167, 0.417)	(0.083, 0.208, 0.458)	(0.042, 0.250, 0.500)

	C32	C33	C34	C35	C36	D41	D42	D43	D44	D45	E51	E52	E53
S1	(0.000, 0.083, 0.333)	(0.167, 0.292, 0.542)	(0.083, 0.250, 0.500)	(0.125, 0.292, 0.542)	(0.208, 0.417, 0.667)	(0.167, 0.375, 0.625)	(0.042, 0.125, 0.375)	(0.167, 0.292, 0.542)	(0.083, 0.208, 0.458)	(0.208, 0.375, 0.625)	(0.042, 0.250, 0.500)	(0.125, 0.250, 0.500)	(0.125, 0.250, 0.500)
S2	(0.208, 0.458, 0.708)	(0.125, 0.333, 0.583)	(0.250, 0.500, 0.750)	(0.125, 0.333, 0.583)	(0.208, 0.458, 0.708)	(0.042, 0.250, 0.500)	(0.125, 0.333, 0.583)	(0.042, 0.292, 0.542)	(0.208, 0.417, 0.667)	(0.083, 0.250, 0.500)	(0.167, 0.375, 0.625)	(0.167, 0.417, 0.667)	(0.167, 0.417, 0.667)
S3	(0.125, 0.375, 0.625)	(0.083, 0.292, 0.542)	(0.250, 0.500, 0.750)	(0.042, 0.208, 0.458)	(0.208, 0.417, 0.667)	(0.167, 0.375, 0.625)	(0.083, 0.292, 0.542)	(0.042, 0.292, 0.542)	(0.125, 0.333, 0.583)	(0.167, 0.417, 0.667)	(0.125, 0.292, 0.542)	(0.167, 0.417, 0.667)	(0.167, 0.417, 0.667)
S4	(0.167, 0.375, 0.625)	(0.083, 0.292, 0.542)	(0.083, 0.250, 0.500)	(0.042, 0.208, 0.458)	(0.000, 0.167, 0.417)	(0.000, 0.167, 0.417)	(0.042, 0.292, 0.542)	(0.000, 0.167, 0.417)	(0.083, 0.292, 0.542)	(0.000, 0.167, 0.417)	(0.167, 0.417, 0.667)	(0.167, 0.417, 0.667)	(0.167, 0.417, 0.667)
S5	(0.208, 0.417, 0.667)	(0.167, 0.375, 0.625)	(0.083, 0.208, 0.458)	(0.125, 0.292, 0.542)	(0.167, 0.375, 0.625)	(0.042, 0.208, 0.458)	(0.042, 0.167, 0.417)	(0.000, 0.167, 0.417)	(0.083, 0.292, 0.542)	(0.000, 0.167, 0.417)	(0.167, 0.417, 0.667)	(0.167, 0.417, 0.667)	(0.167, 0.417, 0.667)
E54	H84	H85	I91	I92	I93	I94	J101	J102	J103	J104	E54	E55	F61
(0.125, 0.250, 0.500)	(0.000, 0.083, 0.333)	(0.125, 0.250, 0.500)	(0.042, 0.167, 0.333)	(0.167, 0.333, 0.583)	(0.083, 0.208, 0.458)	(0.167, 0.375, 0.625)	(0.083, 0.292, 0.542)	(0.167, 0.375, 0.625)	(0.083, 0.292, 0.542)	(0.167, 0.375, 0.625)	(0.167, 0.375, 0.625)	(0.167, 0.375, 0.625)	(0.125, 0.250, 0.500)

Table 22 (continued)

(0.042, 0.208, 0.458)	(0.083, 0.250, 0.500)	(0.125, 0.333, 0.583)	(0.042, 0.250, 0.500)	(0.125, 0.333, 0.583)	(0.083, 0.250, 0.500)	(0.167, 0.333, 0.583)	(0.083, 0.250, 0.500)	(0.125, 0.292, 0.542)	(0.083, 0.292, 0.542)	(0.125, 0.292, 0.542)	(0.042, 0.208, 0.458)	(0.083, 0.333, 0.583)	(0.042, 0.250, 0.500)
(0.083, 0.250, 0.500)	(0.167, 0.292, 0.542)	(0.083, 0.167, 0.417)	(0.083, 0.250, 0.500)	(0.167, 0.333, 0.583)	(0.042, 0.250, 0.500)	(0.125, 0.333, 0.583)	(0.083, 0.250, 0.500)	(0.167, 0.333, 0.583)	(0.042, 0.250, 0.500)	(0.125, 0.292, 0.542)	(0.083, 0.333, 0.583)	(0.042, 0.250, 0.500)	(0.167, 0.333, 0.583)
(0.042, 0.250, 0.500)	(0.083, 0.250, 0.500)	(0.125, 0.333, 0.583)	(0.042, 0.250, 0.500)	(0.125, 0.333, 0.583)	(0.083, 0.250, 0.500)	(0.167, 0.333, 0.583)	(0.083, 0.250, 0.500)	(0.125, 0.292, 0.542)	(0.083, 0.292, 0.542)	(0.125, 0.292, 0.542)	(0.042, 0.208, 0.458)	(0.083, 0.333, 0.583)	(0.042, 0.250, 0.500)
(0.167, 0.333, 0.583)	(0.083, 0.250, 0.500)	(0.125, 0.333, 0.583)	(0.042, 0.250, 0.500)	(0.125, 0.333, 0.583)	(0.083, 0.250, 0.500)	(0.167, 0.333, 0.583)	(0.083, 0.250, 0.500)	(0.125, 0.292, 0.542)	(0.083, 0.292, 0.542)	(0.125, 0.292, 0.542)	(0.042, 0.208, 0.458)	(0.083, 0.333, 0.583)	(0.042, 0.250, 0.500)
(0.167, 0.333, 0.583)	(0.083, 0.250, 0.500)	(0.125, 0.333, 0.583)	(0.042, 0.250, 0.500)	(0.125, 0.333, 0.583)	(0.083, 0.250, 0.500)	(0.167, 0.333, 0.583)	(0.083, 0.250, 0.500)	(0.125, 0.292, 0.542)	(0.083, 0.292, 0.542)	(0.125, 0.292, 0.542)	(0.042, 0.208, 0.458)	(0.083, 0.333, 0.583)	(0.042, 0.250, 0.500)
(0.167, 0.333, 0.583)	(0.083, 0.250, 0.500)	(0.125, 0.333, 0.583)	(0.042, 0.250, 0.500)	(0.125, 0.333, 0.583)	(0.083, 0.250, 0.500)	(0.167, 0.333, 0.583)	(0.083, 0.250, 0.500)	(0.125, 0.292, 0.542)	(0.083, 0.292, 0.542)	(0.125, 0.292, 0.542)	(0.042, 0.208, 0.458)	(0.083, 0.333, 0.583)	(0.042, 0.250, 0.500)

Table 23 Fuzzy normalized values of the evaluation matrix

	A11	A12	A13	A14	A15	A16	B21	B22	B23	B24	B25	C31		
S1	(-0.466, 0.267, 0.867)	(-0.571, 0.142, 0.714)	(-0.769, 0.000, 0.769)	(-0.666, 0.134, 0.800)	(-0.667, 0.067, 0.734)	(-0.692, 0.153, 0.845)	(-0.400, 0.333, 0.933)	(-0.750, 0.000, 0.750)	(-0.771, 0.076, 0.924)	(-0.688, 0.000, 0.688)	(-0.750, 0.166, 0.916)	(-0.714, 0.000, 0.714)		
	(-0.600, 0.133, 0.933)	(-0.429, 0.285, 0.928)	(-0.769, 0.000, 0.847)	(-0.800, 0.000, 0.800)	(-0.734, 0.000, 0.800)	(-0.845, 0.000, 0.923)	(-0.467, 0.266, 0.933)	(-0.582, 0.168, 0.918)	(-0.847, 0.000, 0.847)	(-0.562, 0.126, 0.813)	(-0.916, 0.000, 0.856)	(-0.642, 0.072, 0.856)		
	(-0.733, 0.000, 0.733)	(-0.714, 0.000, 0.858)	(-0.616, 0.153, 1.000)	(-0.533, 0.267, 1.000)	(-0.667, 0.067, 0.867)	(-0.692, 0.153, 1.000)	(-0.467, 0.266, 1.000)	(-0.582, 0.168, 0.918)	(-0.462, 0.384, 1.000)	(-0.562, 0.126, 0.813)	(-0.916, 0.000, 0.856)	(-0.500, 0.214, 0.928)		
	(-0.600, 0.133, 0.733)	(-0.357, 0.357, 0.858)	(-0.538, 0.231, 1.000)	(-0.400, 0.200, 1.000)	(-0.467, 0.267, 1.000)	(-0.845, 0.000, 0.845)	(-0.667, 0.066, 0.800)	(-0.582, 0.168, 1.000)	(-0.462, 0.384, 1.000)	(-0.313, 0.375, 1.000)	(-0.666, 0.250, 1.000)	(-0.428, 0.286, 1.000)		
S2	(-0.333, 0.400, 1.000)	(-0.429, 0.285, 1.000)	(-0.616, 0.153, 0.924)	(-0.466, 0.334, 1.000)	(-0.534, 0.200, 0.867)	(-0.461, 0.384, 1.000)	(-0.733, 0.000, 0.733)	(-0.500, 0.250, 0.918)	(-0.771, 0.076, 0.924)	(-0.313, 0.375, 0.876)	(-0.750, 0.166, 1.000)	(-0.570, 0.144, 0.856)		
	E55	F61	F62	F63	F64	F65	G71	G72	G73	H81	H82	H83		
	(-0.616, 0.153, 0.847)	(-0.400, 0.267, 0.867)	(-0.539, 0.231, 1.000)	(-0.667, 0.000, 0.667)	(-0.692, 0.153, 0.923)	(-0.688, 0.000, 0.688)	(-0.616, 0.231, 1.000)	(-0.712, 0.144, 0.856)	(-0.571, 0.214, 0.930)	(-0.624, 0.126, 0.813)	(-0.200, 0.467, 1.000)	(-0.667, 0.067, 0.734)		
	(-0.538, 0.231, 1.000)	(-0.600, 0.067, 0.867)	(-0.616, 0.153, 1.000)	(-0.769, 0.000, 0.769)	(-0.614, 0.231, 1.000)	(-0.688, 0.000, 0.751)	(-0.847, 0.000, 0.847)	(-0.712, 0.144, 0.928)	(-0.643, 0.142, 0.930)	(-0.750, 0.000, 0.667)	(-0.667, 0.000, 0.667)	(-0.667, 0.067, 0.800)		
S3	(-0.616, 0.153, 0.924)	(-0.769, 0.000, 0.769)	(-0.539, 0.231, 0.847)	(-0.400, 0.134, 0.867)	(-0.537, 0.308, 1.000)	(-0.563, 0.125, 0.875)	(-0.693, 0.153, 0.847)	(-0.856, 0.000, 0.856)	(-0.714, 0.072, 0.858)	(-0.499, 0.250, 0.933)	(-0.334, 0.333, 0.933)	(-0.534, 0.200, 0.934)		
	(-0.667, 0.000, 0.667)	(-0.616, 0.153, 0.924)	(-0.461, 0.308, 1.000)	(-0.400, 0.267, 1.000)	(-0.537, 0.308, 1.000)	(-0.563, 0.125, 0.875)	(-0.693, 0.153, 0.847)	(-0.856, 0.000, 0.856)	(-0.714, 0.072, 0.858)	(-0.499, 0.250, 0.933)	(-0.334, 0.333, 0.933)	(-0.534, 0.200, 0.934)		
	(-0.769, 0.000, 0.769)	(-0.267, 0.400, 1.000)	(-0.692, 0.077, 0.847)	(-0.267, 0.400, 1.000)	(-0.614, 0.231, 1.000)	(-0.125, 0.563, 1.000)	(-0.693, 0.153, 0.924)	(-0.570, 0.286, 0.928)	(-0.429, 0.357, 1.000)	(-0.375, 0.375, 1.000)	(-0.400, 0.267, 0.867)	(-0.467, 0.267, 1.000)		
	S1	C32	C33	C34	C35	C36	D41	D42	D43	D44	D45	E51	E52	E53
S2	(-0.177, 0.530, 1.000)	(-0.692, 0.153, 0.845)	(-0.375, 0.375, 1.000)	(-0.771, 0.076, 0.847)	(-0.648, 0.058, 0.706)	(-0.733, 0.000, 0.733)	(-0.462, 0.384, 1.000)	(-0.692, 0.000, 0.692)	(-0.428, 0.358, 1.000)	(-0.625, 0.063, 0.688)	(-0.571, 0.214, 1.000)	(-0.499, 0.250, 0.813)	(-0.571, 0.214, 0.858)	
	(-0.706, 0.000, 0.706)	(-0.768, 0.077, 0.923)	(-0.750, 0.000, 0.750)	(-0.847, 0.000, 0.847)	(-0.706, 0.000, 0.706)	(-0.533, 0.200, 0.933)	(-0.847, 0.000, 0.847)	(-0.692, 0.000, 0.923)	(-0.786, 0.000, 0.786)	(-0.438, 0.250, 0.876)	(-0.786, 0.000, 0.786)	(-0.750, 0.000, 0.750)	(-0.499, 0.286, 1.000)	
	(-0.589, 0.117, 0.823)	(-0.692, 0.153, 1.000)	(-0.750, 0.000, 0.750)	(-0.616, 0.231, 1.000)	(-0.648, 0.058, 0.706)	(-0.666, 0.067, 0.733)	(-0.771, 0.076, 0.924)	(-0.692, 0.000, 0.923)	(-0.642, 0.144, 0.928)	(-0.688, 0.000, 0.750)	(-0.643, 0.142, 0.858)	(-0.687, 0.063, 0.750)	(-0.786, 0.000, 0.786)	
	(-0.472, 0.234, 0.764)	(-0.375, 0.308, 1.000)	(-0.375, 0.308, 1.000)	(-0.616, 0.231, 1.000)	(-0.295, 0.411, 1.000)	(-0.400, 0.333, 1.000)	(-0.540, 0.307, 1.000)	(-0.306, 0.386, 1.000)	(-0.572, 0.214, 1.000)	(-0.375, 0.313, 0.786)	(-0.714, 0.072, 0.937)	(-0.499, 0.250, 0.937)	(-0.429, 0.357, 0.930)	
S3	(-0.648, 0.058, 0.706)	(-0.845, 0.000, 0.845)	(-0.312, 0.438, 1.000)	(-0.693, 0.153, 0.847)	(-0.472, 0.234, 0.764)	(-0.466, 0.267, 0.933)	(-0.540, 0.307, 1.000)	(-0.306, 0.386, 1.000)	(-0.500, 0.286, 1.000)	(-0.313, 0.375, 1.000)	(-0.643, 0.142, 0.930)	(-0.312, 0.438, 1.000)	(-0.429, 0.357, 0.930)	
	S1	C32	C33	C34	C35	C36	D41	D42	D43	D44	D45	E51	E52	E53
	(-0.177, 0.530, 1.000)	(-0.692, 0.153, 0.845)	(-0.375, 0.375, 1.000)	(-0.771, 0.076, 0.847)	(-0.648, 0.058, 0.706)	(-0.733, 0.000, 0.733)	(-0.462, 0.384, 1.000)	(-0.692, 0.000, 0.692)	(-0.428, 0.358, 1.000)	(-0.625, 0.063, 0.688)	(-0.571, 0.214, 1.000)	(-0.499, 0.250, 0.813)	(-0.571, 0.214, 0.858)	
	(-0.706, 0.000, 0.706)	(-0.768, 0.077, 0.923)	(-0.750, 0.000, 0.750)	(-0.847, 0.000, 0.847)	(-0.706, 0.000, 0.706)	(-0.533, 0.200, 0.933)	(-0.847, 0.000, 0.847)	(-0.692, 0.000, 0.923)	(-0.786, 0.000, 0.786)	(-0.438, 0.250, 0.876)	(-0.786, 0.000, 0.786)	(-0.750, 0.000, 0.750)	(-0.499, 0.286, 1.000)	

Table 23 (continued)

E54	H84	H85	I91	I92	I93	I94	J101	J102	J103	J104	E54	E55	F61
(-0.616, 0.153, 0.847)	(-0.306, 0.386, 1.000)	(-0.750, 0.166, 0.916)	(-0.307, 0.462, 1.000)	(-0.643, 0.214, 0.928)	(-0.616, 0.231, 0.924)	(-0.572, 0.214, 0.856)	(-0.499, 0.214, 0.858)	(-0.562, 0.187, 0.750)	(-0.571, 0.214, 0.930)	(-0.786, 0.000, 0.786)	(-0.616, 0.153, 0.847)	(-0.400, 0.267, 0.867)	(-0.616, 0.153, 0.847)
(-0.538, 0.231, 1.000)	(-0.614, 0.077, 0.847)	(-0.916, 0.000, 0.916)	(-0.616, 0.153, 1.000)	(-0.643, 0.214, 1.000)	(-0.771, 0.076, 0.847)	(-0.642, 0.144, 1.000)	(-0.714, 0.000, 0.714)	(-0.499, 0.250, 0.876)	(-0.643, 0.142, 0.930)	(-0.643, 0.142, 0.858)	(-0.538, 0.231, 1.000)	(-0.600, 0.067, 0.867)	(-0.616, 0.153, 1.000)
(-0.616, 0.153, 0.924)	(-0.692, 0.000, 0.692)	(-0.584, 0.332, 1.000)	(-0.616, 0.153, 0.924)	(-0.787, 0.070, 0.928)	(-0.540, 0.307, 1.000)	(-0.642, 0.144, 0.856)	(-0.357, 0.357, 0.928)	(-0.375, 0.375, 1.000)	(-0.499, 0.286, 1.000)	(-0.571, 0.214, 0.930)	(-0.616, 0.153, 0.924)	(-0.667, 0.000, 0.800)	(-0.769, 0.000, 0.769)
(-0.616, 0.153, 1.000)	(-0.461, 0.231, 0.847)	(-0.834, 0.082, 1.000)	(-0.462, 0.307, 1.000)	(-0.858, 0.000, 0.858)	(-0.771, 0.076, 0.847)	(-0.786, 0.000, 0.786)	(-0.214, 0.499, 1.000)	(-0.750, 0.000, 0.750)	(-0.786, 0.000, 0.786)	(-0.571, 0.214, 1.000)	(-0.616, 0.153, 1.000)	(-0.667, 0.000, 0.667)	(-0.616, 0.153, 0.924)
(-0.769, 0.000, 0.769)	(-0.537, 0.155, 0.847)	(-0.834, 0.082, 0.916)	(-0.769, 0.000, 0.769)	(-0.429, 0.429, 1.000)	(-0.847, 0.000, 0.847)	(-0.642, 0.144, 0.928)	(-0.499, 0.214, 0.928)	(-0.436, 0.313, 0.876)	(-0.786, 0.000, 0.786)	(-0.499, 0.286, 0.930)	(-0.769, 0.000, 0.769)	(-0.267, 0.400, 1.000)	(-0.693, 0.076, 0.924)

Table 24 The fuzzy values S , R , and Q

	Fuzzy R	Fuzzy S	Fuzzy Q
S1	(−0.004, 0.011, 0.021)	(−0.596, 0.179, 0.860)	(−0.862, 0.112, 0.978)
S2	(−0.009, 0.006, 0.021)	(−0.684, 0.090, 0.875)	(−0.978, 0.000, 0.982)
S3	(−0.007, 0.008, 0.021)	(−0.645, 0.129, 0.883)	(−0.941, 0.046, 0.985)
S4	(−0.005, 0.010, 0.021)	(−0.555, 0.219, 0.931)	(−0.863, 0.114, 1.000)
S5	(−0.003, 0.012, 0.021)	(−0.537, 0.237, 0.927)	(−0.826, 0.142, 0.999)

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Data Availability All data generated or analyzed during this study are included in this manuscript.

Declarations

Ethical approval It is certified that all the authors have complied with ethical requirements.

Consent to participate All the authors participated equally in writing the manuscript.

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