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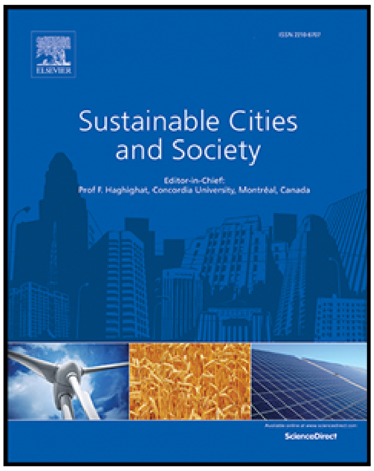

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Green Strategies in Mobility Planning Towards Climate Change Adaption of Urban Areas Using Fuzzy 2D Algorithm

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Highlights

- ✓ This study analyzes the decision-making process for urban mobility planning.
- ✓ The fuzzy D PIPRECIA algorithm is improved to determine the weights.
- ✓ The fuzzy D Dombi (fuzzy 2D) algorithm is proposed to evaluate the alternatives.
- ✓ A new methodology for evaluating green strategies is proposed.

Abstract

Urban mobility planning must urgently confront the challenges attendant to the low carbon transition and green transformation. The necessary paradigm shift from the traditional approaches to embracing environmental sustainability requires maintaining a firm and stable balancing act between opposing forces. The policy-making process in the transition period is complex and requires a detailed analysis that the academic literature lacks. This study analyzes the decision-making process for urban mobility planning to contribute the academic literature on sustainable transitions. In order to illustrate the complexities in the decision-making process, we design an original case scenario. In the case, the planners are supposed to choose the best project from among four recent green strategies. In the process, they need to take the conflicting requirements on the social, economic, environmental and technical issues into account. Sixteen constraints reflect the available physical and financial conditions. Because the decision-making process includes complexities, a novel two-stages model is introduced in the method that is used to solve the problem. In the first stage, the fuzzy D PIvot Pairwise RElative Criteria Importance Assessment (PIPRECIA) algorithm is applied to determine the weights. In the second stage, the fuzzy D Dombi (fuzzy 2D) algorithm is proposed to evaluate the alternatives. The results show that societal dynamics are crucially important in choosing the best alternative. Among four alternatives, the one that is inclusive and makes the existing investments more efficient is highly prioritized. Our findings offer policy implications emphasizing the importance of green mobility projects that favors the social benefits as well as financial issues.

Keywords: Green strategies, Climate change, D numbers, Multi-criteria decision making, Dombi.

1. Introduction

More than half of the world's population lives in cities, which are responsible for a lot of economic and institutional activity and control most of the financial capital (Field and Barros, 2014). Urban planning is crucial to human society because the maintenance and the use of urban space directly affects the quality of life. Policy formulations and implementations reflect the governments' intentions for long-term land use and growth in a selected region for a certain period (Campbell, 1996; Barton and Tsourou, 2000).

As the degradation of the natural environment started to affect the quality of life of citizens, urban planning grew connected with rational comprehensive models. (Gunderson, 2003). As of 2022, the central challenges in urban planning are strongly dominated by sustainability requirements. Climate change adaptation in urban areas and the maintenance of urban green spaces are critical (Niemelä, 1999; Field and Barros, 2014; Bayulken et al, 2021). Rapid growth of metropolitan areas results in defective infrastructural service supply leading increased sensitivity to the effects of climate change (Birkmann et al., 2010; Ahmed et al, 2020).

Several modern problems in cities are strongly related to poor planning such as ancillary infrastructural complications, pollution, and inequality in accessing to retailing and services. The major task of urban planning is to substitute current resource-intensive and environmentally harmful practices with environmentally sustainable ones. Yet, the actions that are taken in pursuit of this purpose must be ethical. A city should ensure that the residents' essential requirements are adequately provided and maintained (Næss, 2001). Under a comprehensive framework perspective, the decision-makers should analyze all courses of action to achieve the predetermined goals, evaluate all the repercussions of each plan of action, then choose the most favorable alternative (Oliveira and Pinho, 2010). Including Green Infrastructure (GI) in planning appears as one of the most relevant and effective means of improving the microenvironment and mitigating the consequences of climate change (Salata and Yiannakou, 2016). In response to challenges created by the urban life, smart cities are rapidly evolving, and these services affect policymaking and management (Anthopoulos and Vakali, 2012). Addanki and Venkataraman (2017) analyze the worldwide smart city practices to show that the sustainability of the city is not guaranteed by the smart growth of the city. Greening the city requires comprehensive socio-technical change. Drivers of the change include the planning, innovation and changes to the way of life of the citizenry (Addanki and Venkataraman, 2017).

The transportation system is responsible for the heavy effects of air pollution, congestion, deteriorated natural environments, and so on. Data shows that the transportation sector has been one of the leading causes of climate change, and can also promote the spread of a variety of infectious diseases (Dulal et al., 2011; Haines, 2004, Hysing, 2009). Due to the lack of stringent environmental-friendly policy formulations and implementations in transportation planning, the sector's contribution to environmental damage has worsened over years (Banister, 2005).

Although the need for sustainable transportation is becoming more widely recognized, transportation policy is extremely difficult to adjust (Low et al., 2003, Budd and Ison, 2020). While improving the quality of life, urban growth management mechanisms should be utilized in constructing transportation planning strategies. Wey (2019) surveys international practices on sustainable transportation planning strategies in the vein of growth principles and quality of life concepts (Wey, 2019). In a systematic literature review covering the period of 1990-2020, Wimbadi et al. (2021) shows that transportation should be the focus of the planning. The Avoid-Shift-Improve (ASI) framework in transportation planning offers the success in reducing the gas emissions in cities. However, the practice of the theory is not easy. Their study analyzes 64 cities from all around the world where urban transport experiments were conducted. They categorize the experiments into five groups: alternative fuel vehicles, infrastructure and land-use change, service and business practices, urban transport policy, and citizen practices (Wimbadi, et al., 2021). Miskolczi et al. (2021) analyze the literature in a comprehensive way to forecast the future of urban mobility practices. They predict the electromobility and dominance of automation (Miskolczi et al., 2021).

Sustainable mobility planning that addresses urban transportation issues involves urban study, strategy development, and target setting. Preparing urban areas for the consequences of climate change is critical considering their high population densities, infrastructural problems, essential linkages with the macroeconomy, and inherent vulnerabilities (Birkmann et al., 2010). Unlike typical transportation planning strategies, climate adaptation emphasizes resident and stakeholder involvement across segments, authority levels, and neighboring authorities. Plans for sustainable mobility necessitate a long-term strategy within this framework (Wefering et al., 2013; Griese et al, 2021). The required paradigm shift and the transformation period requires a detailed analysis. Ibrahim et al. (2018) provides a systematic transformation road-map by linking the theory of change to sustainability concepts for urban areas (Ibrahim et al., 2018).

The number of the studies that analyze the complexities in the urban mobility planning is restricted in the literature. Especially, the conflicting constraints that are binding in the decision-making process can cause the planners to take biased actions. The main objective of this study is to analyze the complexities of the decision-making process for the urban planners. Conflicting constraints are incorporated in terms of the economic, social, and technical dimensions, while choosing among the green strategies in urban mobility planning. The constraints in the planning process may be influenced by many factors, such as budget constraints, existence of financial support, technological infrastructure, physical and technical capacity, demographic variables.

As reviewed above the existing literature provides a wide range of urban mobility project practices from all around the world. We also survey the opinions of the experts from the field and academia in Turkey. The experts are selected according to their experiences in the sector and their academic studies. Then we designed a case scenario to illustrate the complex decision-making process of the planners. In the case scenario, we have pooled four successful green strategy alternatives that are practiced in different cities in the world. Using the literature and experts' suggestions, 16 criteria are set representing the economic, social, technical, and environmental dimensions of the problem. The urban planner's choice is expected to make different demands of the stakeholders. The case scenario explores the general decision-making process and leads us to important policy implications. Successful cases from European cities support our conclusions regarding setting green strategies under conflicting needs of the society. The analysis of the decision-making process requires a composite method. Although we reduce the problem in a case scenario to make it tractable, it still requires the use of an advanced logical method. Therefore, a novel multi-criteria framework for evaluating green strategies in mobility planning based on the application of D numbers and fuzzy sets is proposed.

Most of the studies that deal with green strategies in mobility planning and evaluate them apply traditional crisp crisp or fuzzy multicriteria models. However, crisp and fuzzy extensions of traditional MCDM techniques cannot adequately manipulate uncertainties in information. Due to its efficiency in processing uncertain and indeterminate information in the last few years, Dempster-Shafer's evidence (DSE) theory is applicable in many areas (Sadiq et al., 2006; Ju and Wang, 2012; Huang et al., 2014). Therefore, a hybrid methodology based on the application of DSE and fuzzy theory for the processing of ambiguous and indeterminate information in group decision making is proposed in this study. The application of DSE theory enables the processing and manipulation of uncertainties in expert preferences by applying fuzzy linguistic variables and probabilities. In this study, a novel multi-criteria framework for evaluating green strategies in mobility planning based on the application of D numbers and fuzzy sets is proposed. An original reasoning algorithm has been implemented in the proposed methodology, enabling efficient processing and analysis of information presented in an uncertain environment. The multi-criteria framework is based on the application of two modules. The first module involves the application of the D numbers-based fuzzy PIvot Pairwise RElative Criteria Importance Assessment (PIPRECIA) model to determine the weights of the criteria. The second module was used to evaluate green strategies in urban mobility and is based on applying nonlinear Dombi functions (Dombi, 1982) in D numbers and fuzzy environments. A multi-criteria framework has been developed to effectively solve the problem of evaluation of green strategies in mobility planning when there is a need to engage more experts and the need to process hierarchically organized criteria represented by certain and uncertain information. The following section presents the novelty of the proposed methodology:

- A new methodology for evaluating green strategies based on the application of D numbers for fuzzy information processing has been proposed.
- A novel extension of the PIPRECIA method, which can process fuzzy information using the D numbers-based reasoning algorithm.
- A novel algorithm for evaluating green strategies based on the application of nonlinear Dombi functions is proposed. The application of the Dobmi function is adapted for the evaluation of information defined by D numbers and fuzzy sets. The Dombi algorithm (fuzzy 2D) for strategy evaluation has stabilization parameters that enable flexible decision-making and simulation of different levels of risk to verify the robustness of the results effectively.
- An original algorithm for standardization of information has been implemented, enabling the preservation of the disposition of natural and normalized attribute values.

In addition, the proposed standardization algorithm eliminates the shift of the area of normalized values of cost and benefit criteria.

– Within the fuzzy 2D model, an original aggregation mechanism for fusing weighted alternative strategies was presented. The proposed model for aggregation of weighted functions enables efficient uncertainty managing and processing complex information in group decision making.

The decision-making process in urban mobility planning is a complex issue that requires a comprehensive approach. In this approach, all the conflicting needs of the society should be taken into account simultaneously. This study aims to contribute to the literature by exploring the process in an original case scenario. In the scenario, some recent green projects are pooled in a set of alternatives and conflicting constraints are set. The use of a novel method described above allows us to comment on possible policies of the planners. The optimal choice of the planner in this complex decision-making process is supposed to bring the conflicting demands into an agreement.

The rest of the paper is as follows: In Section 2, the problem is defined, and the constructed case scenario is explained. The framework of proposed model is presented in the Section 3. The method is applied to the case and the sensitivity analysis is revealed in Section 4. Section 5 presents the results. Section 6 comments on the policy implications of the study and Section 7 concludes.

2. Problem Definition

In this study, to illustrate the complex decision-making process, we construct a case scenario on which an urban mobility planner is about to choose among four different green strategies. The green strategies are chosen according to their easiness to implement, their success in reducing the gas emissions and popularity in practice. The planner's choice is subject to certain constraints for the successful implementation of the chosen alternative. We used the literature, real-life cases, and the opinions of the experts in developing the set of alternatives and the set of criteria. The set of criteria reflects the conflicting requirements that the planner is expected to take into consideration. The hierarchical structure of decision-making problem is illustrated in Fig. 1. The definition of the alternatives and criteria are as follows:

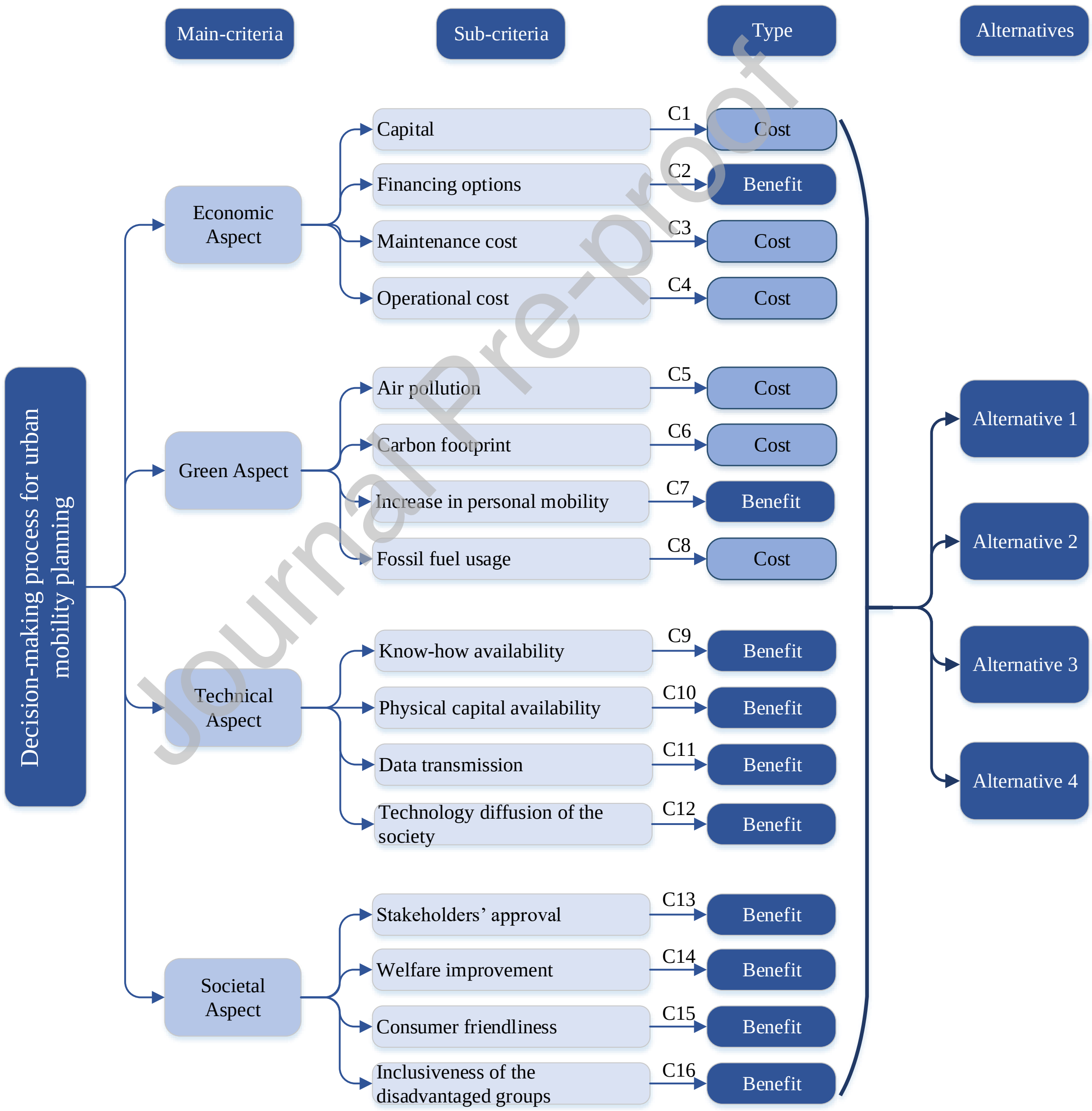

Fig. 1. The hierarchy structure of decision-making problem.

2.1. Definition of Alternatives

A_1: Particulate Filter with Transportation Modes Using Highway: To set general requirements, the European Union will implement CO_2 legislation beginning in 2012. The threshold for all recently registered Passenger Cars is established at 130 g/km depending on the fleet average of the automobile manufacturers. In order to reduce pollution even more, the limitation will be reduced to 95 g/km in 2020. Gasoline cars have a high ability to minimize fuel use and thus CO_2 emissions. Particulate Mass is now regulated by European regulation, and Particle Number (PN) for diesel engines will be limited, beginning with Euro 5b in 2011. The same PN regulatory limit of 6.0 1011 #/km is anticipated to be introduced for gasoline engines in 2014 for Euro 6. As a consequence of this potential constraint, additional emission control devices for GDI are being developed. The same PN regulatory limit of 6.0 1011 #/km is expected to be introduced for gasoline engines for Euro 6 in 2014. With this limited amount of data, new pollution control devices for GDI engines may be required to meet the stricter future regulatory limits. The reduction of CO_2 emissions is a main problem for the vehicle industry (Saito et al., 2011). Gasoline Direct Injection engines guarantee a lot. SUM-Turkey and IETT developed a pilot project for the facility of "Diesel Particulate Filters" to reduce exhaust emission emissions. 2 IETT buses that have the Euro 3 category were selected for this project (https://wrisehirler.org/news/iett-otobüslerine-dizel-partikül-filtre-takılması).

A_2: Full Transformation of the Fleet to Electrical Vehicles: Transportation covers nearly one-third of CO_2 from burning in the United States, and approximately a quarter worldwide. Light-duty vehicles account for around 62% of transport. Schiffer believes that electric cars are a potential answer to reducing noise and harmful emissions. Today, freight transportation accounts

for about half of all transit CO_2 emissions, and projections indicate a 160% percent growth in the CO_2 transport sector, as total freight demand is expected to treble by 2050 (OECD 2017). The transition to all-electric cars may occur in phases. The effects of this shift in climate change will be favorable, but how beneficial will rely not only on the adoption of electric cars but also on how cars are integrated with alternative fuels, which are also being produced at this time (Barkenbus, 2009). Electricity cuts pollutants since electric motor driving is naturally far more effective than the typical internal combustion in supplying the vehicle (Marland et al., 2008). ICE engines usually transfer just 15–30% of the power production to propel the car, with the remainder being squandered by energy loss. Electric engines are 90% effective, more than compensating for the losses that occur at the power plant while transforming basic heat into electricity.

A_3: Centrally Planned Operated and Regulated Micro-mobility: Justifying micro-mobility besides other means of public transit. In cities all across the world, smart transportation solutions, such as micro-mobility, have emerged (Eccarius and Lu, 2020). It swiftly appears in several urban locations, including Berlin (Aartsma, 2020). The present use of these systems yields mixed results in terms of sustainability and acceptability, according to research. It is said to solve environmental problems as well as citizens' life quality (Turo et al., 2019) and is the most rapid and reliable means of individual transportation in cities after public transportation systems (Brunner et al., 2018). In Germany, the transportation sector represents a key impediment to meeting the country's climate targets (Aartsma, 2020). Although German cities ostensibly discourage automobile usage and improve transportation alternatives, there is no cohesive, coherent strategy in place to make that happen, and no major drop in-car use is seen (Gössling and Metzler, 2017). Meanwhile, Berlin is one town experiencing the fastest growth in the micro-

mobility industry (Zagorskas and Burinskien, 2019). By 2025, the urban aims at increasing the modal shift of pedestrians, e-bike and e-scooter users, and urban transport users to 75% (Senate Department for Urban Development and the Environment of the State of Berlin, 2014). At the same time, it is hoped that the proportion of motorized individual transportation will fall to 20% (Aartsma, 2020). To that end, the urban passed new mobility legislation in 2018 that grants legal protections to cyclists, pedestrians, and public transportation users (Bartsch et al., 2019).

A_4: Integration of Road Transport with Environment Friendly Modes: Transportation is responsible for much of the world's fossil energy use and, hence, CO_2 emissions; on a global scale, transportation contributes to around 16% of CO_2 emissions from burning fuel, 25% in Europe, and 46% in Sweden (International Energy Agency, 2009). The transportation system also pollutes local and regional surroundings and burdens civilization with issues like traffic and accidents (Börjesson and Ahlgren, 2011). Plans to promote the use of public transportation must be part of a comprehensive policy. The integrated policy involves the integration of various modes of transportation, diverse government objectives, the demands of various socioeconomic groups, and the coordination of action among the necessary government entities. There is an indication that poor coordination can jeopardize policy priorities. A sustainable transportation policy model must also be integrated with land-use policies (Börjesson and Ahlgren, 2011). These could be fairly limited inside urban areas, but as population increases and new settlements are built, urban planners must place a greater priority on land use for sustainable transportation to reduce traffic and CO_2 emissions. The sustainable land-use policy can steer urban development toward public transportation. There are several options for public transportation. It can include railways and ferries that use rivers that run through cities and towns. The services are supported by a local authority, but sometimes they are run by private enterprises under agreement with the

local or regional government (Börjesson and Ahlgren, 2011). Integrated meaning is broad in transportation policy. It is in the sense of merging several forms of transportation or planning land use and developing transportation regulations that are congruent with environmental, health, economic, and societal goals.

2.2.Definition of Criteria

(1) Economic Aspect

C_1. Capital Cost: Building a sustainable transportation system in poor countries is a demanding task. Low-income countries frequently lack the financial resources and governance mechanisms required to construct low-carbon transportation infrastructure (Santos et al., 2010).

C_2. Financing Options: Cities frequently encounter institutional resource constraints and challenges in procuring the necessary staff and funding for participation; also, internal administrative organization of participation is a common challenge. Processes, as well as administrators' duties and the relationships between them, are frequently confusing. Furthermore, the roles and obligations of other agencies and local entities may be unclear (Lindenau and Böhler-Baedeker, 2014).

C_3. Maintenance Cost: To manage the operation of the demands made on DOTs (departments of transportation) by weather extremes and rising signs of global warming, DOT maintenance and managers suggest that DOTs be implicated in the formation of an agency-wide responding to changing adaptive capacity, including staff involved in programming and planning to adapt transportation (Venner and Zamurs, 2012). There are some issues with the development of green infrastructure for towns or people. It necessitates expenditures and upkeep to provide assistance and advantages (Salata and Yiannakou, 2016). The heavy investment would be necessary to change manufacturing processes for the new ultra-efficient vehicles, to source large quantities of

alternative energy sources, and to provide incentives to businesses and individuals to utilize these new vehicles (Banister, 2011).

C_4. Operational Cost: Weather events can make transportation activities more difficult (Venner and Zamurs, 2012). Even if there is no concept, mobility can still be designed. Building a new model or modifying an existing one necessitates cash and competent personnel. The extent of the costs depends on the complexity of the model and the size of the city, and it can sometimes be the biggest obstacle (Okraszewska et al., 2018).

(2) Green Aspect

C_5. Air Pollution: Growing electric drivetrains generates traffic congestion, pollution, and noise and affects road safety. As a result, environmental, economic, and social expenses are incurred (Van Wee and Ettema, 2016). In the European Union alone, the entire external costs of urban transportation (congestion, air quality, accidents, noise, and CO_2 emissions) exceed EUR 230 billion (European Commission DG MOVE, 2013). GI investments can help mitigate the effects of industrialization sustainably by avoiding urban expansion while reducing consumption for transportation (lowering traffic and pollution) (Salata and Yiannakou, 2016).

C_6. Carbon footprint: All activities are becoming worldwide, and travel is an important element of that process. To contrast that optimism, there is evidence that we already live in a carbon culture, and that emissions are having a permanent long-term impact on the global climate. There are several good instances of energy consumption reductions in transportation in metropolitan settings, notably via effective procurement investment in public transportation, prioritization of cycling and walking, and a variety of soft measures aimed primarily at reducing the use of high occupancy cars (Banister, 2011).

C_7. Increase in Personal mobility: Graeme Hugo led to this impartial as well as an optimistic view of human mobility. Similarly, as a geologist and demographer, he committed himself to understand the link between environmental events and human mobility (Hugo 1996, 2008a). Hugo did not rule out the prospect that climate change may drive unwanted and politically unpopular migration patterns, especially across international borders, but this was far from his major concern (Barnett and McMichael, 2018). Rather, he was interested in understanding how climate change can affect commonplace human motions, as well as how human mobility can creatively aid in adaptation to climate change (Bardsley and Hugo, 2010).

C_8. Fossil fuel usage: Despite studies to limit automobile use in areas and improve efficiency everywhere, there has been a significant increase in distances as cities have expanded. The preference for low population density car-based lifestyles has been prominent (Banister, 2011). Innovation has not kept up with the increase in car-based travel, and even a significant move to more powerful engines and other fuels will not completely address the issues. The advanced practice of technological innovation to decrease CO_2 emissions in the UK transport sector over the next 25 years is predicted to be around 21MtC (Banister and Hickman, 2006).

(3) Technical Capability Aspect

C_9. Know-how availability: In addition, investigators must understand how a person engages with infrastructure and public areas. Technical information must be combined with narratives and understanding of local. More searches are needed to do to understand the long-term performance and productivity of green strategies (Bai et al., 2018). Incorporation of GI into planning and design, both in existing compressed city centers and in major innovations, should be viewed as a struggle for planning systems, as these methods are called on to clarify the techniques for climate change adaptation, based on prior knowledge and practices (Salata and Yiannakou, 2016).

C_{10}. Physical capital availability: The availability of the inputs and the material is crucial regarding the financial burden on the project. Especially if the income inequality is high in the society, the financial requirement to buy the scarce resources can create additional problems. Also, the disadvantaged population suffers from financial deficiencies and has lower-quality physical capital that is more vulnerable to climate change (Urothody and Larsen, 2010).

C_{11}. Data transmission infrastructure availability: Governments should produce the right resources and organizations. Also, they should provide more data to the private industry and build a fundamental understanding of adaptable technologies (Heller and Mani, 2002). Authorities must provide incentive schemes etc. Deployment is based on technology selection since technological attributes must meet users' requirements and supportive environments. Developing acceptable adaptation technologies has been the main emphasis of the United Nations Framework Convention on Climate Change process. It is a vital part of adapting projects. A range of techniques was used, like glacial monitoring systems. Monitoring and data gathering technologies have traditionally necessitated significant technical knowledge to conduct data analysis (Biagini et al., 2014).

C_{12}. Technology diffusion of the society: Many of the technologies predicted by longer-term tendencies are now available or could be developed *(*Gidhagen et al., 2010). Any climate change adaptation strategy for compact cities should acknowledge that their susceptibility is highly tied to a number of their fundamental qualities related to how they are planned. Climate change management programs for adaptation and recovery are based on western scientific understanding (Makondo and Thomas, 2018). The capacity of planning to handle emerging competing interests, foster involvement, and assist produce and distributing information and best practices all

contribute significantly to the sustainability and resilience of urban communities (Salata and Yiannakou, 2016).

(4) Societal Aspect

C_{13}. *Stakeholders' approval*: A "stakeholder" is a phrase used frequently in participation research to describe an individual, group, or organization that is affected by a proposed plan or project, or who can influence a project and its implementation. Also, cultural and educational organizations, such as schools and kindergartens, typically have an interest in mobility and frequently solicit participation (Krause, 2014). Transport planning frequently influences a wide range of economic, public, and social interest groups, either positively or negatively, resulting in complex relationships between the local council and the parties with a stake in the choices taken. It is critical to incorporate all sorts of stakeholders throughout the planning process and fulfill their individual needs (Lindenau and Böhler-Baedeker, 2014).

C_{14}. *Welfare improvement:* The level of welfare is described as real generalized wealth. We cannot expect big percentage increases in total welfare from existing transportation regulations. All instruments that reduce congestion externalities will be more effective in terms of welfare. The overall welfare impact of air pollution and fuel efficiency programs will be heavily influenced by their side effects on congestion (Proost and Van Dender, 2001).

C_{15}. *Consumer friendliness:* Customers, regulators, and stakeholders all want insurance companies to deliver more commodities that respond to the worldwide economy's ‘greening,’ increase industry attempts to improve disaster risk reduction, and overall be proactive about the climate change danger. Use contract terms to encourage clients to make actuarially informed ‘climate-friendly; decisions. This could range from promoting risk-aversion behavior to exempting persons who make risky decisions as greenhouse gas emitters or risk managers from climate change liability insurance products (Mills, 2009).

C_{16}. *Inclusiveness of the disadvantaged groups*: Public transportation provides a social service by ensuring that disadvantaged populations, such as those with limited incomes, the elderly, or the disabled, are not socially excluded (Van Goeverden et al., 2006).

3. D numbers based MCMD framework

The following section presents the methodological steps of the novel multi-criteria framework that allows the exploitation of uncertainty and uncertainty in expert preferences using fuzzy and D numbers. The presented methodology exploits uncertainty in expert estimates using fuzzy linguistic variables and probabilities. Using the D methodology, the probability is integrated into fuzzy linguistic variables. This allows the limit values of fuzzy variables to be shifted depending on the degree of uncertainty. The multi-criteria methodology is shown in Fig. 2.

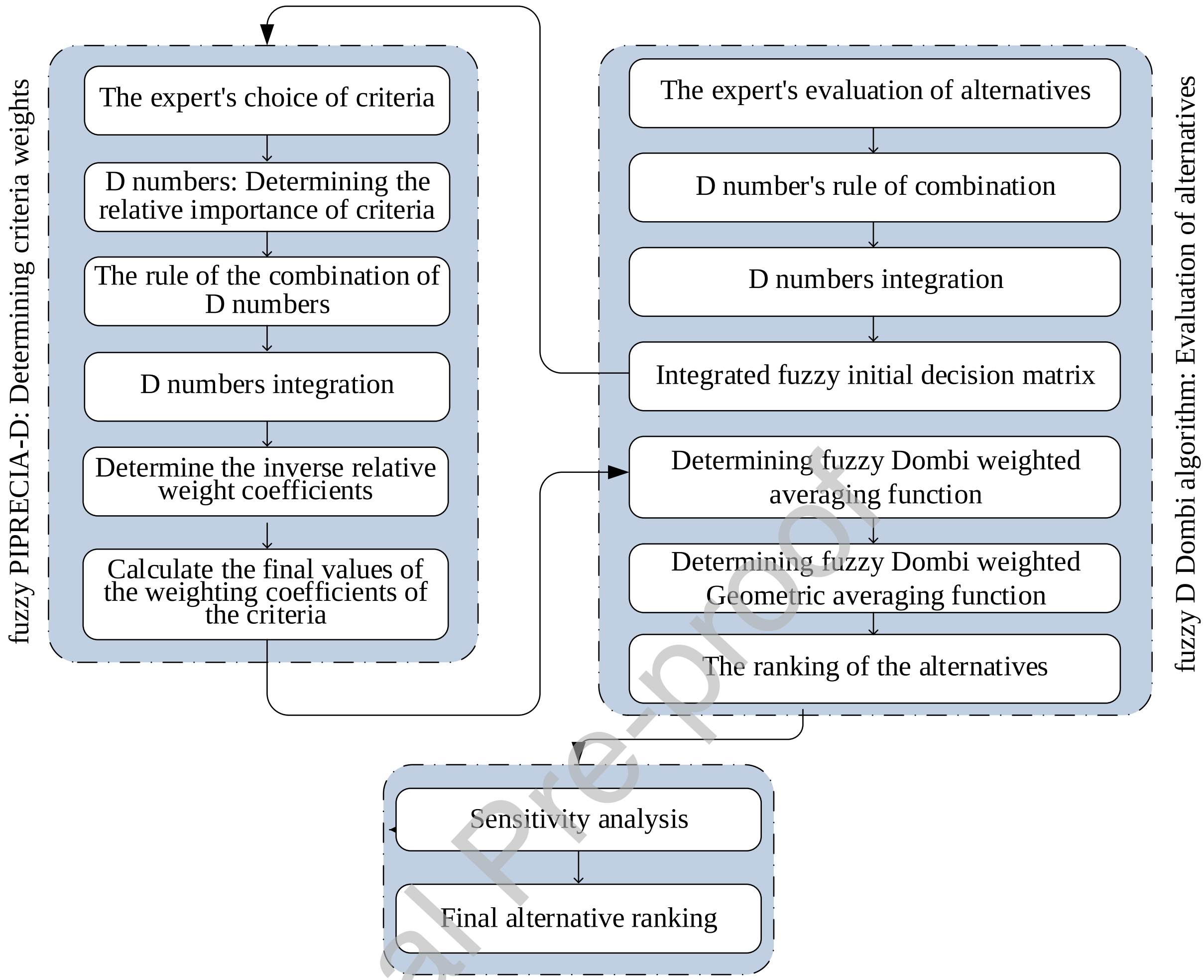

Fig. 2. Multi-criteria methodology based on fuzzy D numbers.

From Fig. 2 we can see that the multi-criteria framework is based on the application of the fuzzy D PIPRECIA algorithm for determining the weights and the fuzzy D Dombi (fuzzy 2D) algorithm for evaluating alternatives. The fuzzy D algorithm of the PIPRECIA and fuzzy 2D methodology is presented in the next two sections.

Suppose that in a multi-criteria model, there is a set of *m* alternatives (B_i) and *n* criteria (C_j) for evaluation. Also, suppose that *e* experts $E=\{E_1,E_2,...,E_e\}$ present their preferences by applying fuzzy linguistic variables from the set $\Psi=\{\Psi_b, b=1,2,...,h\}$. Then we can define detailed steps of the multi-criteria framework as follows.

3.1. *Fuzzy D PIPRECIA algorithm*

The following section defines the algorithm for applying the fuzzy D PIPRECIA as follows:

Step 1. Forming a set of *n* criteria and sorting the criteria according to marks from the first to the last, and this means that they need to be sorted unclassified.

Step 2. In group decision-making *r* experts $R=\{R_1, R_2, ..., R_n\}$ present their preferences by applying fuzzy linguistic variables from Tables 1 and 2. Each expert individually evaluates pre-sorted criteria by starting from the second criterion (Stević et al. 2018).

Table 1.
Scale for the assessment of criteria when the criterion is of greater importance in relation to the previous one

Linguistic Variables		Trinagular Fuzzy Number
Almost equal value	AE	(1.00, 1.00, 1.00)
Slightly more significant	SMS	(1.10, 1.15, 1.20)
Moderately more significant	MMS	(1.20, 1.30, 1.35)
More significant	MS	(1.30, 1.45, 1.50)
Much more significant	MMRS	(1.40, 1.60, 1.65)
Dominantly more significant	DMS	(1.50, 1.75, 1.80)
Absolutely more significant	AMS	(1.60, 1.90, 1.95)

Table 2.
Scale for the assessment of criteria when the criterion is of less importance compared to the previous one

Linguistic Variables		Trinagular Fuzzy Number
Weakly less significant	WLS	(0.667, 1.000, 1.000)
Moderately less significant	MLS	(0.500, 0.667, 1.000)
Less significant	LS	(0.400, 0.500, 0.667)
Really less significant	RLS	(0.333, 0.400, 0.500)
Much less significant	MLSS	(0.286, 0.333, 0.400)
Dominantly less significant	DLS	(0.250, 0.286, 0.333)
Absolutely less significant	ALS	(0.222, 0.250, 0.286)

Step 3. Transformation of fuzzy D linguistic variables in the $\overline{s_j}$ matrix. The evaluation of the C_j ($j=2,...,n$) criteria under the C_{j-1} ($j=1,2,...,n-1$) criteria is represented by the D number $D_{\partial_{ij}}=\left\{(\xi^1_{\partial_{ij}},\upsilon^1_{\partial_{ij}}),...,(\xi^i_{\partial_{ij}},\upsilon^i_{\partial_{ij}}),...,(\xi^h_{\partial_{ij}},\upsilon^h_{\partial_{ij}})\right\}$, where $\xi^i_{\partial_{ij}}$ represents the fuzzy linguistic variable from Table 1 or 2, $\upsilon^i_{\partial_{ij}}$ represents the probability of choosing the fuzzy linguistic variable. Applying the rules for the combination of D numbers (A8) and (A9) (Appendix A1) the final values of fuzzy D

numbers are transformed into fuzzy values $\overline{S}_j = \left(s_j^l, s_j^m, s_j^u\right)$. Thus an aggregated fuzzy D matrix $S = \left[\overline{S}_j\right]_{n\times 1}$ was obtained.

$$\overline{s_j} = \begin{cases} > (1,1,1) & if \quad C_j > C_{j-1} \\ = (1,1,1) & if \quad C_j = C_{j-1} \\ < (1,1,1) & if \quad C_j < C_{j-1} \end{cases} \tag{1}$$

Step 4. Determining the coefficient $\overline{k_j}$

$$\overline{k_j} = \begin{cases} = (1,1,1) & if \quad j = 1 \\ 2 - \overline{s_j} & if \quad j > 1 \end{cases} \tag{2}$$

Step 5. Determining the fuzzy weight $\overline{q_j}$

$$\overline{q_j} = \begin{cases} = (1,1,1) & if \quad j = 1 \\ \dfrac{\overline{q_{j-1}}}{\overline{k_j}} & if \quad j > 1 \end{cases} \tag{3}$$

Step 6. Determining the relative weight of the criterion $\overline{w_j}$

$$\overline{w_j} = \frac{\overline{q_j}}{\sum_{j=1}^{n} \overline{q_j}} \tag{4}$$

In the following steps, the inverse methodology of fuzzy D PIPRECIA method needs to be applied.

Step 7. Performing the assessment, but this time starting from a penultimate criterion. The evaluation of the C_j ($j = n-1,...,1$) criteria under the C_{j+1} ($j = n,...,2$) criteria is represented by the D number $D_{\partial_{ij}} = \left\{(\xi_{\partial_{ij}}^1, \upsilon_{\partial_{ij}}^1),...,(\xi_{\partial_{ij}}^i, \upsilon_{\partial_{ij}}^i),...,(\xi_{\partial_{ij}}^h, \upsilon_{\partial_{ij}}^h)\right\}$, where $\xi_{\partial_{ij}}^i$ represents the fuzzy linguistic variable from Table 1 or 2, $\upsilon_{\partial_{ij}}^i$ represents the probability of choosing the fuzzy linguistic variable. Applying the rules for the combination of D numbers (A8) and (A9) (Appendix A1) the final values of fuzzy D numbers are transformed into fuzzy values $\overline{S}'_j = \left(s_j^{l'}, s_j^{m'}, s_j^{u'}\right)$. Thus an aggregated fuzzy D matrix $S = \left[\overline{S}'_j\right]_{n\times 1}$ was obtained.

$$\overline{s_j}' = \begin{cases} > (1,1,1) & if \quad C_j > C_{j+1} \\ = (1,1,1) & if \quad C_j = C_{j+1} \\ < (1,1,1) & if \quad C_j < C_{j+1} \end{cases} \tag{5}$$

Step 8. Determining the coefficient $\overline{k_j}'$

$$\overline{k_j}' = \begin{cases} = (1,1,1) & if \quad j = n \\ 2 - s_j' & if \quad j > n \end{cases} \tag{6}$$

Step 9. Determining the fuzzy weight $\overline{q_j}'$

$$\overline{q_j}' = \begin{cases} = (1,1,1) & if \quad j = n \\ \dfrac{\overline{q_{j+1}}'}{\overline{k_j}'} & if \quad j > n \end{cases} \tag{7}$$

Step 10. Determining the relative weight of the criterion $\overline{w_j}'$

$$\overline{w_j}' = \frac{\overline{q_j}'}{\sum_{j=1}^{n} \overline{q_j}'} \tag{8}$$

Step 11. Calculation of the final weights of criteria:

$$\overline{w_j}'' = \frac{1}{2}(w_j + w_j') \tag{9}$$

Step 12. Checking the results obtained by applying the Spearman and Pearson correlation coefficients (Vesković et al. 2020; Memis et al 2020).

3.2.Fuzzy D numbers based Dombi (fuzzy 2D) algorithm

The following section defines the algorithm for applying the fuzzy 2D algorithm as follows:

Step 1. Transformation of fuzzy D linguistic variables in the home matrix. The evaluation of the B_i $(i = 1, 2, ..., m)$ alternative under the C_j $(j = 1, 2, ..., n)$ criteria is represented by the D number $D_{\partial_{ij}} = \left\{(\xi^1_{\partial_{ij}}, \upsilon^1_{\partial_{ij}}), ..., (\xi^i_{\partial_{ij}}, \upsilon^i_{\partial_{ij}}), ..., (\xi^h_{\partial_{ij}}, \upsilon^h_{\partial_{ij}})\right\}$, where $\xi^i_{\partial_{ij}}$ represents the fuzzy linguistic variable from Ψ, $\upsilon^i_{\partial_{ij}}$ represents the probability of choosing the fuzzy linguistic variable. Applying the rule for the combination of D numbers (A8) (Appendix A1) defines the degree of uncertainty in fuzzy D numbers. Suppose part of the uncertainty is at the intersection of two or more fuzzy linguistic variables (see Fig. 3). In that case, it is necessary to define the value at the intersection of two fuzzy variables as shown in Fig. 3.

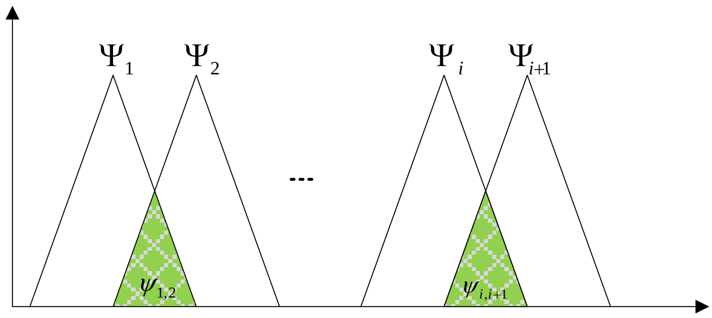

Fig. 3. Fuzzy linguistic variables.

The transformation of fuzzy variables is performed based on the area ratio.

$$D(\Psi_i) = D(\Psi_i) + D(\Psi_i, \Psi_{i+1}) \frac{\psi_{i,i+1}/\psi_i}{\psi_{i,i+1}/\psi_i + \psi_{i,i+1}/\psi_{i+1}} \tag{10}$$

$$D(\Psi_{i+1}) = D(\Psi_{i+1}) + D(\Psi_i, \Psi_{i+1}) \frac{\psi_{i,i+1}/\psi_{i+1}}{\psi_{i,i+1}/\psi_i + \psi_{i,i+1}/\psi_{i+1}} \tag{11}$$

where $\psi_{i,i+1}$ represents the intersection between linguistic variables Ψ_i and Ψ_{i+1}.

By applying Eq. (A9) (Appendix A1), the final values of fuzzy D numbers are transformed into fuzzy values $\hat{\xi}_{ij} = \left(\xi_{ij}^l, \xi_{ij}^m, \xi_{ij}^u\right)$. Thus an aggregated fuzzy D home matrix $\Im = \left[\hat{\xi}_{ij}\right]_{m\times n}$ was obtained.

Step 2. Home matrix standardization. Unification of home matrix information $\Im = \left[\hat{\xi}_{ij}\right]_{m\times n}$ is performed to transform all elements of the home matrix into an interval [0,1]. By applying Eqs. (12) and (13) we obtain a standardized home matrix $\Im^N = \left[\bar{\bar{\xi}}_{ij}\right]_{m\times n}$.

a) Standardization of Benefit Criteria:

$$\bar{\bar{\xi}}_{ij} = \frac{\hat{\xi}_{ij}}{\xi_j^+} = \left(\frac{\xi_{ij}^l}{\xi_j^+}, \frac{\xi_{ij}^m}{\xi_j^+}, \frac{\xi_{ij}^u}{\xi_j^+}\right) \tag{12}$$

where $\xi_j^+ = \max_{1\le i\le m}(\xi_{ij})$.

b) Standardization of Cost Criteria:

$$\overline{\overline{\xi}}_{ij}=\left(\begin{array}{l}-\dfrac{\xi_{ij}^{l}}{\xi_{j}^{+}}+\max\limits_{1\le i\le m}\left(\dfrac{\xi_{ij}^{l}}{\xi_{j}^{+}}\right)+\min\limits_{1\le i\le m}\left(\dfrac{\xi_{ij}^{l}}{\xi_{j}^{+}}\right),\\ -\dfrac{\xi_{ij}^{m}}{\xi_{j}^{+}}+\max\limits_{1\le i\le m}\left(\dfrac{\xi_{ij}^{m}}{\xi_{j}^{+}}\right)+\min\limits_{1\le i\le m}\left(\dfrac{\xi_{ij}^{m}}{\xi_{j}^{+}}\right),\\ -\dfrac{\xi_{ij}^{u}}{\xi_{j}^{+}}+\max\limits_{1\le i\le m}\left(\dfrac{\xi_{ij}^{u}}{\xi_{j}^{+}}\right)+\min\limits_{1\le i\le m}\left(\dfrac{\xi_{ij}^{u}}{\xi_{j}^{+}}\right)\end{array}\right) \tag{13}$$

where $\xi_j^{+}=\max\limits_{1\le i\le m}(\xi_{ij})$ and $\hat{\xi}_{ij}$ represents elements of the home matrix $\Im=\left[\hat{\xi}_{ij}\right]_{m\times n}$.

Step 3. Calculation of weighted strategy alternatives. Based on arithmetic operations with fuzzy numbers (Đalić et al. 2020; Bakır et al., 2021; Ali et al., 2021), operators for arithmetic and geometric weight averaging, as well as *Definitions 1 and 2*, we can derive fuzzy Dombi functions for calculating weighted strategy alternatives: 1) weighted fuzzy Dombi function ($\Im_i^{(1)\lambda}$) and 2) weighted geometric fuzzy Dombi function ($\Im_i^{(2)\lambda}$), Eqs. (14) and (15).

If we assume that $\overline{\overline{\xi}}_{ij}$ $(i=1,2,...,m;\ j=1,2,...,n)$ represents a set of fuzzy elements of the standardized matrix $\Im^{N}=\left[\overline{\overline{\xi}}_{ij}\right]_{m\times n}$, and if we denote by $\omega_j=\left(\omega_1,\omega_2,...,\omega_n\right)^{T}$ the vector of the weight coefficients of the criteria, then we can represent the fuzzy weighted Dombi strategy alternative as follows:

a) The first weighted strategy ($\Im_i^{(1)\lambda}$):

$$\Im_i^{(1)\lambda}=\left(\begin{array}{l}\sum_{j=1}^{n}\overline{\overline{\xi}}_{ij}^{l}-\dfrac{\sum_{j=1}^{n}\overline{\overline{\xi}}_{ij}^{l}}{1+\left\{\sum\limits_{j=1}^{n}\omega_j^{l}\left(\dfrac{f\left(\overline{\overline{\xi}}_{ij}^{l}\right)}{1-f\left(\overline{\overline{\xi}}_{ij}^{l}\right)}\right)^{\lambda}\right\}^{1/\lambda}},\sum_{j=1}^{n}\overline{\overline{\xi}}_{ij}^{m}-\dfrac{\sum_{j=1}^{n}\overline{\overline{\xi}}_{ij}^{m}}{1+\left\{\sum\limits_{j=1}^{n}\omega_j^{m}\left(\dfrac{f\left(\overline{\overline{\xi}}_{ij}^{m}\right)}{1-f\left(\overline{\overline{\xi}}_{ij}^{m}\right)}\right)^{\lambda}\right\}^{1/\lambda}},\\ \sum_{j=1}^{n}\overline{\overline{\xi}}_{ij}^{u}-\dfrac{\sum_{j=1}^{n}\overline{\overline{\xi}}_{ij}^{u}}{1+\left\{\sum\limits_{j=1}^{n}\omega_j^{u}\left(\dfrac{f\left(\overline{\overline{\xi}}_{ij}^{u}\right)}{1-f\left(\overline{\overline{\xi}}_{ij}^{u}\right)}\right)^{\lambda}\right\}^{1/\lambda}}\end{array}\right) \tag{14}$$

b) The second weighted strategy ($\Im_i^{(2)\lambda}$):

$$\mathfrak{I}_i^{(2)\lambda} = \left(\begin{array}{l} \dfrac{\sum_{j=1}^{n} \overset{=l}{\xi}_{ij}}{1+\left\{ \sum_{j=1}^{n} \omega_j^l \left(\dfrac{1-f\left(\overset{=l}{\xi}_{ij}\right)}{f\left(\overset{=l}{\xi}_{ij}\right)} \right)^{\lambda} \right\}^{1/\lambda}}, \dfrac{\sum_{j=1}^{n} \overset{=m}{\xi}_{ij}}{1+\left\{ \sum_{j=1}^{n} \omega_j^m \left(\dfrac{1-f\left(\overset{=m}{\xi}_{ij}\right)}{f\left(\overset{=m}{\xi}_{ij}\right)} \right)^{\lambda} \right\}^{1/\lambda}}, \\ \dfrac{\sum_{j=1}^{n} \overset{=u}{\xi}_{ij}}{1+\left\{ \sum_{j=1}^{n} \omega_j^u \left(\dfrac{1-f\left(\overset{=u}{\xi}_{ij}\right)}{f\left(\overset{=u}{\xi}_{ij}\right)} \right)^{\lambda} \right\}^{1/\lambda}} \end{array} \right) \tag{15}$$

where $f\left(\overset{=l}{\xi}_{ij}\right) = \overset{=l}{\xi}_{ij} \Big/ \sum_{j=1}^{n} \overset{=l}{\xi}_{ij}$, $f\left(\overset{=m}{\xi}_{ij}\right) = \overset{=m}{\xi}_{ij} \Big/ \sum_{j=1}^{n} \overset{=m}{\xi}_{ij}$ and $f\left(\overset{=u}{\xi}_{ij}\right) = \overset{=u}{\xi}_{ij} \Big/ \sum_{j=1}^{n} \overset{=u}{\xi}_{ij}$ represents additive functions of fuzzy sequences.

Step 4. Calculation fuzzy score function ($\mathbb{Q}_i$), Eq. (16).

$$\mathbb{Q}_i = \frac{\mathfrak{I}_i^{(1)\lambda} + \mathfrak{I}_i^{(2)\lambda}}{1+\left\{ \delta \left(\dfrac{1-\mathfrak{I}_i^{(1)\lambda}}{\mathfrak{I}_i^{(1)\lambda}} \right)^{\vartheta} + (1-\delta) \left(\dfrac{1-\mathfrak{I}_i^{(2)\lambda}}{\mathfrak{I}_i^{(2)\lambda}} \right)^{\vartheta} \right\}}; \delta \geq 0; \vartheta > 0 \tag{16}$$

The coefficient δ determines the degree of influence of weighted strategies ($\mathfrak{I}_i^{(1)\lambda}$ and $\mathfrak{I}_i^{(2)\lambda}$) on the value of fuzzy score function ($\mathbb{Q}_i$). The coefficient δ is defined from the interval [0,1]. It is recommended to adopt the value δ=0.5 for the calculation of the initial solution. This allows the equal impact of weighted alternative strategies ($\mathfrak{I}_i^{(1)\lambda}$ and $\mathfrak{I}_i^{(2)\lambda}$) on the initial results.

The coefficient ϑ represents the stabilization parameter fuzzy score function ($\mathbb{Q}_i$). When calculating the initial results, it is recommended to adopt the value of $\vartheta = 1$. This allows a straightforward calculation of the initial results. Finally, the ranking of alternatives is done based on fuzzy score functions $\mathbb{Q}_i$.

4. Case Study

Transportation is continuously regarded as the most challenging and costly industry and reduces energy demand and greenhouse gas emissions (HM Treasury, 2006). Decreasing CO_2

emissions in travel is generally the first step toward the strong potential for sustainability in transportation, with environmental, economic, social, and institutional implications (Hickman et al., 2013).

One of the most urgent problems confronting metropolitan regions, especially confined ones, is climate change adaption (Salata and Yiannakou, 2016) The interaction between climate change and urban areas has long been acknowledged over a decade of research (Kern, 2010). Cities present obvious signs of what used to be called ‘unintended climate change’ (Oke, 1987)(Underdal, 2019). The situation is related to the increasing urbanization and the physical, social, and behavioral processes associated with it, which have exacerbated ecological difficulties. Environmental issues in cities expand beyond their borders, contributing to worldwide environmental destruction (Gorsevski et al., 1998).

Policymakers must approach developing a future sustainable mobility paradigm with a trinity of transportation policy. Economic policies provide significant financial incentives for individuals to switch to low-carbon modes of transportation and for businesses to invest in energy-efficient transportation systems. Physical strategies give viable and long-term transportation alternatives. Policymakers should evaluate the alternatives for urban areas against climate change.

4.1. Application of Multi-Criteria Framework Based on Fuzzy D Numbers

The multi-criteria framework is based on the application of two modules. The first module presents the definition of criterion weight coefficients using the fuzzy D PIPRECIA methodology. In the second module, the evaluation of alternatives is performed using the fuzzy 2D algorithm.

4.1.1. Application of fuzzy D numbers based PIPRECIA Methodology

Five experts participated in the research, who were divided into two expert groups. Expert groups presented their preferences using the fuzzy scale (Table 1 and Table 2) in D numbers. Using fuzzy D numbers, Table A2.1 (Appendix A2) presents the expert assessments of the first group of experts (D_1) and the second group of experts (D_2).

In the following section, the uncertainty from Table A2.1 (Appendix A2) is processed by applying the rules for the combination of D numbers. Then, using Eq. (A8) (Appendix A1), the expert estimates were fused into a unique fuzzy D number (see Table 3).

Table 3
Sj matrix with aggregated fuzzy D numbers.

	C_j/C_{j-1} for main criteria		C_j/C_{j+1} for main criteria
C_2/C_1	D={(SMS,0.822),(MMS,0.128)}	C_3/C_4	D={(MLS,0.822),(RLS,0.128)}
C_3/C_2	D={(AE,0.529),(MMS,0.371)}	C_2/C_3	D={(WLS,0.529),(LS,0.371)}
C_4/C_3	D={(SMS,0.661),(MS,0.289)}	C_1/C_2	D={(MLS,0.822),(LS,0.128)}
	C_j/C_{j-1} for economic criteria		C_j/C_{j+1} for economic criteria
C_2/C_1	D={(SMS,0.903)}	C_3/C_4	D={(WLS,0.405),(MLS,0.592)}
C_3/C_2	D={(MLS,0.552),(LS,0.398}	C_2/C_3	D={(SMS,0.556),(MMS,0.444)}
C_4/C_3	D={(AE,0.5),(SMS,0.5)}	C_1/C_2	D={(MLS,1)}
	C_j/C_{j-1} for green criteria		C_j/C_{j+1} for green criteria
C_2/C_1	D={(AE,0.6),(MS,0.4)}	C_3/C_4	D={(WLS,0.279),(MLS,0.621)}
C_3/C_2	D={(AE,0.632),(SMS,0.368}	C_2/C_3	D={(WLS,0.632),(MLS,0.368)}
C_4/C_3	D={(AE,0.274),(SMS,0.676)}	C_1/C_2	D={(WLS,0.6),(RLS,0.4)}
	C_j/C_{j-1} for technical capability criteria		C_j/C_{j+1} for technical capability criteria
C_2/C_1	D={(SMS,0.837),(MMRS,0.065)}	C_3/C_4	D={(SMS,0.842),(MMS,0.128)}
C_3/C_2	D={(SMS,0.4),(MS,0.6}	C_2/C_3	D={(MLS,0.4),(RLS,0.6)}
C_4/C_3	D={(AE,0.842),(MS,0.108)}	C_1/C_2	D={(MLS,0.837),(MLSS,0.065)}
	C_j/C_{j-1} for societal criteria		C_j/C_{j+1} for societal criteria
C_2/C_1	D={(MMS,0.714),(MS,0.286)}	C_3/C_4	D={(LS,1)}
C_3/C_2	D={(MLS,0.571),(WLS,0.429}	C_2/C_3	D={(AE,0.714),(SMS,0.286)}
C_4/C_3	D={(MMS,1)}	C_1/C_2	D={(LS,0.714),(RLS,0.286)}

Using Eq. (A9) (Appendix A1), the fuzzy D numbers are transformed into triangular fuzzy numbers. Table 4 presents an aggregated fuzzy home matrix,

Table 4
Aggregated fuzzy matrix.

	Main	economic	green	technical capability	societal
C_1					
C_2	(1.058,1.112,1.159)	(0.993,1.038,1.083)	(1.12,1.18,1.23)	(1.012,1.067,1.112)	(1.229,1.343,1.393)
C_3	(0.974,1.011,1.056)	(0.435,0.567,0.817)	(1.037,1.055,1.105)	(1.22,1.33,1.38)	(0.571,0.81,1)
C_4	(1.103,1.179,1.227)	(1.05,1.075,1.125)	(1.018,1.051,1.099)	(0.972,0.982,1.03)	(1.2,1.3,1.35)

The results obtained by using the fuzzy D PIPRECIA and inverse fuzzy D PIPRECIA methods for the main criteria are given in Table A2.2 (Appendix A2), for economic criteria (see Table A2.3, Appendix A2), for green criteria (see Table A2.4, Appendix A2), technical capability (see Table A2.5, Appendix A2) and societal criteria (see Table A2.6, Appendix A2). Multiplying the fuzzy weights of the main criteria with the fuzzy weights of the sub-criteria within their group, the final fuzzy weights of all criteria are obtained, which are shown in Fig. 4. These fuzzy weights are further implemented in the model.

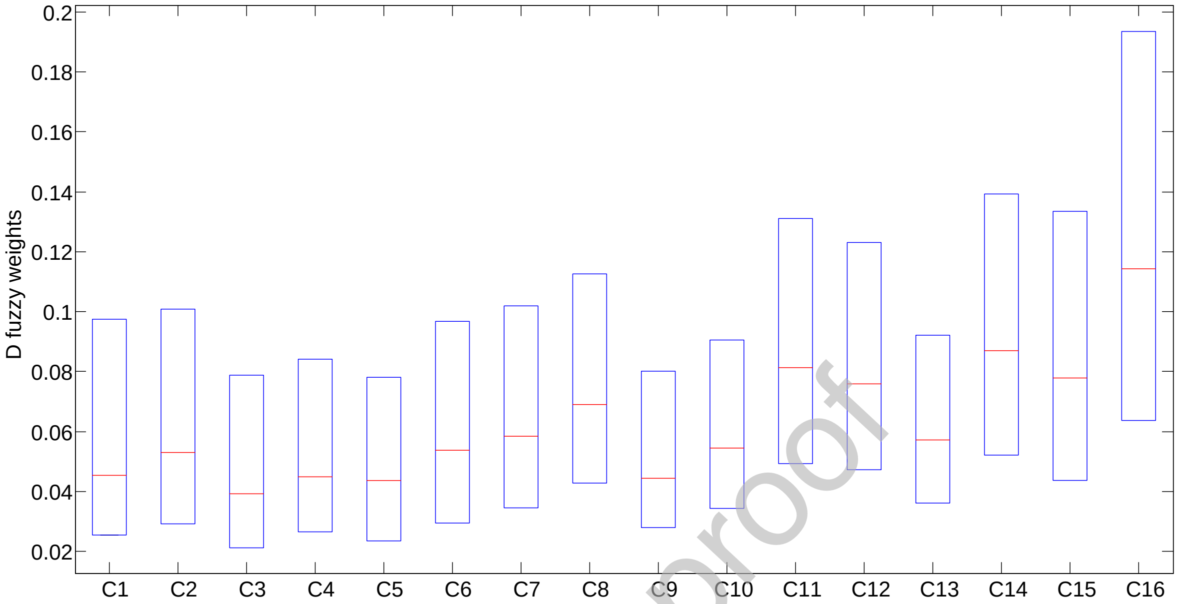

Fig. 4. The representation of fuzzy criteria weights.

4.1.2. Evaluation of Alternatives - Application of Fuzzy 2D Algorithm

After calculating the weight coefficients of the criteria, using the fuzzy 2D methodology, the evaluation of four alternatives was performed: A_1 - Particulate Filter: Transportation modes using highway; A_2 - Full Transformation of the Fleet to Electrical vehicles; A_3 - Centrally planned operated and regulated micro-mobility; and A_4 - Integration of road transport with environment friendly modes (sea transport, rail transport).

Step 1: Five experts participated in the research, who were divided into two expert groups. To evaluate the alternatives, the experts used the fuzzy scale given in Table 5.

Table 5
Fuzzy linguistic variables.

Linguistic terms	Linguistic values of TrFNs
Absolutely low (AL)	(1, 1, 1)
Very low (VL)	(1, 2, 4)
Low (L)	(1, 3, 5)
Medium low (ML)	(2, 4, 6)
Equal (E)	(3, 5, 7)
Medium high (MH)	(4, 6, 8)
High (H)	(5, 7, 9)

Very high (EH)	(6, 8, 9)
Absolutely high (AH)	(7, 9, 9)

Expert groups presented their preferences using the fuzzy scale (see Table 5) in D numbers. Using fuzzy D numbers, Table 6 presents the expert assessments of the first group of experts (D_1) and the second group of experts (D_2).

Table 6
Expert assessments of alternatives.

Crit.	A_1	A_2
C_1	D_1={(L,0.45),(L;ML,0.25),(ML,0.25)}; D_2={(L,0.45),(ML,0.55)}	D_1={(AL,0.6),(AL;VL,0.4)}; D_2={(AL,0.25),(VL,0.5),(L,0.25)}
C_2	D_1={(MH,0.35),(H,0.35),(VH,0.3)}; D_2={(MH,0.45),(H,0.55)}	D_1={(VH,0.25),(VH;AH,0.4),(AH,0.35)}; D_2={(VH,0.4),(AH,0.6)}
C_3	D_1={(ML,0.45),(ML;E,0.25),(E,0.25)}; D_2={(ML,0.65),(E,0.3)}	D_1={(L,0.35),(L;ML,0.35),(ML,0.25)}; D_2={(ML,0.6),(ML;E,0.25),(E,0.1)}
C_4	D_1={(E,0.5),(MH,0.2),(H,0.2)}; D_2={(E,0.35),(MH,0.35),(H,0.3)}	D_1={(VL;L,0.4),(L,0.6)}; D_2={(L,0.4),(ML,0.4),(E,0.15)}
C_5	D_1={(VL,0.35),(L,0.35),(ML,0.3)}; D_2={(L,0.45),(L;ML,0.25),(ML,0.25)}	D_1={(AL,0.65),(AL;VL,0.3),(VL,0.05)}; D_2={(AL,0.5),(VL,0.4),(L,0.05)}
C_6	D_1={(L,0.4),(L;ML,0.25),(ML,0.3)}; D_2={(L,0.5),(ML;E,0.25),(E,0.25)}	D_1={(AL,0.6),(AL;VL,0.35)}; D_2={(AL,0.7),(VL,0.2)}
C_7	D_1={(VL;L,0.35),(L,0.35),(L;ML,0.3)}; D_2={(L,0.5),(ML,0.25),(E,0.25)}	D_1={(AL,0.55),(AL;VL,0.45)}; D_2={(AL,0.6),(VL,0.35)}
C_8	D_1={(E;MH,0.55),(MH,0.25),(MH;H,0.2)}; D_2={(H,0.45),(VH,0.35),(AH,0.15)}	D_1={(AL,0.65),(VL,0.35)}; D_2={(AL,0.7),(VL,0.15),(0,)}
C_9	D_1={(ML,0.35),(ML;E,0.45),(E,0.15)}; D_2={(E,0.5),(MH,0.35),(H,0.1)}	D_1={(E;MH,0.2),(MH,0.55),(MH;H,0.25)}; D_2={(MH,0.6),(H,0.25),(VH,0.15)}
C_{10}	D_1={(MH,0.45),(H,0.3),(H;VH,0.25)}; D_2={(MH,0.5),(MH;H,0.25),(H,0.25)}	D_1={(VH,0.15),(VH;AH,0.35),(AH,0.5)}; D_2={(VH,0.25),(AH,0.7)}
C_{11}	D_1={(VL;L,0.55),(L,0.25),(ML,0.15)}; D_2={(L,0.4),(ML,0.4),(E,0.2)}	D_1={(AL,0.65),(VL,0.3)}; D_2={(AL,0.55),(VL,0.45)}
C_{12}	D_1={(VL,0.5),(VL;L,0.35),(L,0.1)}; D_2={(L,0.35),(ML,0.5),(E,0.15)}	D_1={(VL;L,0.45),(L,0.55)}; D_2={(VL,0.35),(L,0.6),(ML,0.05)}
C_{13}	D_1={(MH,0.45),(MH;H,0.4),(H,0.15)}; D_2={(E,0.15),(E;MH,0.5),(H,0.25)}	D_1={(MH,0.25),(H,0.5),(H;VH,0.2)}; D_2={(H,0.35),(VH,0.55)}
C_{14}	D_1={(L,0.4),(ML,0.35),(E,0.25)}; D_2={(VL,0.25),(VL;L,0.4),(L,0.35)}	D_1={(VH;AH,0.4),(AH,0.6)}; D_2={(VH,0.45),(AH,0.55)}
C_{15}	D_1={(VL;L,0.4),(L,0.3),(L;ML,0.2)}; D_2={(L,0.35),(ML,0.55),(E,0.05)}	D_1={(L,0.45),(ML,0.25),(E,0.25)}; D_2={(VL,0.2),(L,0.6),(ML,0.15)}
C_{16}	D_1={(E,0.6),(E;MH,0.25),(MH,0.15)}; D_2={(E,0.55),(MH,0.4)}	D_1={(L;ML,0.3),(ML,0.65),(E,0.05)}; D_2={(ML,0.5),(E,0.25),(MH,0.2)}
Crit.	A_3	A_4
C_1	D_1={(VH,0.25),(VH;AH,0.25),(AH,0.45)}; D_2={(VH,0.3),(AH,0.65)}	D_1={(L,0.25),(L;ML,0.25),(ML,0.5)}; D_2={(L,0.2),(ML,0.45),(E,0.2)}
C_2	D_1={(VL,0.65),(L,0.25),(ML,0.1)}; D_2={(VL;L,0.55),(L,0.35),(L;ML,0.1)}	D_1={(H,0.1),(VH,0.25),(AH,0.65)}; D_2={(VH,0.4),(AH,0.55)}
C_3	D_1={(VH;AH,0.45),(AH,0.55)}; D_2={(H,0.2),(VH,0.2),(AH,0.55)}	D_1={(ML,0.25),(ML;E,0.35),(E,0.4)}; D_2={(L,0.1),(ML,0.4),(E,0.5)}

C_4	D_1={(ML,0.65),(E,0.2),(MH,0.1)}; D_2={(ML,0.5),(E,0.25),(MH,0.25)}	D_1={(L,0.7),(L;ML,0.15),(ML,0.15)}; D_2={(VL,0.3),(L,0.4),(ML,0.3)}
C_5	D_1={(ML,0.3),(E,0.5),(MH,0.2)}; D_2={(L,0.15),(ML,0.35),(E,0.45)}	D_1={(VL,0.25),(VL;L,0.3),(L,0.45)}; D_2={(L,0.4),(ML,0.3),(E,0.2)}
C_6	D_1={(ML;E,0.25),(E,0.6),(MH,0.15)}; D_2={(ML,0.3),(E,0.65)}	D_1={(L,0.25),(L;ML,0.25),(ML,0.5)}; D_2={(ML,0.4),(E,0.25),(MH,0.2)}
C_7	D_1={(VH,0.2),(AH,0.8)}; D_2={(VH;AH,0.5),(AH,0.45)}	D_1={(VH,0.2),(VH;AH,0.3),(AH,0.45)}; D_2={(VH,0.35),(AH,0.55)}
C_8	D_1={(ML,0.65),(E,0.25),(MH,0.05)}; D_2={(ML,0.7),(E,0.25)}	D_1={(MH,0.6),(MH;H,0.25),(H,0.15)}; D_2={(MH,0.35),(H,0.35),(VH,0.2)}
C_9	D_1={(VH,0.25),(VH;AH,0.35),(AH,0.4)}; D_2={(VH,0.35),(AH,0.5)}	D_1={(L,0.45),(L;ML,0.3),(ML,0.25)}; D_2={(L,0.4),(ML,0.4),(E,0.2)}
C_{10}	D_1={(VL,0.4),(VL;L,0.3),(L,0.3)}; D_2={(VL,0.55),(L,0.4)}	D_1={(ML,0.5),(ML;E,0.25),(E,0.2)}; D_2={(ML,0.45),(E,0.4)}
C_{11}	D_1={(VH,0.25),(AH,0.7)}; D_2={(VH,0.4),(AH,0.6)}	D_1={(VH,0.15),(VH;AH,0.35),(AH,0.5)}; D_2={(H,0.2),(VH,0.25),(AH,0.55)}
C_{12}	D_1={(VH,0.15),(AH,0.85)}; D_2={(VH,0.4),(AH,0.6)}	D_1={(VH,0.25),(AH,0.75)}; D_2={(VH,0.35),(AH,0.55)}
C_{13}	D_1={(VH,0.1),(AH,0.9)}; D_2={(VH;AH,0.45),(AH,0.55)}	D_1={(ML,0.65),(ML;E,0.25),(E,0.05)}; D_2={(ML,0.55),(E,0.45)}
C_{14}	D_1={(H,0.7),(VH,0.2),(AH,0.1)}; D_2={(MH,0.3),(H,0.55),(VH,0.15)}	D_1={(VH,0.1),(AH,0.75)}; D_2={(VH;AH,0.4),(AH,0.45)}
C_{15}	D_1={(VH,0.25),(VH;AH,0.25),(AH,0.5)}; D_2={(VH,0.3),(AH,0.65)}	D_1={(VH,0.1),(VH;AH,0.25),(AH,0.65)}; D_2={(VH,0.35),(AH,0.65)}
C_{16}	D_1={(AL,0.75),(AL;VL,0.2),(VL,0.05)}; D_2={(AL,0.45),(VL,0.45)}	D_1={(VH,0.15),(VH;AH,0.2),(AH,0.65)}; D_2={(VH,0.25),(AH,0.55)}

In the following section, the uncertainty from Table 6 is processed by applying the rules for the combination of D numbers. Then, using Eq. (A8) (Appendix A1), the expert estimates were fused into a unique fuzzy D number (see Table A2.7, Appendix A2). The following section shows the application of the rules for combining fuzzy D numbers (A8) (Appendix A1). Based on the data in Table 6, for position A_1-C_1 expert preferences are expressed using two fuzzy D numbers: D_1={(L,0.45),(L;ML,0.25),(ML,0.25)} and D_2={(L,0.45),(ML,0.55)}. The following section presents the intersection table (see Table 7) in between D^1_{A1-C1} and D^2_{A1-C1}.

Table 7
Intersection table.

$D_{A1-C1} = D^1_{A1-C1} \odot D^2_{A1-C1}$	D_1 (L)=0.45	D_1 (L;ML)=0.25	D_1 (ML)=0.25
D_2 (L)=0.45	{L} (0.2025)	{L} (0.1125)	Ø (0.1125)
D_2 (ML)=0.55	Ø (0.2475)	{ML} (0.1375)	{ML} (0.1375)

Using Eq. (A8) (Appendix A1) for the combination of D numbers $D_{A1-C1} = D_{A1-C1}^{1} \odot D_{A1-C1}^{2}$ we can define the relationships between fuzzy D numbers as follows:

$$\mathbb{Z}_D = \frac{1}{\mathbb{R}_1 \mathbb{R}_2}\left(D_{A1-C1}^{1}(ML)\cdot D_{A1-C1}^{2}(L) + D_{A1-C1}^{1}(L)\cdot D_{A1-C1}^{2}(ML)\right) = 0.379$$

$$\mathbb{R}_1 = D_{A1-C1}^{1}(L) + D_{A1-C1}^{1}(L;ML) + D_{A1-C1}^{1}(ML) = 0.95$$

$$\mathbb{R}_2 = D_{A1-C1}^{2}(L) + D_{A1-C1}^{2}(ML) = 1.0$$

So we get:

$$D_{A1-C1}(L) = \frac{1}{1-\mathbb{Z}_D}\left(D_{A1-C1}^{1}(L)D_{A1-C1}^{2}(L) + D_{A1-C1}^{1}(L)D_{A1-C1}^{2}(L;ML)\right) = 0.507$$

$$D_{A1-C1}(ML) = \frac{1}{1-\mathbb{Z}_D}\left(D_{A1-C1}^{1}(L;ML)D_{A1-C1}^{2}(ML) + D_{A1-C1}^{1}(ML)D_{A1-C1}^{2}(ML)\right) = 0.443$$

Using Eq. (A9) (Appendix A1), the fuzzy D numbers from Table A2.7 (Appendix A2) are transformed into triangular fuzzy numbers. Table 8 presents an aggregated fuzzy home matrix,

Table 8
Aggregated fuzzy home matrix.

Crit.	A_1	A_2	A_3	A_4
C_1	(2.00,3.29,5.19)	(1.00,1.44,2.33)	(6.67,9.06,10.44)	(1.51,3.21,4.91)
C_2	(4.55,6.55,8.55)	(6.63,8.63,9.00)	(0.44,1.28,2.12)	(6.44,8.34,8.55)
C_3	(2.03,3.83,5.64)	(1.81,3.61,5.42)	(6.52,8.42,8.55)	(2.45,4.45,6.45)
C_4	(3.26,5.06,6.86)	(0.95,2.85,4.75)	(2.14,4.04,5.94)	(1.21,3.21,5.21)
C_5	(1.31,3.21,5.11)	(0.95,1.17,1.60)	(2.55,4.45,6.35)	(0.90,2.70,4.50)
C_6	(1.61,3.51,5.41)	(0.86,0.94,1.10)	(2.74,4.64,6.54)	(1.85,3.55,5.25)
C_7	(1.39,3.39,5.39)	(0.95,1.15,1.54)	(6.54,8.44,8.55)	(5.73,7.44,7.70)
C_8	(4.75,6.65,8.55)	(0.85,0.94,1.11)	(1.91,3.72,5.52)	(3.89,5.69,7.49)
C_9	(2.71,4.51,6.32)	(4.09,6.09,8.09)	(5.64,7.34,7.65)	(1.42,3.42,5.42)
C_{10}	(4.45,6.45,8.45)	(6.49,8.39,8.55)	(0.95,2.26,4.16)	(1.90,3.51,5.13)
C_{11}	(1.10,3.00,4.90)	(0.95,1.21,1.73)	(6.47,8.37,8.55)	(6.79,8.79,9.00)
C_{12}	(0.95,2.85,4.75)	(1.00,2.79,4.79)	(6.89,8.89,9.00)	(6.14,7.94,8.10)
C_{13}	(3.82,5.62,7.42)	(4.54,6.25,7.70)	(6.95,8.95,9.00)	(2.10,4.00,5.90)
C_{14}	(1.00,3.00,5.00)	(6.75,8.75,9.00)	(5.07,7.07,9.00)	(5.01,6.46,6.50)
C_{15}	(1.08,2.79,4.50)	(1.01,2.82,4.62)	(6.43,8.33,8.55)	(6.83,8.83,9.00)
C_{16}	(3.09,4.99,6.89)	(1.92,3.82,5.72)	(0.90,1.09,1.46)	(5.47,7.07,7.20)

Step 2: Using the Eqs. (12) and (13), the elements of the standardized home matrix are calculated $\Im^N = \left[\bar{\bar{\xi}}_{ij}\right]_{4\times16}$, as reported in Table A2.8 (Appendix A2). An example of standardization of the element at position A_1-C_1 in Table A2.8 (Appendix A2) using Eq. (13) is shown in the following section:

$$\bar{\bar{\xi}}_{11} = \begin{pmatrix} -\frac{2}{10.44} + \max\limits_{1\le i\le4}\left(\frac{2}{10.44},\frac{1}{10.44},\frac{6.67}{10.44},\frac{1.51}{10.44}\right) + \min\limits_{1\le i\le4}\left(\frac{2}{10.44},\frac{1}{10.44},\frac{6.67}{10.44},\frac{1.51}{10.44}\right), \\ -\frac{3.29}{10.44} + \max\limits_{1\le i\le4}\left(\frac{3.29}{10.44},\frac{1.44}{10.44},\frac{9.06}{10.44},\frac{3.21}{10.44}\right) + \min\limits_{1\le i\le4}\left(\frac{3.29}{10.44},\frac{1.44}{10.44},\frac{9.06}{10.44},\frac{3.21}{10.44}\right), \\ -\frac{5.19}{10.44} + \max\limits_{1\le i\le4}\left(\frac{5.19}{10.44},\frac{2.33}{10.44},\frac{10.44}{10.44},\frac{4.91}{10.44}\right) + \min\limits_{1\le i\le4}\left(\frac{5.19}{10.44},\frac{2.33}{10.44},\frac{10.44}{10.44},\frac{4.91}{10.44}\right) \end{pmatrix}$$
$$= (0.543, 0.691, 0.726)$$

The standardization of the remaining elements from Table A2.8 (Appendix A2) was performed similarly.

Step 3: Weighted alternative strategies were calculated using Eqs. (14) and (15), as follows:

$$\Im_i^{(1)\lambda} = \begin{matrix} A1 \\ A2 \\ A3 \\ A4 \end{matrix} \begin{bmatrix} (0.175, 0.482, 1.101) \\ (0.257, 0.631, 1.322) \\ (0.275, 0.595, 1.092) \\ (0.325, 0.720, 1.299) \end{bmatrix}; \quad \Im_i^{(2)\lambda} = \begin{matrix} A1 \\ A2 \\ A3 \\ A4 \end{matrix} \begin{bmatrix} (0.304, 0.363, 0.298) \\ (0.400, 0.405, 0.334) \\ (0.351, 0.320, 0.244) \\ (0.668, 0.578, 0.397) \end{bmatrix}$$

The following section presents the calculation of weighted strategy for the first alternative:

a) The first weighted strategy ($\Im_1^{(1)\lambda}$):

$$\Im_1^{(1)\lambda=1} = \begin{pmatrix} 4.992 - \frac{4.992}{1+\left(0.025\times\left(\frac{0.109}{1-0.109}\right)+0.029\times\left(\frac{0.101}{1-0.101}\right)+...+0.064\times\left(\frac{0.429}{1-0.429}\right)\right)}, \\ 7.915 - \frac{7.915}{1+\left(0.045\times\left(\frac{0.087}{1-0.087}\right)+0.053\times\left(\frac{0.092}{1-0.092}\right)+...+0.114\times\left(\frac{0.088}{1-0.088}\right)\right)}, \\ 10.568 - \frac{10.568}{1+\left(0.097\times\left(\frac{0.069}{1-0.069}\right)+0.101\times\left(\frac{0.090}{1-0.090}\right)+...+0.194\times\left(\frac{0.091}{1-0.091}\right)\right)} \end{pmatrix}$$
$$= (0.175, 0.482, 1.101)$$

b) The second weighted strategy ($\Im_1^{(2)\lambda}$):

$$\mathfrak{I}_1^{(2)\lambda=1} = \left(\begin{array}{c} \dfrac{4.992}{1+\left(0.025\times\left(\dfrac{1-0.109}{0.109}\right)+0.029\times\left(\dfrac{1-0.101}{0.101}\right)+...+0.064\times\left(\dfrac{1-0.429}{0.429}\right)\right)}, \\ \dfrac{7.915}{1+\left(0.045\times\left(\dfrac{1-0.087}{0.087}\right)+0.053\times\left(\dfrac{1-0.092}{0.092}\right)+...+0.114\times\left(\dfrac{1-0.088}{0.088}\right)\right)}, \\ \dfrac{10.568}{1+\left(0.097\times\left(\dfrac{1-0.069}{0.069}\right)+0.101\times\left(\dfrac{1-0.090}{0.090}\right)+...+0.194\times\left(\dfrac{1-0.091}{0.091}\right)\right)} \end{array} \right)$$

$$=\left(0.304, 0.363, 0.298\right)$$

Based on the weighted alternative strategies, we can define the ranking of alternatives for each defined strategy. Thus, for the first weighted strategy ($\mathfrak{I}_i^{(1)\lambda}$), we get the rank $A_4 > A_2 > A_3 > A_1$, while for the second weighted strategy ($\mathfrak{I}_i^{(2)\lambda}$), we get the next rank $A_4 > A_2 > A_1 > A_3$.

Step 4: By applying Eq. (16), the score functions alternative as follows are defined:

$$\mathbb{Q}_i^{\delta=0.5,\vartheta=1} = \begin{array}{c} A1 \\ A2 \\ A3 \\ A4 \end{array} \begin{bmatrix} (0.118, 0.362, 1.730) \\ (0.221, 0.564, 3.715) \\ (0.198, 0.451, 1.616) \\ (0.550, 0.861, 3.709) \end{bmatrix}$$

For the initial solution calculation (see Fig. 5), the value δ=0.5 was adopted. This enables both strategies to have an equal impact on defining the initial solution. Also, during the initial solution calculation, the value of the stabilization parameter $\vartheta = 1$ was adopted. Based on the defined settings, the initial ranking of alternatives as follows $A_4 > A_2 > A_3 > A_4$ was obtained.

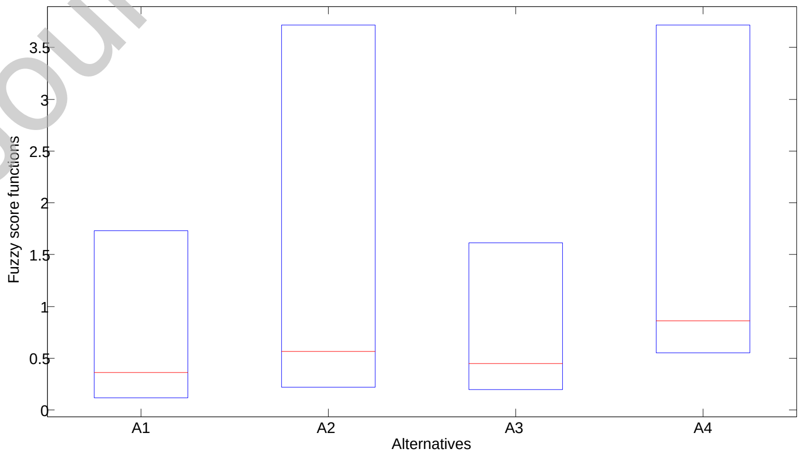

Fig. 5. The initial solution of the model.

4.2. Sensitivity analysis

In this section, the sensitivity analysis of the initial solution was performed. The sensitivity analysis aims to check the stability of the solution when simulating the change of subjectively defined parameters of a multi-criteria model. In the presented methodology, three parameters were identified on the basis of which the sensitivity analysis was performed. The first part of the sensitivity analysis simulates the parameter change λ in the interval $1 \le \lambda \le 100$, while the second part simulates the change of the parameter $0 \le \delta \le 1$ and $1 \le \vartheta \le 100$.

The λ parameter represents the stabilization parameter of the fuzzy Dombi functions used to calculate the weighted alternative strategies ($\Im_i^{(1)\lambda}$ and $\Im_i^{(2)\lambda}$). Based on the mathematical setting of the fuzzy Dombi function, it is evident that the parameter λ affects the transformation of Eqs. (14) and (15), which is also confirmed in Fig. 6.

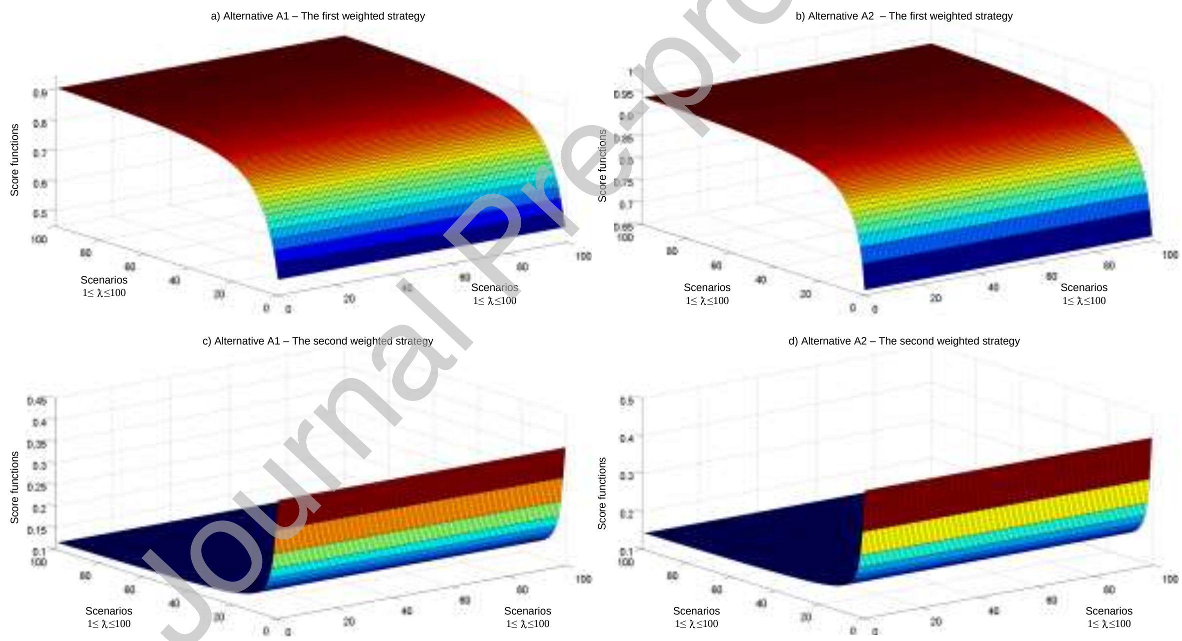

Fig. 6. Influence of change of parameter λ on change of fuzzy Dombi function.

Fig. 6 simulates the change of the parameter λ in the interval $1 \le \lambda \le 100$. Simultaneously with the parameter change λ, the influence of the mentioned parameter on the change of weighted functions was analyzed. Figs. 6(a) and (b) show the dependence of the fuzzy Dombi function $\Im_1^{(1)\lambda}$ and $\Im_2^{(1)\lambda}$ on the parameter change, while Figs. 6(c) and (d) show the fuzzy Dombi function $\Im_1^{(2)\lambda}$ and $\Im_2^{(2)\lambda}$. Similar changes occur with the A_3 and A_4 alternatives. To comprehensively understand the impact of the parameter $ƛ$, Fig. 7 shows the change in the fuzzy score function of the alternatives.

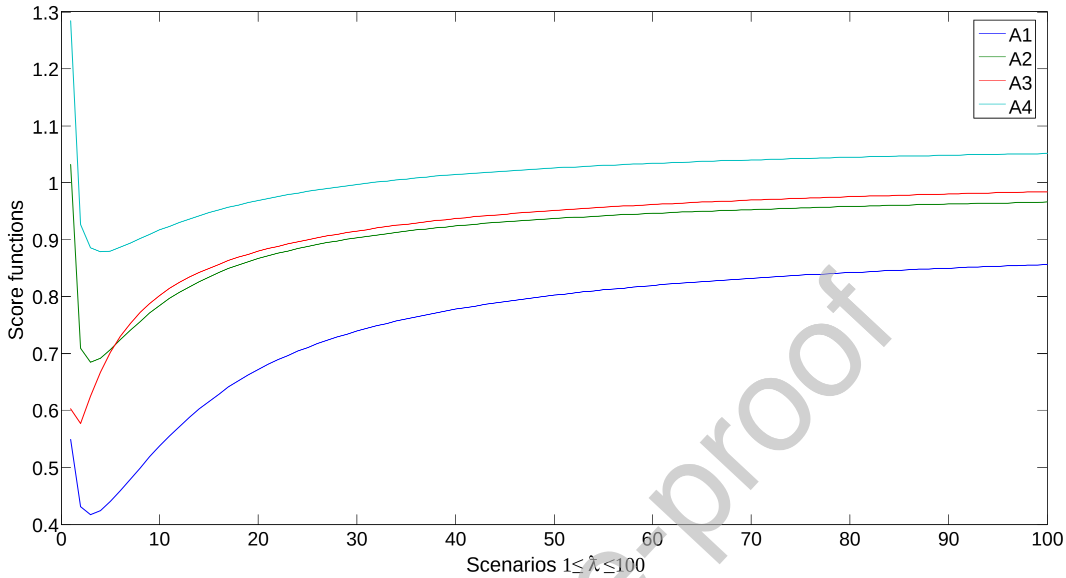

Fig. 7. Change fuzzy score function alternatives ($\mathbb{Q}_i$).

From Fig. 7 it can be seen that for the values of parameter $1 \le ƛ \le 6$, the initial solution is confirmed, while the values of parameter $7 \le ƛ \le 100$ initiate the change of ranks of alternatives A_2 and A_3. However, during the 100 scenarios considered in this experiment, the dominance of A_4 alternatives was confirmed. Also, based on this experiment, we can conclude that alternative A_1 is the worst solution. Analysis of the results from Fig. 7 shows that increasing parameter $1 \le ƛ \le 100$ causes a reduction in the gap between the fuzzy score functions of the alternatives. To see the gap between the alternatives, it is recommended to define the parameters in the range $1 \le ƛ \le 15$. The values adopted in this way enable a clear separation of the dominant alternatives and a rational and objective decision.

In the following section, the influence of changing the parameters $0 \le \delta \le 1$ and $1 \le \vartheta \le 100$ changing the fuzzy score function ($\mathbb{Q}_i$) is analyzed. In the experiment shown in Fig. 8, the change in the parameter δ was simulated. The simulation was conducted through twenty scenarios. In the first scenario, the value δ=0.0 was adopted, while in each subsequent scenario, the value of δ was increased by 0.05.

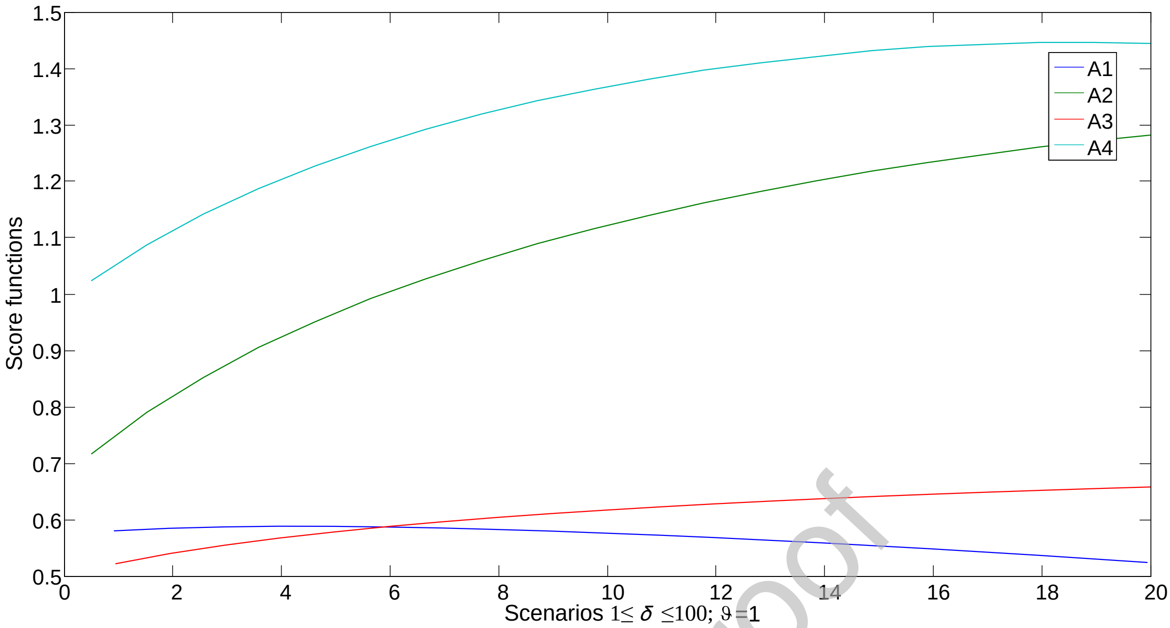

Fig. 8. The analysis of the influence of the parameter $0 \le \delta \le 1$.

Fig. 8 show that the initial rank $A_4 > A_2 > A_1 > A_3$ was confirmed for the value of the parameter $0.25 \le \delta \le 1.0$. However, parameter values in the interval $0.0 \le \delta \le 0.25$ cause changes in the range of alternatives A_1 and A_3. Such changes have been expected since $\Im_3^{(1)\lambda} > \Im_1^{(1)\lambda}$ and $\Im_3^{(2)\lambda} < \Im_1^{(2)\lambda}$.

Fig. 9 shows an experiment during which the change of the stabilization parameter $1 \le \vartheta \le 100$ was simulated. At the same time, the influence of the specified parameter on the shift of fuzzy score functions ($\mathbb{Q}_i$) was monitored.

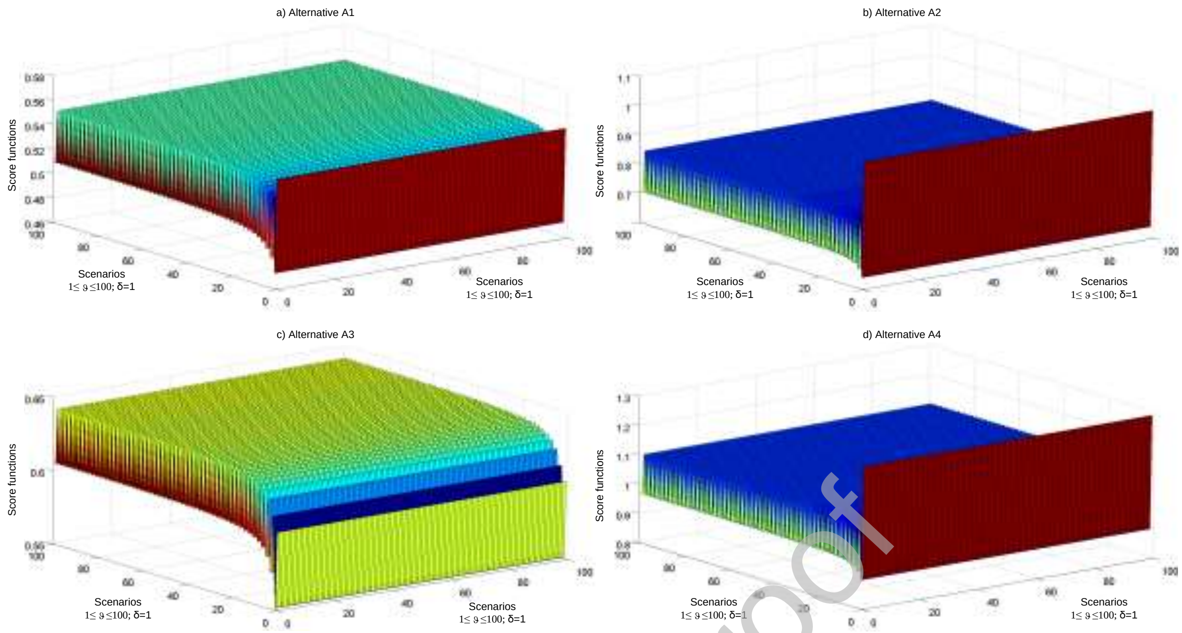

Fig. 9. The analysis of the influence of the parameter $1 \le \vartheta \le 100$.

The results in Figs. 9(a)-(d) show that increasing the parameter leads to a clear definition of the gap between the fuzzy score functions. Despite significant changes in the value of this parameter, the initial rank remained unchanged. These results confirm that the A_4 alternative has a distinct dominance and is the best solution.

5. Results and Discussion

In solving the decision-making problem of the planner in the illustrative case scenario, a survey is created after the alternatives and criteria have been decided. The survey questions are filled out by experts. Based on the responses, the findings of the model prioritize the four alternatives as follows. The centrally planned, operated and regulated micro-mobility alternative is the least advantageous. The particulate filter with transportation modes using the highway is the second least advantageous one. The second most advantageous alternative is the full transformation of the fleet into electric vehicles. Finally, integrating road transport with the environment is the most promising alternative among the others.

New mobility options, such as micro-mobility, have emerged in cities around the world in recent years. Cities have been overwhelmed by crowded populations or intensive traffic conditions (Médard de Chardon, 2019). Micro-mobility provides a financially accessible, time-effective alternative. At the same time, it can help to boost low-carbon transportation in cities. However, how and who changes to employ micro-mobility is a critical component of the equation (Eccarius and Lu, 2020). The goal is to build green, livable cities that increases the quality of life in all aspects. In terms of the subject, the alternative is insufficient. The criteria on inclusive transportation and technical availabilities are binding in determining the ranking of the alternative.

Diesel particulate filters (DPF) have been used in all medium- and heavy-duty engines in North America since 2007 to meet particulate matter emissions levels. During normal operation, particulate matter generated by the engine is trapped within the DPF. In modern systems, both passive and active regeneration strategies are required to periodically remove the particulate matter from the filter (Mamakos et al., 2013). According to costs, the highest cost elements are the manufacturing costs in DPF (Lu et al., 2015). This alternative cannot be suitable for municipalities with hard budget constraints. Also, the green effect of the alternative is not satisfactory compared to its costs. The transaction costs in adapting the existing engines to meet the particulate matter emission levels are both implicitly and explicitly high. The maintenance costs are added to these transaction costs.

Electric vehicles play an important part in sustainable mobility for all kinds of transit. Urban areas with large densities, in particular, are attempting to minimize the number of conventionally powered vehicles (Illgen and Höck, 2018). Both EVs and alternative fuel vehicles are predicted to enhance air quality, especially in cities with high population density and accompanying transport. Nevertheless, the amount to which renewable energy is used is yet another crucial aspect in determining the level of improvement that may be realized. The economic case for electric vehicles is compelling (Smit et al., 2018).

Urban planning and territorial administration are critical in mitigating the consequences of climate change. Our findings show that the most expensive alternative which is the full transformation of the fleet into electric vehicles is the second-best alternative. Society is ready to accept the financial burden if the climate action is really effective.

In the developed world, the drastic destruction of the natural setting, air pollution, and climate change urged the societal models with a ‘green’ and ‘sustainable’ image. Numerous climate adaption methods have been introduced at differing paces. Adaptation and mitigation methods must be developed to boost resilient cities. Our findings reveal that the use of existing infrastructure is the most preferrable alternative. It is not easy to abandon the traditional public transportation. The familiarity and the quality that it provides for some disadvantaged groups is important. Therefore, the urgent call for climate actions can be responded by the transformation of the existing infrastructure into green versions.

The range of practices in European cities support our findings. Local legislation for environmental sustainability that has had an impact is pretty uncommon. However, some cities have accomplished beneficial results, for example, Heidelberg, Vaxjo, and others have reduced CO2 emissions by more than 40% in the fifteen years between 1993 and 2012. Those have created communities where the energy infrastructure is produced from renewable sources. In the setting of increasing self-sufficiency, these experiences will respond to strong regulations, but the majority of the city benefits only incompletely since they cannot integrate the numerous regulations around renewable energy in their districts.

Development in urban areas will contribute to minimizing transportation emissions. An average population, combined with varied usage and green areas, helps to reduce greenhouse gas emissions and contributes to adaptation (Pinto, 2014). Legal obligations are causing a renewed emphasis on methods for assessing trip changes and reducing emissions, ranging from spreadsheet approaches to integrated transportation–land-use models (Ülengin et al., 2018). These analytical advancements seek to increase the ability to measure the success of pricing and land-use strategies in reducing overall travel. Before adopting or executing any policy, policymakers must be aware of its long-term consequences, which must be assessed using an integrated approach (Malayath and Verma, 2013).

6. Policy Implications

As noted above, more than half of the global population lives in cities, which hold most of its capital and are responsible for much commercial and financial activity (Field and Barros, 2014). Significant volatility in climatic conditions projected for the twenty-first century, along with the proven repercussions of existing climate extremes, ensure that adjustment will remain a major concern for metropolitan areas (Carter et al., 2015).

Green Infrastructure (GI) in design and construction appears to be one of the most important and effective strategies of enhancing the microclimate and minimizing the effects of climate change (Salata and Yiannakou, 2016). Greater emphasis has been placed on urban mobility, a semi-sector in which rational environmental changes may and should be undertaken (Commission of the European Communities, 2007). The transportation system is largely to be blamed for the negative effects of air pollution, traffic congestion, and deteriorating natural ecosystems, among other things. It is also a significant contribution and is becoming more so, to global environmental challenges such as climate change, as has been noticed for over fifteen years (Commission of the European Communities, 2007).

The paradigm shift in urban mobility planning is not easy. It requires persuading the different groups of stakeholders who have conflicting interests even after finding the required financials and preparing for the ultimate change from traditional resource-oriented approaches to green thinking. To illustrate the complexity of the whole process, we have developed a case scenario that presents the conflicting constraints and possible green alternatives. After the choice set and criteria have been determined, a survey is constructed. Specialists fill out the questionnaires. The four options are ranked based on the replies. The most favorable option chosen is to integrate road transportation with the environment.

The green transformation is a challenging issue. On the one hand, the familiarity of the traditional and already constructed infrastructure with a considerable amount of investment, on the other hand, the urgent call for rethinking the consumption of today's resources for the sake of future generations. The equilibrium is more about the agreement of the opposing forces: the traditional versus the new, today versus tomorrow, what it is versus what it ought to be. The results of our study confirm these challenges. The alternative that represents the technical transformation of the existing engines is not enough for green action. The greenest alternative that requires the transformation of the vehicles to electrical systems is not only financially challenging, but also asks for the consent of the owners of the vehicles. The balance is reached where the traditional infrastructure meets with the green one. So that the efficiency is increased for both. The planners are supposed to prioritize inclusive, financially feasible alternatives that increase the efficiency of the existing infrastructure with the support of green strategies. Climate change adaptation must certainly be considered by governments when developing green mobility initiatives.

7. Conclusion

The findings of our study show that the centrally planned operated and regulated micro-mobility is the least advantageous alternative, followed by the alternative of the particulate filter with preservation of motorway use for most transport modes. The second most advantageous alternative is the full transformation of the fleet to electric vehicles, and the most advantageous alternative is the integration of road transport with the environment.

The fast rise of the world's population, along with a rising number of vehicles, is putting a strain on the mobility and energy sectors, leading to increased traffic jams, and deteriorating air quality. As a result, global awareness of land use management, environmental emissions reduction, and climate change mitigation has increased. It has become critical to create new modes of transportation and adapt current ones to move people in more sustainable and cost-effective ways. However, as the practices from all around the world exhibits and the academic literature supports, the transformation from conventional modes is simple neither for the society nor for the planners. Besides the economic burden, the change in the way of life, losing the familiar and adopting the new is challenging both in policy formulation and implementation. In that respect, the transition period can give rise to the use of improved green version of existing infrastructure in transportation.

The findings of study illustrate the difficulty and the complexity of the decision-making process. The constraints that originate from economic, social, environmental or technical reasons are conflicting with each other. The binding constraints may change over time and across societies. However, the existing economic and societal dynamics of cities shows us that climate actions will never be straightforward to take. The challenges in the development process of sustainable cities may change. The existing physical and cultural infrastructure and the demography of the society will play the crucial role in this change.

This study addresses a gap in the literature regarding the selection process of the best policy of the most appropriate green approach for addressing climate change. The optimum approach to integrating road transportation with the environment is identified. Still, depending on the suitability of the place and the time constraints, options and criteria may differ, and outcomes may differ, but the process remains the same. As a result, the suggested technique of this study has the potential to serve as a guide for authorities in determining the most optimal strategies for adapting to climate change in mobility.

In this study, a novel multi-criteria framework based on Dempster-Shafer evidence theory for the evaluation of green strategies in mobility planning is presented. Dempster-Schafer theory and fuzzy theory were used for the development of the original algorithm for processing uncertain information. The PIPRECIA methodology used to determine the weighting coefficients of the evaluation criteria was extended using fuzzy D numbers. To select green strategies in mobility planning, a new algorithm for processing uncertain information based on the application of fuzzy D numbers and Dombi norms has been proposed. The Fuzzy 2D model is designed to enable flexible decision making with the ability to simulate different levels of risk across scenarios. Also, within the fuzzy 2D methodology, a new algorithm for standardizing fuzzy D information has been proposed. The inverse sorting algorithm enables the preservation of the disposition of normalized values on the measuring scale and eliminates the shift in the areas of normalized values.

Future research can be conducted by considering a real-time case study of urban logistics to seek further answers for practical difficulties. The opinions of the actual stakeholders from the sector can be surveyed to observe whether support is provided to different alternatives from different groups. The results may be tested against the development level of the urban area. A comparative study for a developing and developed city can be useful in analyzing how the economic and social development levels of cities affect the choice of green strategies in urban mobility planning.

Besides the apparent advantages, the proposed methodology has certain limitations. For example, one limitation of the multi-criteria model is its inability to deal with the interrelationships between arguments in the home matrix. To eliminate this limitation, it is recommended to implement the Heronian and Bonferroni functions in the fuzzy 2D model. The application of the Heronian and Bonferroni functions would improve the flexibility of the fuzzy 2D model by increasing the number of stabilization parameters of the aggregation functions. In addition, further directions should be directed to applying Einstein and Hamacher norms in the fuzzy 2D model. Also, an exciting focus for further research is the implementation of rough sets in combination with D numbers to address uncertainties in group models for decision making.

Conflict of interests

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.

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Appendix A1

A1.1. Operational lows with Dombi norms

Definition 1 (Dombi, 1982). Let $\wp_1$ and $\wp_2$ be two real numbers, then, the Dombi *T*-norm and *T*-conorm are defined as follows (Dombi, 1982):

$$\Theta = \frac{1}{1+\left\{\left((1-\wp_1)/\wp_1\right)^{\lambda}+\left((1-\wp_2)/\wp_2\right)^{\lambda}\right\}^{1/\lambda}} \tag{A1}$$

$$\Theta_c = \frac{1}{1+\left\{\left(\wp_1/(1-\wp_1)\right)^{\lambda}+\left(\wp_2/(1-\wp_2)\right)^{\lambda}\right\}^{1/\lambda}} \tag{A2}$$

where $\lambda > 0$ and $\wp_1, \wp_2 \in [0,1]$.

According to the Dombi *T*-norm and *T*-conorm, we define the Dombi operations as given in *Definition 2.*

Definition 2 (Sinani et al., 2020). Let $\wp_1$ and $\wp_2$ be two real numbers, $\phi,\lambda>0$ and $f\left(\wp_i\right)=\wp_i\Big/\sum_{i=1}^{n}\wp_i$, then we can define operational lows of real numbers based on the Dombi norms:

$$\wp_1+\wp_2=\left(\wp_1+\wp_2\right)-\frac{\wp_1+\wp_2}{1+\left\{\left(f\left(\wp_1\right)/(1-f\left(\wp_1\right))\right)^{\lambda}+\left(f\left(\wp_2\right)/(1-f\left(\wp_2\right))\right)^{\lambda}\right\}^{1/\lambda}} \tag{A3}$$

$$\wp_1\times\wp_2=\frac{\wp_1+\wp_2}{1+\left\{\left(\left(1/\left(\wp_1\right)\right)/f\left(\wp_1\right)\right)^{\lambda}+\left(\left(1-f\left(\wp_2\right)\right)/f\left(\wp_2\right)\right)^{\lambda}\right\}^{1/\lambda}} \tag{A4}$$

$$\phi\times\wp_1=\wp_1-\frac{\wp_1}{1+\left\{\phi\left(f\left(\wp_1\right)/\left(1-f\left(\wp_1\right)\right)\right)^{\lambda}\right\}^{1/\lambda}} \tag{A5}$$

$$\wp_1^{\phi}=\frac{\wp_1}{1+\left\{\phi\left(\left(1-f\left(\wp_1\right)\right)/f\left(\wp_1\right)\right)^{\lambda}\right\}^{1/\lambda}} \tag{A6}$$

A1.2. D numbers

To simplify the presentation of the multi-criteria framework, in the following section, through *Definitions 1 and 2*, the basic settings of D numbers are presented.

Definition 3. Let $\mathbb{Q}$ be a finite nonempty set, and a D number is a mapping that $D:\mathbb{Q}\to[0,1]$, with

$$\sum_{\zeta\subseteq\mathbb{Q}}D(\zeta)\le 1 \;\; and \;\; D(\varnothing)=0 \tag{A7}$$

where $\emptyset$ is an empty set and ζ is any subset of $\mathbb{Q}$. If $\sum_{\zeta\subseteq\mathbb{Q}}D(\zeta)\le 1$ the presented information is complete; otherwise, the information is incomplete.

For the set $\mathbb{Q}=\left\{\xi_1,\xi_2,...,\xi_i,\xi_j,...,\xi_n\right\}$, where $\xi_i\in R$ and $\xi_i\ne\xi_j$ (when $i\ne j$), then D numbers can be represented as $D=\{(\xi_1,\upsilon_1),(\xi_2,\upsilon_2)\ ...\ (\xi_i,\upsilon_i),\ (\xi_j,\upsilon_j)...\ (\xi_n,\upsilon_n)\}$, where the condition that $\upsilon_i>0$ and $\sum_{i=1}^{n}\upsilon_i\le 1$ is satisfied.

Definition 4. Let D_1 and D_2 be two D numbers of $D_1 = \{(\xi_1, \upsilon_1), ..., (\xi_i, \upsilon_i), ..., (\xi_n, \upsilon_n)\}$ and $D_2 = \{(\xi_n, \upsilon_n), ..., (\xi_i, \upsilon_i), ..., (\xi_1, \upsilon_1)\}$. Then we can define a rule for the combination of D numbers $D = D_1 \odot D_2$ as follows:

$$\begin{cases} D(\varnothing) = 0 \\ D(\aleph) = 1/(1 - \mathbb{Z}_D) \sum_{B_1 \cap B_2 = B} D_1(\aleph_1) D_2(\aleph_2), \quad \aleph \neq \varnothing \end{cases}$$

with

$$\mathbb{Z}_D = \frac{1}{\mathbb{R}_1 \mathbb{R}_2} \sum_{\aleph_1 \cap \aleph_2 = \varnothing} D_1(\aleph_1) D_2(\aleph_2) \tag{A8}$$

$$\mathbb{R}_1 = \sum_{\aleph_1 \subseteq \Theta} D_1(\aleph_1)$$

$$\mathbb{R}_2 = \sum_{\aleph_2 \subseteq \Theta} D_2(\aleph_2)$$

The rule for the combination of D numbers as given in Eq. (8) allows the fusion of uncertain information presented in D numbers. The integration of D numbers obtained by using Eq. (8) is done using Eq. (9).

$$\mathrm{K}(D) = \sum_{i=1}^{n} \xi_i \upsilon_i; \quad \xi_i \in R^+, \upsilon_i > 0 \tag{A9}$$

Appendix A2

Table A2.1
Expert assessments of criteria.

	C_j/C_{j-1} for main criteria		C_j/C_{j+1} for main criteria
C_2/C_1	D_1={(SMS,0.8),(MMS,0.2)}; D_2={(AE,0.3),(SMS,0.4),(MMS,0.25)}	C_3/C_4	D_1={(MLS,0.8),(RLS,0.2)}; D_2={(SMS,0.3),(MLS,0.4;RLS,0.25)}
C_3/C_2	D_1={(AE,0.5),(MMS,0.4)}; D_2={(AE,0.4),(SMS,0.25),(MMS,0.35)}	C_2/C_3	D_1={(WLS,0.5),(LS,0.4)}; D_2={(WLS,0.4),(MLS,0.25),(LS,0.35)}
C_4/C_3	D_1={(SMS,0.55),(MS,0.4)}; D_2={(MLS,0.2),(SMS,0.5),(MS,0.3)}	C_1/C_2	D_1={(MLS,0.8),(LS,0.2)}; D_2={(WLS,0.3),(MLS,0.4),(LS,0.25)}
	C_j/C_{j-1} for economic criteria		C_j/C_{j+1} for economic criteria
C_2/C_1	D_1={(AE,0.7),(SMS,0.25)}; D_2={(SMS,0.2),(MMS,0.5),(MS,0.25)}	C_3/C_4	D_1={(WLS,0.55),(MLS,0.45)}; D_2={(WLS,0.4),(MLS,0.4;MLS;LS,0.25)}
C_3/C_2	D_1={(MLS,0.5),(LS,0.45)}; D_2={(MLS,0.5),(LS,0.4),(MS,0.1)}	C_2/C_3	D_1={(SMS,0.5),(MMS,0.5)}; D_2={(SMS,0.5),(MMS,0.4),(RLS,0.1)}
C_4/C_3	D_1={(AE,0.55),(SMS,0.45)}; D_2={(AE,0.45),(SMS,0.4),(SMS;MS,0.15)}	C_1/C_2	D_1={(WLS,0.7),(MLS,0.3)}; D_2={(MLS,0.25),(LS,0.5),(RLS,0.25)}
	C_j/C_{j-1} for green criteria		C_j/C_{j+1} for green criteria
C_2/C_1	D_1={(AE,0.6),(MS,0.4)}; D_2={(AE,0.5),(MMS;MS,0.25),(MS,0.25)}	C_3/C_4	D_1={(WLS,0.45),(MLS,0.45)}; D_2={(WLS;MLS,0.45),(MLS,0.4;MLS;LS,0.15)}
C_3/C_2	D_1={(AE,0.3),(SMS,0.7)}; D_2={(MLS,0.5),(AE,0.4),(SMS,0.1)}	C_2/C_3	D_1={(WLS,0.3),(MLS,0.7)}; D_2={(SMS,0.5),(WLS,0.4),(MLS,0.1)}
C_4/C_3	D_1={(AE,0.45),(SMS,0.5)}; D_2={(AE;SMS,0.45),(SMS,0.4),(SMS;MS,0.15)}	C_1/C_2	D_1={(WLS,0.6),(RLS,0.4)}; D_2={(WLS,0.5),(LS;RLS,0.25),(RLS,0.25)}
	C_j/C_{j-1} for technical capability criteria		C_j/C_{j+1} for technical capability criteria
C_2/C_1	D_1={(MMS,0.6),(MMS;MS,0.15)}; D_2={(MLS,0.1),(SMS,0.6),(MS;MMRS,0.25)}	C_3/C_4	D_1={(SMS,0.7),(MMS,0.3)}; D_2={(AE,0.3),(SMS,0.5;MMS,0.15)}
C_3/C_2	D_1={(SMS,0.4),(MMS;MS,0.6)}; D_2={(AE,0.2),(SMS,0.4),(MS,0.4)}	C_2/C_3	D_1={(MLS,0.4),(LS;RLS,0.6)}; D_2={(WLS,0.2),(MLS,0.4),(RLS,0.4)}
C_4/C_3	D_1={(AE,0.7),(MMS,0.3)}; D_2={(MLS,0.3),(AE,0.5),(MMS,0.15)}	C_1/C_2	D_1={(MLS,0.8),(MLSS,0.15)}; D_2={(SMS,0.1),(MLS,0.6),(RLS;MLSS,0.25)}
	C_j/C_{j-1} for societal criteria		C_j/C_{j+1} for societal criteria
C_2/C_1	D_1={(SMS,0.8),(MMRS,0.15)}; D_2={(MMS,0.5),(MS,0.4),(MMS;MS,0.1)}	C_3/C_4	D_1={(LS,0.6),(MLSS,0.4)}; D_2={(MLS,0.2),(LS,0.5),(RLS,0.3)}
C_3/C_2	D_1={(MLS,0.4),(WLS,0.6)}; D_2={(LS,0.2),(MLS,0.4),(MLS;WLS,0.4)}	C_2/C_3	D_1={(SMS,0.4),(AE,0.6)}; D_2={(SMS,0.4),(MMS,0.2),(AE;SMS,0.4)}
C_4/C_3	D_1={(MMS,0.6),(MMRS,0.4)}; D_2={(SMS,0.2,(MMS,0.5),(MS,0.3)}	C_1/C_2	D_1={(LS,0.6),(LS;RLS,0.4)}; D_2={(LS,0.5),(RLS,0.4),(RLS;MLSS,0.1)}

Table A2.2
Details of the calculation carried out using fuzzy D PIPRECIA for the main criteria.

fuzzy D PIPRECIA				
	$\overline{s_j}$	$\overline{k_j}$	$\overline{q_j}$	$\overline{w_j}$
C_1		(1,1,1)	(1,1,1)	(0.197,0.215,0.235)
C_2	(1.058,1.112,1.159)	(0.841,0.888,0.942)	(1.061,1.126,1.189)	(0.209,0.242,0.28)
C_3	(0.974,1.011,1.056)	(0.944,0.989,1.026)	(1.035,1.139,1.26)	(0.204,0.245,0.297)
C_4	(1.103,1.179,1.227)	(0.773,0.821,0.897)	(1.153,1.387,1.629)	(0.227,0.298,0.383)
SUM			(4.249,4.651,5.079)	
inverse fuzzy D PIPRECIA				
C_1	(0.462,0.612,0.907)	(1.093,1.388,1.538)	(0.281,0.4,0.671)	(0.085,0.15,0.285)

C_2	(0.501,0.715,0.776)	(1.224,1.285,1.499)	(0.431,0.555,0.734)	(0.131,0.208,0.311)
C_3	(0.454,0.599,0.886)	(1.114,1.401,1.546)	(0.647,0.714,0.898)	(0.196,0.267,0.381)
C_4		(1,1,1)	(1,1,1)	(0.303,0.375,0.424)
SUM			(2.359,2.669,3.302)	

Table A2.3
Details of the calculation carried out using fuzzy D PIPRECIA for economic criteria

fuzzy D PIPRECIA				
	$\overline{s_j}$	$\overline{k_j}$	$\overline{q_j}$	$\overline{w_j}$
C_1		(1,1,1)	(1,1,1)	(0.246,0.282,0.303)
C_2	(0.993,1.038,1.083)	(0.917,0.962,1.007)	(0.993,1.039,1.091)	(0.244,0.293,0.331)
C_3	(0.435,0.567,0.817)	(1.183,1.433,1.565)	(0.634,0.725,0.922)	(0.156,0.204,0.28)
C_4	(1.05,1.075,1.125)	(0.875,0.925,0.95)	(0.668,0.784,1.054)	(0.164,0.221,0.32)
SUM			(3.295,3.549,4.067)	
inverse fuzzy D PIPRECIA				
C_1	(0.5,0.667,1)	(1,1.333,1.5)	(0.543,0.798,1.36)	(0.115,0.216,0.445)
C_2	(1.144,1.217,1.267)	(0.733,0.783,0.856)	(0.815,1.064,1.36)	(0.173,0.288,0.445)
C_3	(0.566,0.8,0.998)	(1.003,1.2,1.434)	(0.697,0.833,0.998)	(0.148,0.226,0.326)
C_4		(1,1,1)	(1,1,1)	(0.212,0.271,0.327)
SUM			(3.056,3.695,4.718)	

Table A2.4
Details of the calculation carried out using fuzzy D PIPRECIA for green criteria.

fuzzy D PIPRECIA				
	$\overline{s_j}$	$\overline{k_j}$	$\overline{q_j}$	$\overline{w_j}$
C_1		(1,1,1)	(1,1,1)	(0.187,0.205,0.221)
C_2	(1.12,1.18,1.23)	(0.77,0.82,0.88)	(1.136,1.22,1.299)	(0.212,0.25,0.288)
C_3	(1.037,1.055,1.105)	(0.895,0.945,0.963)	(1.18,1.291,1.451)	(0.22,0.265,0.321)
C_4	(1.018,1.051,1.099)	(0.901,0.949,0.982)	(1.201,1.361,1.611)	(0.224,0.279,0.357)
SUM			(4.517,4.871,5.361)	
inverse fuzzy D PIPRECIA				
C_1	(0.533,0.76,0.8)	(1.2,1.24,1.467)	(0.325,0.55,0.758)	(0.091,0.183,0.307)
C_2	(0.605,0.877,1)	(1,1.123,1.395)	(0.477,0.681,0.909)	(0.133,0.227,0.368)
C_3	(0.497,0.693,0.9)	(1.1,1.307,1.503)	(0.665,0.765,0.909)	(0.186,0.255,0.368)
C_4		(1,1,1)	(1,1,1)	(0.28,0.334,0.405)
SUM			(2.467,2.996,3.576)	

Table A2.5
Details of the calculation carried out using fuzzy D PIPRECIA for technical capability criteria.

fuzzy D PIPRECIA				
	$\overline{s_j}$	$\overline{k_j}$	$\overline{q_j}$	$\overline{w_j}$
C_1		(1,1,1)	(1,1,1)	(0.172,0.191,0.219)
C_2	(1.012,1.067,1.112)	(0.888,0.933,0.988)	(1.013,1.072,1.127)	(0.174,0.204,0.246)
C_3	(1.22,1.33,1.38)	(0.62,0.67,0.78)	(1.298,1.6,1.817)	(0.223,0.305,0.397)
C_4	(0.972,0.982,1.03)	(0.97,1.018,1.028)	(1.262,1.573,1.873)	(0.217,0.3,0.41)

SUM			(4.573,5.245,5.817)	
inverse fuzzy D PIPRECIA				
C_1	(0.437,0.58,0.863)	(1.137,1.42,1.563)	(0.424,0.529,0.802)	(0.109,0.155,0.255)
C_2	(0.4,0.507,0.7)	(1.3,1.493,1.6)	(0.662,0.751,0.912)	(0.17,0.221,0.29)
C_3	(1.056,1.109,1.156)	(0.844,0.891,0.944)	(1.059,1.122,1.185)	(0.272,0.33,0.377)
C_4		(1,1,1)	(1,1,1)	(0.256,0.294,0.318)
SUM			(3.145,3.402,3.899)	

Table A2.6
Details of the calculation carried out using fuzzy D PIPRECIA for technical social criteria.

fuzzy D PIPRECIA				
	$\overline{s_j}$	$\overline{k_j}$	$\overline{q_j}$	$\overline{w_j}$
C_1		(1,1,1)	(1,1,1)	(0.146,0.178,0.231)
C_2	(1.229,1.343,1.393)	(0.607,0.657,0.771)	(1.296,1.522,1.647)	(0.19,0.27,0.38)
C_3	(0.571,0.81,1)	(1,1.19,1.429)	(0.907,1.278,1.647)	(0.133,0.227,0.38)
C_4	(1.2,1.3,1.35)	(0.65,0.7,0.8)	(1.134,1.826,2.534)	(0.166,0.325,0.584)
SUM			(4.338,5.626,6.828)	
inverse fuzzy D PIPRECIA				
C_1	(0.381,0.471,0.619)	(1.381,1.529,1.619)	(0.397,0.456,0.599)	(0.125,0.162,0.225)
C_2	(1.029,1.043,1.093)	(0.907,0.957,0.971)	(0.643,0.697,0.827)	(0.203,0.247,0.31)
C_3	(0.4,0.5,0.667)	(1.333,1.5,1.6)	(0.625,0.667,0.75)	(0.197,0.237,0.281)
C_4		(1,1,1)	(1,1,1)	(0.315,0.355,0.375)
SUM			(2.666,2.819,3.175)	

Table A2.7
Home matrix with aggregated fuzzy D numbers.

	A_1	A_2	A_3	A_4
C_1	D={(3,0.51),(4,0.44)}	D={(1,0.556),(2,0.44)}	D={(8,0.22),(9,0.68),(2,0.58)}	D={(3,0.19),(4,0.65)}
C_2	D={(6,0.45),(7,0.55)}	D={(8,0.36),(9,0.63)}	D={(3,0.405),(4,0.01)}	D={(8,0.2),(9,0.74)}
C_3	D={(4,0.67),(5,0.22)}	D={(4,0.90)}	D={(8,0.13),(9,0.81)}	D={(4,0.54),(5,0.45)}
C_4	D={(5,0.52),(6,0.21),(7,0.12)}	D={(3,0.95)}	D={(4,0.77),(5,0.12),(6,0.06)}	D={(3,0.79),(4,0.2)}
C_5	D={(3,0.58),(4,0.36)}	D={(1,0.73),(2,0.22)}	D={(4,0.3),(5,0.64)}	D={(3,0.9)}
C_6	D={(3,0.28),(4,0.66)}	D={(1,0.77),(2,0.08)}	D={(4,0.11),(5,0.83)}	D={(4,0.7),(5,0.14)}
C_7	D={(3,0.61),(4,0.39)}	D={(1,0.75),(2,0.19)}	D={(8,0.11),(9,0.84)}	D={(8,0.25),(9,0.6)}
C_8	D={(7,0.95)}	D={(1,0.76),(2,0.08)}	D={(4,0.79),(5,0.11)}	D={(6,0.61),(7,0.28)}
C_9	D={(5,0.90)}	D={(6,0.91),(7,0.09)}	D={(8,0.3),(9,0.54)}	D={(3,0.57),(4,0.42)}
C_{10}	D={(6,0.551),(7,0.44)}	D={(8,0.16),(9,0.78)}	D={(2,0.58),(3,0.36)}	D={(4,0.52),(5,0.28)}
C_{11}	D={(3,0.8),(4,0.15)}	D={(1,0.69),(2,0.26)}	D={(8,0.18),(9,0.76)}	D={(8,0.21),(9,0.78)}
C_{12}	D={(3,0.95)}	D={(2,0.21),(3,0.79)}	D={(8,0.1),(9,0.89)}	D={(8,0.15),(9,0.74)}
C_{13}	D={(6,0.68),(7,0.22)}	D={(7,0.59),(8,0.26)}	D={(8,0.04),(9,0.95)}	D={(4,0.74),(5,0.20)}
C_{14}	D={(3,1)}	D={(8,0.25),(9,0.75)}	D={(7,0.92),(8,0.07)}	D={(8,0.04),(9,0.68)}
C_{15}	D={(3,0.63),(4,0.22)}	D={(3,0.792),(4,0.11)}	D={(8,0.22),(9,0.73)}	D={(8,0.17),(9,0.827)}
C_{16}	D={(5,0.71),(6,0.24)}	D={(4,0.93),(5,0.02)}	D={(1,0.71),(2,0.18)}	D={(8,0.12),(9,0.67)}

Table A2.8
Standardized home matrix.

Crit.	A_1	A_2	A_3	A_4
C_1	(0.543,0.691,0.726)	(0.639,0.868,1.00)	(0.096,0.138,0.224)	(0.591,0.699,0.754)
C_2	(0.506,0.728,0.950)	(0.737,0.959,1.00)	(0.049,0.142,0.236)	(0.716,0.927,0.950)
C_3	(0.736,0.958,0.974)	(0.762,0.984,1.00)	(0.211,0.422,0.633)	(0.686,0.886,0.878)
C_4	(0.138,0.415,0.692)	(0.475,0.738,1.00)	(0.302,0.565,0.827)	(0.437,0.685,0.933)
C_5	(0.337,0.379,0.447)	(0.393,0.701,1.00)	(0.142,0.184,0.252)	(0.401,0.459,0.543)
C_6	(0.303,0.315,0.340)	(0.419,0.709,1.00)	(0.131,0.143,0.168)	(0.267,0.310,0.366)
C_7	(0.163,0.397,0.631)	(0.111,0.134,0.18)	(0.765,0.987,1.00)	(0.670,0.870,0.900)
C_8	(0.099,0.110,0.130)	(0.556,0.778,1.00)	(0.431,0.453,0.484)	(0.200,0.222,0.254)
C_9	(0.334,0.557,0.78)	(0.506,0.753,1.00)	(0.697,0.907,0.945)	(0.176,0.423,0.670)
C_{10}	(0.520,0.754,0.988)	(0.758,0.981,1.00)	(0.111,0.265,0.487)	(0.222,0.411,0.600)
C_{11}	(0.122,0.333,0.544)	(0.106,0.134,0.192)	(0.719,0.930,0.950)	(0.754,0.977,1.00)
C_{12}	(0.106,0.317,0.528)	(0.111,0.310,0.532)	(0.766,0.988,1.00)	(0.683,0.883,0.900)
C_{13}	(0.424,0.624,0.824)	(0.504,0.694,0.855)	(0.772,0.995,1.00)	(0.234,0.445,0.656)
C_{14}	(0.111,0.333,0.556)	(0.750,0.973,1.00)	(0.564,0.786,1.00)	(0.557,0.718,0.723)
C_{15}	(0.120,0.310,0.500)	(0.113,0.313,0.514)	(0.714,0.925,0.950)	(0.759,0.981,1.00)
C_{16}	(0.429,0.693,0.957)	(0.267,0.531,0.795)	(0.125,0.151,0.203)	(0.760,0.982,1.00)