



## Research article

## Assessment of sustainability science education criteria in online-learning through fuzzy-operational and multi-decision analysis and professional survey



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## ABSTRACT

Sustainable development in education is growing a public awareness and is gaining an increasing importance to improve a long-term learning program. However, a higher sustainability education is an initial phase as ever in many universities. E-learning systems in science education based on innovative information and Information and Communication Technologies (ICTs) have close relationship in effective long-standing learnings of sustainability and numerous criteria. Also, the technological challenge integrated to sustainability science education has been focused on e-learning programs, which can fill current educational niche. This paper presents a combined application, Fuzzy-DEcision-MAking Trial and Evaluation Laboratory/Multi-Criteria Decision Analysis (F-DEMATEL/MCDA) technique, identifying and analyzing e-learning systems' the most essential criteria for sustainability science education. The main criteria to accomplish this goal proposed are delineated, weighted, appraised and assigned into four groups such as sustainability, science education, e-learning and technology criteria. Sixteen sub-criteria were analyzed by the participatory F-DEMATEL technique on the basis of coefficients' value and computation in the context of impact and examination. For the final decision problem, the most important criteria are acquired with the help of Weighted Linear Combination (WLC) assessed by six implementation strategies' sensitivity analysis (A to F) and the sub-criteria by a professional online survey. Analysis on F-DEMATEL/MCDA shows sustainability criteria (Strategy A, 0.54 with 84% most likely and likely professional perception survey) that is the most essential criteria in sustainability and e-learning systems science education. Also, it indicates information environmental (0.57 with 77% most likely and likely professional perception survey) is the most essential variable among sub-criteria. Strategy F considering the most important criteria as equal (0.25) got 19% positively perception professional assessment. Consequently, fuzzy-operational and multi-decision analysis and professional survey could be utilized to find out the most essential sustainability science e-learning criteria that also could be engaged to make pliable and pertinent decision features.

## 1. Introduction

Sustainability issues are getting more public attentions together with concurrent science courses' increase and offer based on e-learning systems of novel information and Information and Communication Technologies (ICTs) (Lozano et al., 2013; Pereira et al., 2008). However, sustainable science instruction is still in an early stage of higher education that requires various criteria such as new competences, flexibility, and competition among universities (Jeong and González-Gómez, 2020; Lozano and Young, 2013). Thus, science e-learning education systems on the basis of innovative information and ICTs have great connection for successful long-standing learnings in sustainable development (Shee and

Wang, 2008). Here, the technological challenges integrated to sustainability science education has been focused on e-learning programs, which can fill current educational niche (Eneroth, 2000). For multi-criteria decision-makings, the e-learning systems' widespread assortment and appraisal for initiating e-learning systems' ranking together with the Fuzzy-DEcision-MAking Trial and Evaluation Laboratory (F-DEMATEL) method have been utilized to form an operational organization amongst the criteria and worth (Jain et al., 2015; Jeong and Ramírez-Gómez, 2018). Numerous features and aspects of e-learning connected with applications that are utilizing the F-DEMATEL/MCDA have been analyzed to show whole qualifications and experiences, which are equivalent for both e-learning and conventional procedures (Su et al., 2016; Wan and

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Dong, 2020; Wan et al., 2018). Because of the reasons detected and the absence of literature, it is necessary to scrutinize the criteria and sub-criteria for e-learning systems in sustainability science education. So, the research suggested will fill the current gap and present its states of art related with the topic proposed.

In this work, the distinct criteria and sub-criteria are identified and analyzed for sustainability science e-learning systems with a help of F-DEMATEL/MCDA method as a combined application that is on the basis of the beginning outcomes by an ongoing development, in a more long-term learning program. The main criteria to accomplish this goal proposed are delineated, weighted, appraised and apportioned into four groups such as sustainability, science education, e-learning and technology criteria and sixteen sub-criteria with regard to the participatory F-DEMATEL technique with the coefficients' value and calculation in the context of influence and examination. In the final decision problem, the most important criteria are attained through the application of the Weighted Linear Combination (WLC). Afterwards, this work deliberates the proposed six implementation strategies' likelihood of sensitivity analysis and their sub-criteria (A to F) by an online decision-makers survey. The recommended approach is structured firstly addressing and discussing the states of arts of this work related with the current literature in the "Theoretical foundations". Secondly, it defines the "Materials and methods" presenting the F-DEMATEL/MCDA method that mainly verified in the projected educational environments. In the "Results and discussions" part, it discusses the results from the recommended approach. In the final and last part, the "Conclusions" summarizes reflections and deliberations attained from this method and explains proposals for further work.

## 2. Theoretical foundations

E-learning and online-learning are considered as teaching/learning processes based on a proper educational model, which allow flexible and pertinent learner-centered education due to ICTs in sustainability education (Lee and Lee, 2008; Pereira et al., 2008; Shee and Wang, 2008). The ICTs help e-learning systems being in virtual learning platforms, in which multi-faceted communications can be happening, such as teacher to teacher, teacher to student and student to student (Garrison, 2000; Narciss et al., 2007; Pereira et al., 2008). E-learning system particularly takes the independence of occasion and position, a self-restricted learning procedure and inter- and multi-disciplinary advance in teaching/learning constituting fundamental components for sustainability education (Garrison, 2000; Lee and Lee, 2008; Lozano et al., 2013; Narciss et al., 2007). Hansen (2008) emphasized that students in e-learning system usually have greater sense of knowledge, which lead to successful transformative learning as well other researchers (Arbaugh, 2000; Schramm et al., 2001). Moreover, the learning attainments by students mentioned by Paechter et al. (2010) are meticulously related to e-learning systems' personalities, that is, learning strategies' flexibility and knowledge exchange as multi-directional communications. In self-controlled and cooperative learning process, students' greater learning achievements are related with all important sustainability education issues (Lambrechts et al., 2018; Narciss et al., 2007; Moura et al., 2010). In addition to ICTs and innovative material, science e-learning education systems could be of excessive correlation for sustainable development in actual long-term and life-long learning along with various criteria (Azeiteiro et al., 2014; Garrison, 2000). Also, the technological challenge integrated to sustainability science education has been focused on e-learning programs, which can fill current educational niche (Eneroth, 2000; Paechter et al., 2010). Particularly, for using sustainability education, this area assesses teaching technologies' application integrated to transformational teaching/learning and sustainability challenges, that is, an ICT-based teaching/learning in sustainability education (McVey, 2016; Nowotny et al., 2018; Pavlova, 2013). However, typical e-learning classes are still more dominated that require more specific research for the usefulness of e-learning systems. The review and

debate of recent published articles indicate explanation and comprehensive analysis in higher education for sustainable (science) e-learning education systems (McVey, 2016; Nowotny et al., 2018). Thus, multi-criteria of e-learning system are required to adapt operational methods with various decision-makers in sustainability (science) education.

Sustainability education raises and pursues known consciousness and a life-long education quality as gaining increasing attention in various educational domains (Eneroth, 2000; Lozano et al., 2013; Sterling, 2001). The United Nations Educational, Scientific and Cultural Organization (UNESCO) Decade of Education for Sustainable Development (DESD) in the United Nation (UN) and UNESCO 2015–2030 Agenda have been trying to integrate sustainable education's objectives, philosophies, exercises and beliefs (Pavlova, 2013; Segalàs et al., 2009; UNESCO, 2017). Universities in higher education should be a part of a universal structure suggesting sustainability education, which shapes its aim to people along with ability and knowledge that will reflect on their behavior effects (Barth et al., 2007; González-Gómez et al., 2019; Valcke, 1991; Wiek et al., 2011). Particularly, it is pointed to the achievement of skills, information, knowledge and worth, is reoriented to the academic curricula, and is raised to better concept understanding towards sustainability (Læssøe et al., 2009; Lozano, 2006; Wals, 2010). Sterling (2001) mentioned that sustainable education is an educational culture change for human's potential realization and economic, social and ecological interdependence, which will conduct into transformative learning. Mezirow (1997) in transformative learning indicated the responsibility of instructors who can assist learners that attain a more independent and trustworthy goals. In an instructional culture context, teaching developments and resolutions contemplate on authorizing apprentices in addition to standards, abilities, communication and a thinking-method that execute as transition negotiators to sustainable development (Fadееva and Mochizuki, 2010; Sterling and Thomas, 2006; Thomas, 2009). Sustainability science education is related with knowledge acting and embracing the principles for sustainability education. However, it can't connect a distinct research area that can be own measurements, approaches and proficiencies and scientific dexterities (Bacelar-Nicolau et al., 2009; Kajikawa, 2008; Leal Filho et al., 2018). Also, it is an emergent area inside of educational field that has a strong tie to sustainability science education (Esmailian et al., 2018; Disterherft et al., 2013; Pereira et al., 2008). Conversely, higher sustainable science education is an initial phase as ever in many universities although they have act various parts to transform societies and cultures by enlightening decision-makers that are academics, entrepreneurs and leaders. Thus, it is necessary to reflect characteristics of universities changing relatively in slow speed (Lozano and Young, 2013; Lozano et al., 2013). In the challenging situations, life-long (science) education can produce a pedagogical potential act for filling e-learning system niche (Eneroth, 2000; Paechter et al., 2010).

An application as Multi-Criteria Decision Analysis (MCDA) for numerous situations accelerates various decision-makings by which particular explanations are at a short distance and also varied criteria and sub-criteria must be considered with decision-makers who disagree (Dias et al., 2002; Jeong et al., 2013; Malczewski, 1999). Herein, the MCDA method is considered as a main technique and tool, which has been utilized in numerous foundations and disciplines, along with the Analytic Hierarchy Process (AHP) that is the influential skill and tool used for determining potential components for sustainability (science) education through systems of e-learning (Gemitz et al., 2006; Saaty, 1996; Zare et al., 2016). E-learning systems' widespread assortment highlighted for initiating multi-criteria -learning decision-making systems' ranking (Jain et al., 2015). They also used the MCDA problems to propose an approximation method of weighted distance-based one with ideal elucidation similarity comparison (Jain et al., 2016). Islas-Pérez et al. (2015) defined standard and criteria set for e-learning systems that intended to be funding e-learning tools' clients and management systems to build enhanced decisions. Thus, the F-DEMATEL scheme is exploited

to form an operational preparation amongst the criteria and their worth (Büyükoğuzkan and Çifçi, 2012; Govindan et al., 2015; Jeong and Ramírez-Gómez, 2018; Wan et al., 2018). Numerous features and aspects of e-learning associated applications utilizing the F-DEMATEL/MCDA have been analyzed to show entire qualifications and experiences that are equivalent on behalf of e-learning and conventional procedures (Delivand et al., 2015; Jeong and Ramírez-Gómez, 2018; Parkes et al., 2014; Wan et al., 2019). A novel hybrid model showed with fuzzy multi-criteria decision-makings that the F-DMATEL method was expended for improving a prominent and effective relationship for a network (Su et al., 2016). The context of participatory network is engaged and founded by the F-DEMATEL technique amongst the criteria and the worth (Chen-Yi et al., 2007; Jeong and Ramírez-Gómez, 2018; Lin, 2013). Garg and Jain (2017) mentioned science e-learning configurations with an ordered development scheme using fuzzy MCDA method and F-DEMATEL analytic network process found the influential weights together with the establishment of Yang et al. (2017). F-DEMATEL analytic network process can be used a practical network communication case in service industry as an example (Su et al., 2016; Yang et al., 2017). These reasons aforementioned in addition to literature absence can show the necessity to find out the criteria and sub-criteria of sustainable science e-learning education systems.

### 3. Materials and methods

The F-DEMATEL/MCDA approach in this section is pertained to a science subject in Primary Education, University of Extremadura, Spain. Considering the subject proposed, this method is utilized into these sixteen criteria proposed that are clustered into four groups, that is, sustainability, science education, e-learning and technology criteria. Here, a combined application, the F-DEMATEL/MCDA method together with WLC and sensitivity analysis test through professional online survey, is employed the results to find out the most essential criteria in sustainable science e-learning education system in long-term. A

conceptual F-DEMATEL/MCDA frame is revealed as shown in Figure 1. Assessing the most essential factors of sustainable science e-learning education, the methodology is used for various steps as following.

#### 3.1. Option of the groups, criteria and sub-criteria

The first significant phase of F-DEMATEL/MCDA is the criteria and sub-criteria choice, and it can have probable components' robust inspiration on the assessment of in sustainable science e-learning education systems. Due to the characteristics of this operational methodology, there is a limitation to select the criteria, and it is important to choose the most suitable criteria and sub-criteria selection satisfying the objectives of this research. Criteria in this work as shown in Figure 1 and Table 1 are decided by the authors as the decision-makers. This selection was after the decision-makers' discussion with the real data determined by a wide bibliography, policies and directives of the European Union (EU). Four groups, specifically, sustainability, science education, e-learning and technology criteria, have sixteen criteria. Here, these four different hierarchical stages of organization had been utilized for the sustainability science education decision-problems through e-learning systems.

#### 3.2. Fuzzy-operational and multi-decision analysis

As the second significant phase, the F-DEMATEL technique, along with the comprehensive chosen criteria as a certain out-ranking manner, is employed to process the coefficients of criteria and sub-criteria worth. They contemplate the impact and inspiration in the components of sustainable science e-learning education systems in the context of the AHP frame. On criteria and sub-criteria, the fuzzy-logic arrangement has been betrothed to normalize and systematize the data. Along with common ranking scale 0 to 1, the four groups aforementioned were reckoned, which the least important 0 and the most important 1 for the proportion of every criterion. Now, decision-makers delineate individual criterion's proportional significance score in accordance with Pair-wise Comparison

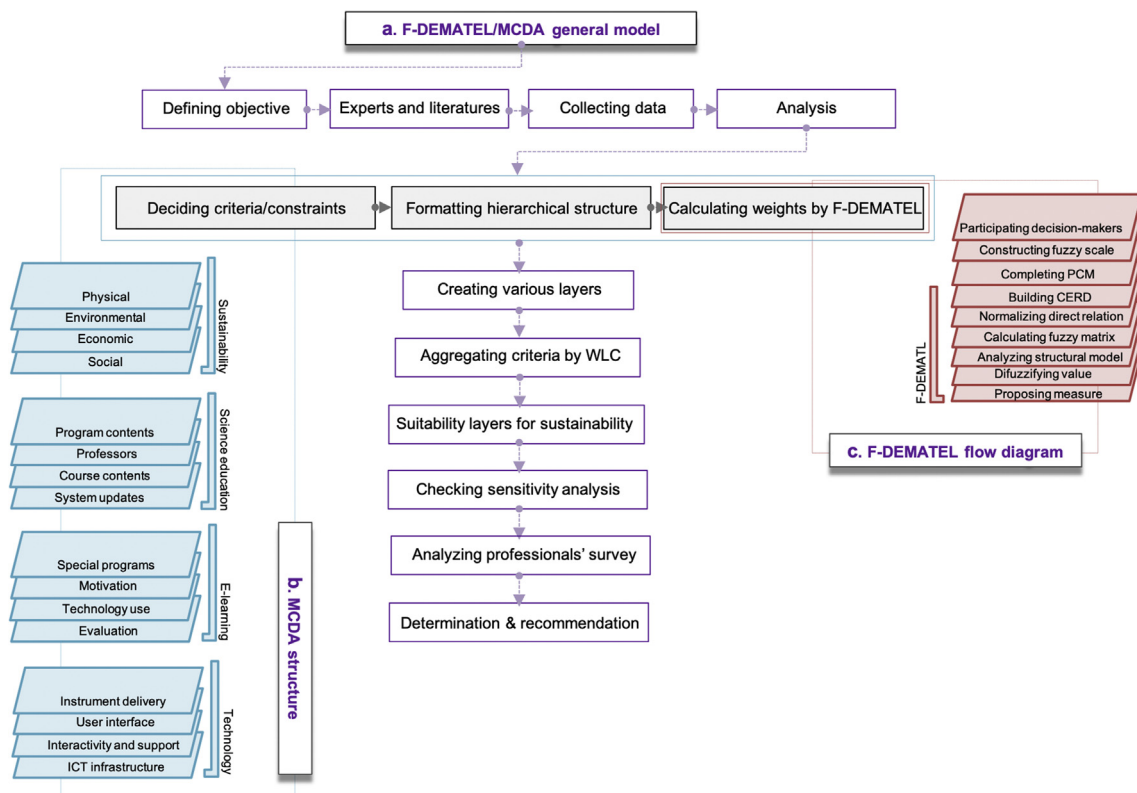


Figure 1. An abstract modeling of F-DEMATEL/MCDA methodology: (a) Overall model of F-DEMATEL/MCDA; (b) Hierarchical MCDA arrangement; and (c) F-DEMATEL scheme.

Matrix (PCM) due to not have the same significance score aforementioned. These criteria and sub-criteria value with the PCM can be decided along with the Consistency Ratio (CR) matrix. In each matrix, it indicates the calculation consistency of the worth committed. When a CR worth is less than 10%, a thumb regulation will be working, but, if a CR worth is more than 10%, decision-makers in this case should amend the made decisions that can be concluded (Kablan, 2004).

3.2.1. F-DEMATEL process

Lotfi Zadeh (1965) introduced the fuzzy-logic that is considered as a robust device. This device deals with ambiguity, uncertainty and vagueness of individual arbitration and valuation in the process of decision-makings. Also, the researcher discussed real troubles in decision-makings and intricated imprecision owing to not recognition of their constraints and probable engagements (Zadeh, 1965). Consequently, during the decision-makings' formula, it is a prerequisite to create fuzzy digits in practice. In this research, a fuzzified Likert scale is commissioned to determine with regard to gain criteria ordinary matrix

(see Eq. (1)). As shown in Figure 2, a Triangular Fuzzy Number (TFN) is shown in view of fuzzy-marks and connection occupations.

$$P = [p_{ij}] c_i \times c_j \tag{1}$$

Simply, a general triplet (l, m, u) can be articulated inside of this setting respectively l, m and u. They signify the worth in the lower, medium and upper level. Akyuz and Celik (2015) described these worth in a fuzzy set, that is, (x ≤ y ≤ z). Eq. (2) shows the TFN association occasions.

$$\mu(x) = \begin{cases} 0, & x < l \\ \frac{x-l}{m-l}, & l \leq x \leq m \\ \frac{u-x}{u-m}, & m \leq x \leq u \\ 0, & x \geq u \end{cases} \tag{2}$$

Considering the above comments, a TFN can be shown in Figure 2a, which the linguistic and equivalent relations and worth, and triangular-

Table 1. E-learning systems' criteria and sub-criteria considered for sustainability science education.

Criteria	Sub-criteria	Criterion context	Justification	Weight	Validation
Sustainability	Physical	Classification and description of physical sustainability indicating basic and advanced physical parameters related with the objectives presented.	Bacelar-Nicolau et al. (2009); Eneroth (2000); UNESCO, 2005; UNESCO, 2017.	0.25	CR = 0.083 < 0.1
	Environmental	Classification and description of environmental sustainability indicating basic and advanced environmental parameters related with the objectives presented.	Kajikawa (2008); Lozano et al. (2013); UNESCO, 2005; UNESCO, 2017.	0.57	
	Economic	Classification and description of economic sustainability indicating basic and advanced economic parameters related with the objectives presented.	Sterling (2001); Leal Filho et al. (2018); UNESCO, 2005; UNESCO, 2017.	0.06	
	Social	Classification and description of social sustainability indicating basic and advanced social parameters related with the objectives presented.	Esmailian et al. (2018); Pavlova (2013); UNESCO, 2005; UNESCO, 2017.	0.12	
Science education	Program contents	Classification and description of program contents in science education indicating basic and advanced program contents' parameters related with the objectives presented.	Jain et al. (2015); Lin (2013); Su et al. (2016).	0.13	CR = 0.089 < 0.1
	Professors	Classification and description of professors in science education indicating basic and advanced professors' parameters related with the objectives presented.	Islas-Pérez et al. (2015); Lozano and Young (2013); Parkes et al. (2014).	0.56	
	Course contents	Classification and description of course contents in science education indicating basic and advanced course contents' parameters related with the objectives presented.	Chen-Yi et al. (2007); Lozano et al. (2013); Su et al. (2016).	0.26	
	System updates	Classification and description of system updates in science education indicating basic and advanced system updates' parameters related with the objectives presented.	Garg and Jain (2017); Yang et al. (2017); Zare et al. (2016).	0.05	
E-learning	Special programs	Classification and description of special programs in e-learning indicating basic and advanced special programs' parameters related with the objectives presented.	Lee and Lee (2008); Lambrechts et al. (2018); Shee and Wang (2008).	0.57	CR = 0.091 < 0.1
	Motivation	Classification and description of motivation in e-learning indicating basic and advanced motivation parameters related with the objectives presented.	Pereira et al. (2008); Moura et al. (2010); Narciss et al. (2007).	0.24	
	Technology use	Classification and description of technology use in e-learning indicating basic and advanced technology use parameters related with the objectives presented.	Hansen (2008); Lee and Lee (2008); McVey (2016).	0.14	
	Evaluation	Classification and description of evaluation in e-learning indicating basic and advanced evaluation parameters related with the objectives presented.	Garrison (2000); Paechter et al. (2010); Pereira et al. (2008).	0.05	
Technology	Instrument delivery	Classification and description of instrument delivery in technology indicating basic and advanced instrument delivery parameters related with the objectives presented.	Lee and Lee (2008); Lozano et al. (2013); Nowotny et al. (2018).	0.25	CR = 0.059 < 0.1
	User interface	Classification and description of user interface in technology indicating basic and advanced user interface parameters related with the objectives presented.	Narciss et al. (2007); Shee and Wang (2008); Pavlova (2013).	0.12	
	Interactivity and support	Classification and description of interactivity and support in technology indicating basic and advanced interactivity and support parameters related with the objectives presented.	Azeiteiro et al. (2014); Garrison (2000); Lozano et al. (2013).	0.07	
	ICT infrastructure	Classification and description of ICT infrastructure in technology indicating basic and advanced ICT infrastructure parameters related with the objectives presented.	Garrison (2000); Lee and Lee (2008); Pereira et al. (2008).	0.54	



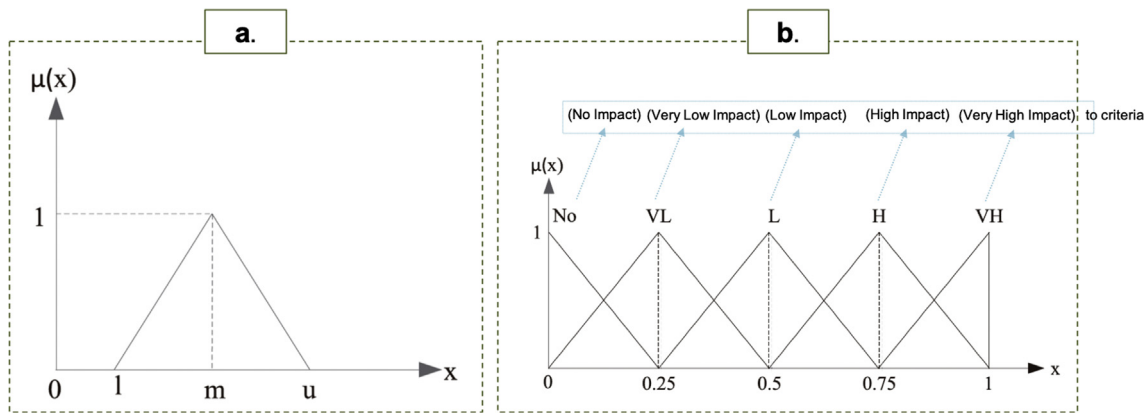


Figure 2. Graph of fuzzy-logic: a. TFN; b. Functions of fuzzy-digits and relationship (Akyuz and Celik, 2015).

fuzzy digits could be estimated on followed by Table 2. In Figure 2b, fuzzy marks and relationship functions also are elucidated.

The Decision-MAKING Trial and Evaluation Laboratory (DEMATEL) practice argued its complete/multifaceted decision-making problems by Battelle Memorial Institute (Geneva, Switzerland) (Gabus and Fontela, 1972). This technique is acknowledged commonly for a complete and multifaced tool that is to perceive the cause/effect correlation amongst criteria estimated (Lin and Tzeng, 2009). Principally, the diagram theory builds its technique that concedes visualization to examine and explain the problems raised (Lin, 2013) and exhibits the relationship of interdependence amongst the criteria and influential effect worth as well (Govindan et al., 2015). The fuzzy-logic sets and DEMATEL procedure for these facets are compound due to consider substantial components in e-learning systems for sustainability science education.

Thus, the technique suggested is valuable to figure out the relations amongst the criteria and organizing the criteria in accordance with the relationships' mode and their effects accuracy on each other criterion. Besides, fuzzy combined DEMATEL has the important benefits that are to reveal the fuzziness setting and directs with flexible fuzziness circumstance (Wu and Lee, 2007; Wu, 2012). In accordance with the benefits proposed, the DEMATEL is utilized and then determines cause/effect interactions on the criteria and attains the model on the basis of the TFN linguistics parameterized. The F-DEMATEL flow diagram in this manner is conveyed along with the key phases delineated as depicted in Figure 1c (Chen-Yi et al., 2007; Liou et al., 2008; Wu and Lee, 2007). Herein, the F-DEMATEL technique stipulates the succeeding phases stipulated with the results attained according to Figure 1b.

1. As direct relationships, it resolves the ordinary matrix of criteria. The authors in the weighting route after the discussion with professors, researchers, educators and authorities contribute and build a conventional mean of the medium through criteria relationship. The decision-makers' amalgamation of ranking worth is terminated in which  $p_{ij}^e$  convey that  $e$  is the inclination of decision-makers and  $k$  is the whole value of decision-makers that can be seen in Eq. (3).

Table 2. Conforming fuzzified Likert range relationship for judging the worth of criteria (Jeong and Ramírez-Gómez, 2018).

Linguistic relation	Linguistic worth	Triangular fuzzy worth
No influence/impact to criterion	0.00	(0.00, 0.00, 0.25)
Very low influence/impact to criterion	0.25	(0.00, 0.25, 0.50)
Low influence/impact to criterion	0.50	(0.25, 0.50, 0.75)
High influence/impact to criterion	0.75	(0.50, 0.75, 1.00)
Very influence/high impact to criterion	1.00	(0.75, 1.00, 1.00)

$$p_{ij} = (p_{ij}^{(l)}, p_{ij}^{(m)}, p_{ij}^{(u)}) = \begin{cases} p_{ij}^{(l)} = \min(p_{ij}^e) \\ p_{ij}^{(m)} = \sqrt[k]{\prod_{i=1}^k p_{ij}^e} \\ p_{ij}^{(u)} = \max(p_{ij}^e) \end{cases} \quad (3)$$

2. It indicates the criteria worth coefficients. Also, it interconnects with entire matrices in correlation, viz. Cause and Effect Relationship Diagram (CERD). Here, the calculation of primary direct-relation medium ( $D$ ) normalized and indirect-relation medium ( $R$ ) could be used to find out the criteria weight coefficients ( $w$ ), which performed by applying Eqs. (4) and (5).

$$w_i = \sqrt{(D_i + R_i)^2 + (D_i - R_i)^2} \quad (4)$$

3. It normalizes the coefficients in criteria worth, which can be figured out normalized and controlled beginning effect matrices that are performed by utilizing Eq. (5).

$$w_i = \frac{w_i}{\sum_{i=1}^n w_i} \quad (5)$$

4. In Eq. (6), it defuzzifies the coefficients in criteria worth. The defuzzified descriptions of the complete relative medium are utilized in accordance with the validations aforementioned.

$$A = (a^{(l)} + 4a^{(m)} + a^{(u)}) \cdot 6^{-1} \quad (6)$$

### 3.2.2. WLC process

For the third significant phase of F-DEMATEL/MCDA, WLC process can be carried out for collecting the standardized and consistent criteria worth in the e-learning systems for sustainability science education proposed. As a relatively easy operational and rational application, the process of WLC could be affected when it handles with the MCDA and could be employed in various circumstances as well. With the criteria worth obtained by the F-DEMATEL with participation of decision-makers (in this case the authors with experts' consultation), the combination of sub-criteria is executed to criteria. Subsequently, the criteria combination is accomplished to final important aspect for identifying e-learning systems in sustainability science education by pertaining the WLC process.

5. In the problems on MCDA, it calculates the suitability worth in accordance with the scoring degree utilized for the appropriateness directory as a mutual classification measure 0 to 1 (the least important 0 and the most important 1) for every criterion in Eq. (7) (Jeong et al., 2014).

**Table 3.** Criteria worth combination through the sensitivity analysis.

Implementations	Criteria weights			
	Sustainability	Science education	E-learning	Technology
Prioritize to Decision-makers (A)	0.54	0.12	0.07	0.25
Prioritize to Sustainability (B)	0.50	0.167	0.167	0.167
Prioritize to Science education (C)	0.167	0.50	0.167	0.167
Prioritize to E-learning (D)	0.167	0.167	0.50	0.167
Prioritize to Technology (E)	0.167	0.167	0.167	0.50
Equal Weights to Groups (F)	0.25	0.25	0.25	0.25

$$SI_i = \sum_{j=1}^n w_i x_{ij} \tag{7}$$

where  $SI$  shows the degree worth on suitability, features' digit indicates  $n$ ,  $w_i$  describes the worth feature  $i$ 's regularized and homogenous sign and  $x_{ij}$  signifies the weight worth  $i$ 's worth on criterion.

**3.2.3. Sensitivity analysis process**

A sensitivity analysis is applied to check the results' constancy acquired against the decision-makers' subjectivity (Meszaros and Rapcsak, 1996). Particularly, as designated in Table 3, it was shepherded by inserting dissimilar group weights that hereto elucidate the results' stability and make six implementations. Meanwhile, it can display correlations' different classes by appropriately choosing the weighting vector amongst the combined criteria. The WLC in these implementations can be delineated together with the  $i$ -th locality and an regimented weighted setting, that is,  $w = w_1, w_2, \dots, w_n$ :

$$w_j \in [0, 1] \text{ where } 1, 2, \dots, n \text{ and } \sum_{j=1}^n w_j = 1 \tag{8}$$

In the same way of WLC process, it can calculate the suitability worth of each implementation that will be suggested and analyzed for the work as a collective position hierarchy 0 to 1 in Eq. (7).

**3.3. Survey modeling**

As the fourth significant phase of F-DEMATEL/MCDA, the finalized results attained by the earlier sensitivity analysis are considered and calculated for e-learning system in sustainability science education. It is fundamental to increase the sample as the broader purpose that yields schemes, strategies and implementations for those decision-makers. With the email questionnaires in a web link, the survey data were collected. The survey questions specifically solved glitches and complications of positive representatives and amplified efficacy by directing them barely to representatives who were willing to judge the implemented strategies suggested (Gillham, 2000). Particularly, with up-to-date standards, the

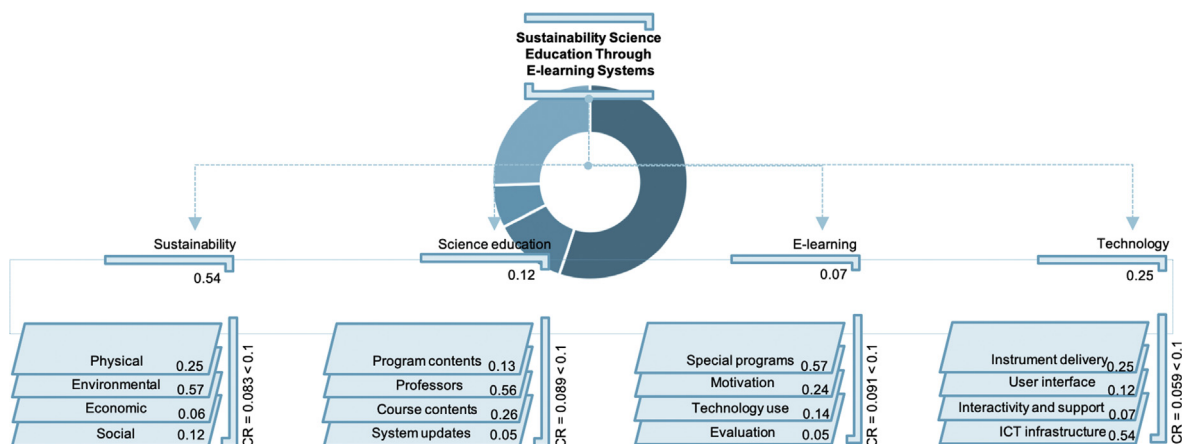
survey was prepared that took out distinct and individual preferences and tendencies through the sizeable series of appraisal representatives (Kim et al., 2008; Reips, 2002).

Thirty-nine answers in total were gathered and completed by the questionnaire-based email survey between November 2018 and April 2019. All the interviewees worked as professors, educators, researchers and authorities that the vast interviewees' majority (over 90%) deals with educational and practical problems every day. The specific demographic information describes that males were 67% and females were 33%. The participants' average age was 42 years old found. The questionnaires have three segments. Firstly, it queries questions for the interviewees' general background information, e.g. work fields and positions of interviewees. Secondly, the interviewees were requested to answer the likelihood of the proposed six implementation strategies' sensitivity analysis and their sub-criteria that could be performed if a guaranteed implementation was used (How degree do you like the implementation proposed?). Thirdly and finally, it provides a part for stating their email if the interviewees are necessary to be notified of the study results in conclusion. Specially, in the second part, the final results of most important components in sustainable science e-learning education systems are specified along with a five-point Likert-type measure. Here, it is required that interviewees should select one of the answers, if not, it could not continue to next part and could not finish the survey. After evaluating the implementations' likelihood, interviewees had the opportunity to explain their answers and reactions into a blank text space. For this part, thirty-one interviewees, 79%, clarified their reactions for at least one feature.

**4. Results and discussions**

**4.1. Results**

Through the F-DEMATEL/MCDA method, the final results in this work acquired was showed together with the WLC and sensitivity test. They were originated by the sixteen possible effects and four groups as



**Figure 3.** E-learning systems in sustainability science education showing their hierarchical assembly.

the indicator-based model to corroborate the most significant criteria of sustainable science e-learning education systems for a program in more long-standing education. Then, the utmost significant criteria are obtained once applying the WLC and are assessed the six implementation strategies' likelihood via sensitivity analysis (A to F). Then, the sub-criteria by a professional online survey is gauged. Subsequently, the main outlines have been exposed by the results that are for addressing sustainable science e-learning education systems.

Figure 3 indicates the layers of each criterion and sub-criterion together with normalized worth, which acknowledged as the 0 to 1 suitability indicator. Also, in Table 1, as it is labeled each information in detail, the framework epitomizes dissimilar sixteen sub-criteria exploration, which have an extensive validity in the context of the complete appraisal. Definitely, the authors in this work as decision-makers after the consultation with an expert panel comprising of professors, researchers, educators and authorities have the total involvements in the weighting and ranking process for this submission. Afterwards, the preferred criteria are categorized into four crucial criteria and sub-criteria, specifically, sustainability, science education, e-learning and technology criteria. Sixteen criteria have a relationship with the growth practice, completely, (1) Physical; (2) Environmental; (3) Economic; (4) Social; (5) Program contents; (6) Professors; (7) Course contents; (8) System updates; (9) Special programs; (10) Motivation; (11) Technology use; (12) Evaluation; (13) Instrument diversity; (14) User interface; (15) Interactivity and support; (16) ICT infrastructure. First sustainability group covers criteria 1 to 4, the second science education group embraces criteria 5 to 8, the third e-learning group entangles criteria 9 to 12, and the fourth technology group encloses criteria 13 to 16. These hierarchical four different stages of organization had been utilized for the sustainability science education decision appraisal through e-learning systems. The weighting values of the intermediate important components are: 0.54 for sustainability; 0.12 for science education; 0.07 for e-learning; and 0.25 for technology criteria. Analysis on F-DEMATEL/MCDA determines the most significant criteria of sustainable science e-learning education systems that are sustainability components. Among them, environmental sub-criterion is the most influenced and affecting parameter.

Then, the sensitivity analysis produced six different implementations along with transformed worth that were utilized into the four groups. The important components to sustainable e-learning science education system are identified as the communal position measure 0–1, viz., the higher the value indicates the more significant index. Definitely, the six dissimilar implementations A to F indicate: A is the most significant criteria with regard to weightings and rankings with authors and expert consultation (0.54, 0.12, 0.07 and 0.25 for four criteria sustainability, science education, e-learning and technology, correspondingly); B is influence and precedence to sustainability criteria (0.50, 0.167, 0.167 and 0.167 for four criteria sustainability, science education, e-learning and technology, correspondingly); C is influence and precedence to science education criteria (0.167, 0.50, 0.167 and 0.167 for four criteria sustainability, science education, e-learning and technology, correspondingly); D is influence and precedence to e-learning criteria (0.167, 0.167,

0.50 and 0.167 for four criteria sustainability, science education, e-learning and technology, correspondingly); E is influence and precedence to technology criteria (0.167, 0.167, 0.167 and 0.50 for four criteria sustainability, science education, e-learning and technology, correspondingly); and F is equal worth for all groups (all 0.25) according to Table 3.

Analysis on F-DEMATEL/MCDA delivers equivalent results aimed at every impact nevertheless of the indicators' value utilized for the assessment. In sustainable science e-learning systems, the most important criteria are obtained through the implementation strategy A (sustainability with 0.54 in the index appropriateness measure 0 to 1). Furthermore, the sensitivity analysis effects confirmed the archetype and pattern shaped via the WLC that had extreme dependability and appropriateness. The divided abstract developments were appraised through the aforementioned decision-makers and, accordingly, these efforts put together what professionals' larger test reflects the likelihoods for the six implemented strategies as exhibited in Table 4 and Figures 4 and 5. With the five-point Likert scale, the thirty-nine decision-makers confirmed these results strengthened by. The scenario A attained a 31% score of very likely (84% most likely and likely positive perception, respectively 31% and 53%), while the scenario F obtained a 6% score of very likely (19% most likely and likely positively perception, respectively 6% and 13%). On the basis of criteria weightings and rankings, and survey analysis, remarkably, the scenario A that we found out was the favored one and the least favored one was the scenario F. In the scenario A, particularly, environmental (0.57) is the most affected variable with 77% positive perception (see Figure 5). Furthermore, the scenarios C and E had a variance, however these scenarios not had a meaningful alteration. Consequently, the implemented strategies are reflected possibility for the applicable implemented strategies of sustainable science e-learning education systems.

#### 4.2. Discussion

The validated results indicate the states of art based on the choice of the significant and diverse criteria and sub-criteria in sustainable science e-learning education systems. Here, an exclusive decision-support scheme specifies for sustainable science e-learning education systems that diverse scenarios from decision-makers' input. Then, it can fill decision-makers' aim further that can a MCDA niche in sustainable science e-learning education systems.

With the ICTs in sustainability science education, its teaching/learning process can be multi-faced among teacher to teacher, teacher/student and student/student (Garrison, 2000; Pereira et al., 2008). Lorenzo Romero et al. (2014) indicated that a system based on e-learning also can be a self-regulated learning process and inter- and multi-disciplinary advance establishing essential components for sustainability science education. Thus, Paechter et al. (2010) specified that the characteristics of systems based on e-learning have knowledge exchange and learning strategies' flexibility as multi-directional communications. Particularly, e-learning systems in science education together with the ICTs and novel information could be associated with sustainable

Table 4. Implementation strategies' likelihood by the professional survey.

Answer grouping		Implementations					
		A	B	C	D	E	F
5	Very likely	31%	21%	13%	8%	17%	6%
4	Likely	53%	37%	32%	19%	33%	13%
3	Not likely, not unlikely	9%	19%	15%	9%	18%	11%
2	Unlikely	3%	14%	23%	40%	17%	43%
1	Very unlikely	2%	4%	13%	18%	11%	20%
0	Do not know/blank	2%	5%	4%	6%	4%	7%
Overall valuation		4.02	3.42	2.97	2.41	3.16	2.21

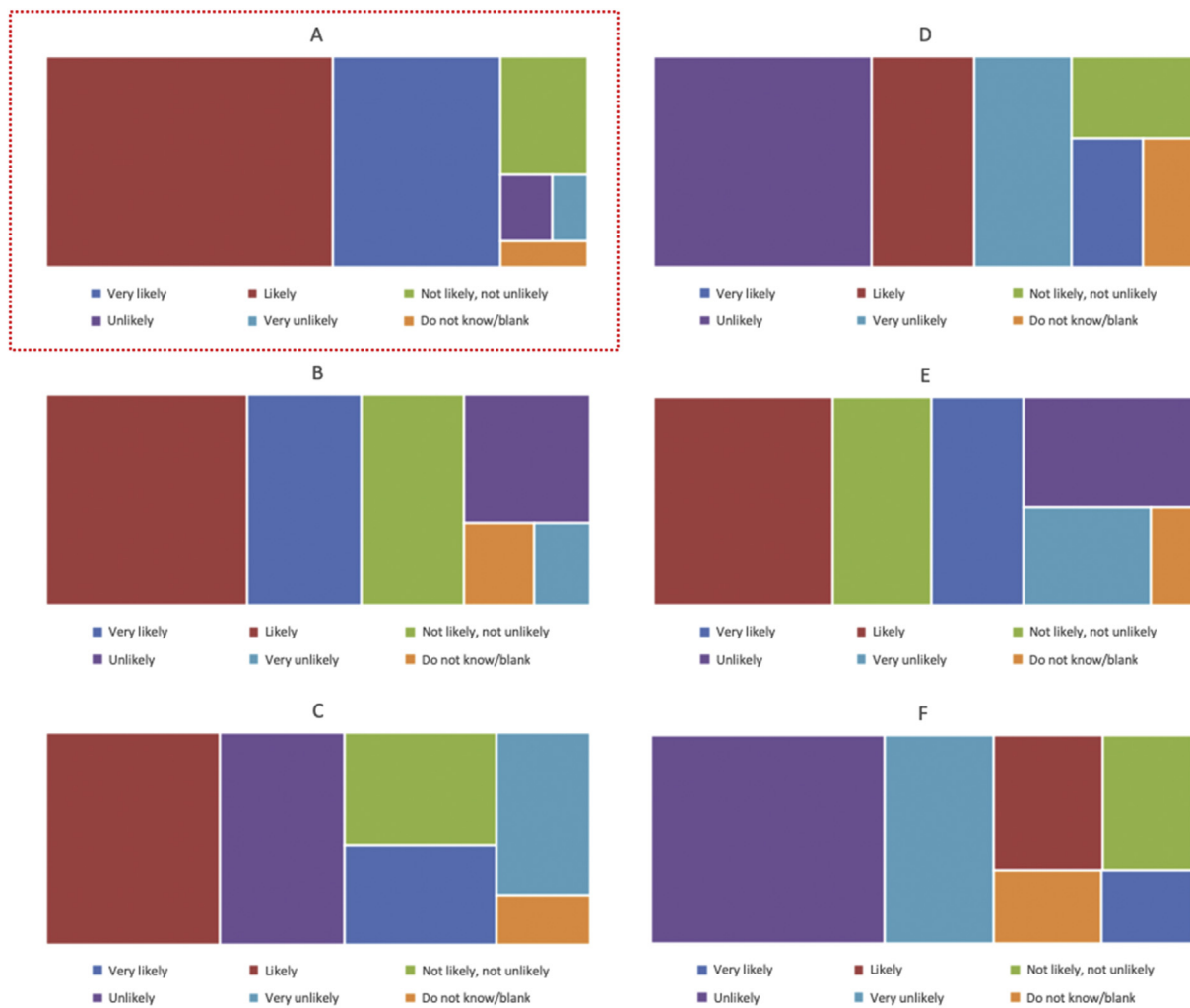


Figure 4. Six implementations Likert range survey analysis via the method of WLC and sensitivity analysis.

development's various criteria (Azeiteiro et al., 2014; Garrison, 2000). The challenge of incorporating the skills and technologies into sustainability science education has been made to pay attention in e-learning programs that fill existing educational gap (Paechter et al., 2010). For using sustainability education, this area measures teaching technologies' application integrated to transformational teaching/learning and sustainability confronts, that is, an ICT-based teaching/learning in sustainability education (Pavlova, 2013). To satisfy the necessity raised, this research found out the relationships between e-learning system's multi-criteria and sustainability science education. A detail examination can be given for sustainable science e-learning education systems in higher and advanced education.

Here, while raising attention to sustainability science education, it is important to integrate various goals, principles, practices and values (González-Gómez et al., 2016; Pavlova, 2013; UNESCO, 2017). It is necessary in higher education to shape its structure of sustainability science education, which aims to persons together with capability and knowledge, which will redirect on their behavior outcomes (Barth et al., 2007; González-Gómez et al., 2019; Wiek et al., 2011). Læssøe et al. (2009) pointed out that the accomplishment of different skills, information, knowledge and worth can be reoriented to the academic curricula and better concept understanding to sustainability science education. Thus, Sterling (2001) indicated that its requirements for sustainability science education were related with human's potential realization and economic, social and ecological interdependence as educational culture change. In the educational and cultural setting, the

procedures and resolutions of teachings focus on empowering learners along with dexterities, standards, evidence and a thinking-method, which execute as sustainability transformation delegates (Fadееva and Mochizuki, 2010; Jeong et al., 2019; Thomas, 2009). Sustainability science education is connected with knowledge performing and comprising the sustainability education principles though a confident examination part can connect with its specific methodologies, capabilities, competences and scientific and practical abilities (Bacelar-Nicolau et al., 2009; González-Gómez and Jeong, 2018; Leal Filho et al., 2018). That is in accordance with the results showed in this research to large cohorts of criteria and sub-criteria of decision-makers as to check their importance indices for the sustainability science education that will fill the pedagogical niche currently has.

Thus, the operational application deals with numerous situations that require decision-makings for various criteria and sub-criteria (Malczewski, 1999). In this research, it can have a strong benefit and direct guidance for selected criteria assessment in sustainable science e-learning education systems as a most significant step. It was emphasized that the extensive assortment and assessment of e-learning systems are for MDCA on multiple criteria to initiate e-learning systems' ranking (Jain et al., 2015). Thus, it was outlined the standard and criteria set through e-learning/management tools envisioned to help e-learning tools' users and management systems to shape improved decisions (Islas-Pérez et al., 2015). Particularly, the combination of the F-DEMATEL and MCDA method can be the complete and multifaced tool as perceiving the cause and effect connection among criteria estimated



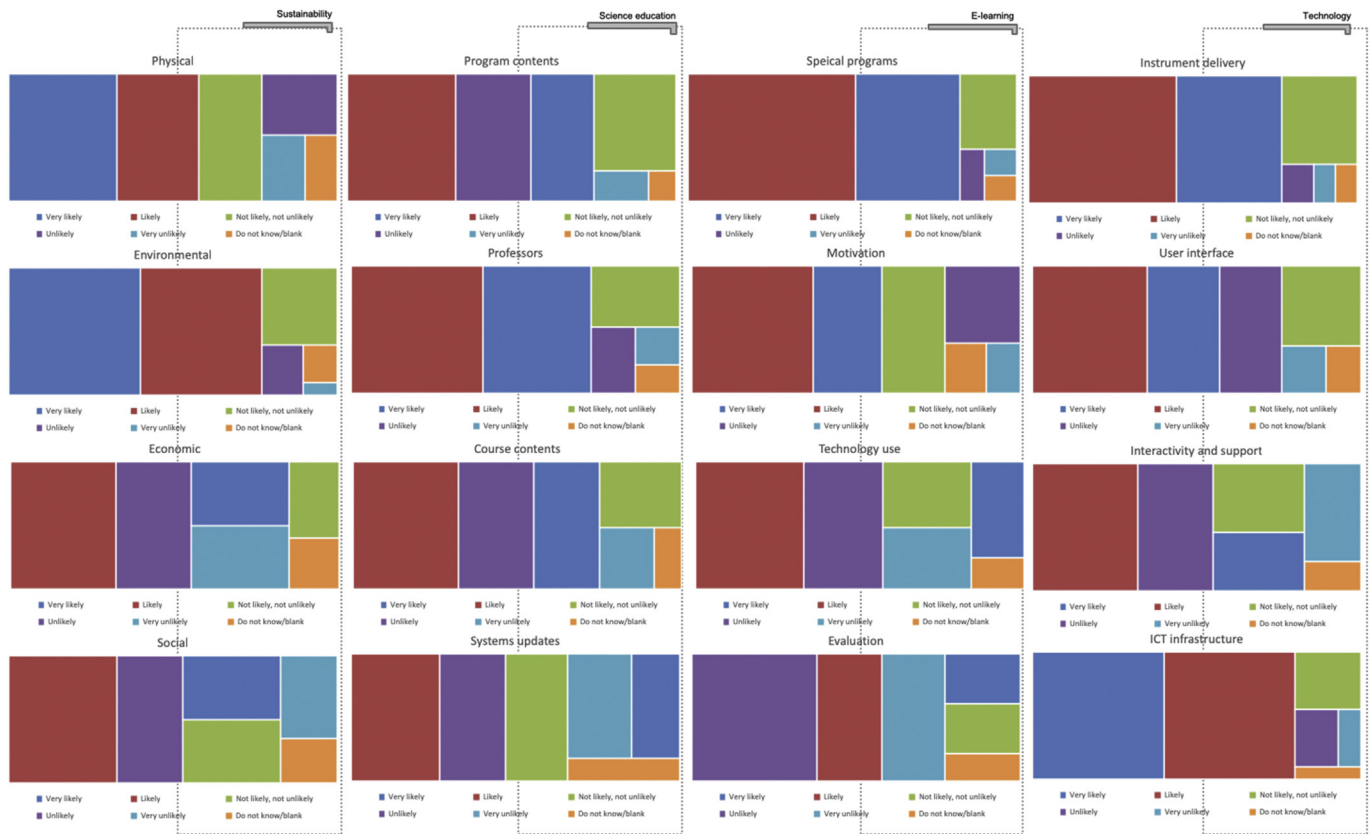


Figure 5. Survey examination through Likert scale for sixteen sub-criteria categorized into four criteria.

(Gabus and Fontela, 1972; Lin and Tzeng, 2009). Besides, the F-DEMATEL method has a probability to engage entities challenging problems, which are necessary for discrete/group decision-makings in the conditions of fuzzy-logic (Wu and Lee, 2007). So, it can consider substantial criteria and sub-criteria in e-learning systems for sustainability science education as to examine and explain the relationship of interdependence amongst the criteria and influential effect worth (Govindan et al., 2015; Lin, 2013). With all interdisciplinary approach, it can give a highlight for the study proposed to prove its states of art comparing with current literature and can fill the gap that currently has. Therefore, we identified and analyzed the criteria and sub-criteria of sustainable science e-learning education systems.

Based on the implications of sustainability science education in online-learning system, the results obtained showed the operational methodology validity that can be utilized to authenticate most significant criteria of sustainable science e-learning teaching systems. Particularly, the results produced by the WLC, sensitivity and survey analysis indicated respondents' patterns and probabilities, which could help probable sixteen influences and four criteria (Jeong et al., 2013; Malczewski, 1999). Here, we can find out the results showed the sustainable science e-learning education systems with regard to criteria/sub-criteria indicator-based model ranking. It demonstrated the influenced six implementations' possibility recompensing in place of their adaptable details (Lin, 2013). The acquired results started from the methods could be utilized by studies to verify most important sustainable science e-learning education system criteria in a corresponding education occurrence (Garg and Jain, 2017; Jain et al., 2016; Su et al., 2016). The results recapitulate possible obstacles and problems originated from conventional education effects, through preferences and accomplishments for e-learning system in sustainability science education that have not yet been sufficiently utilized. Also, it could be commissioned to resolve their decision problems owing to the proposed methodology's flexible and pertinent feature. The important conclusion carried out the most significant criterion in

sustainable science e-learning education systems through the method proposed and applied that could postulate their preliminary classification as well. Thus, using operational process amongst them, the results exhibited a criterion method that can have the uppermost reliability.

### 5. Conclusions

The F-DEMATEL/MCDA combinational method in this research has been used for an obligatory and general science subject as a bachelor's degree in the University of Extremadura, Spain. It could therefore be comprehended as a dominant presentation for identifying and analyzing the most significant criteria of sustainable science e-learning education systems in a more long-term and life-long learning program. The participatory F-DEMATEL scheme in this work is utilized to stipulate the worth coefficients of the criteria and the significance of each criteria/sub-criteria according to professional decision-makers. Afterwards, the WLC and sensitivity analysis are utilized to recapitulate the criteria worth and the categorization of certain important components of sustainability science e-learning systems with validation by professionals' survey. Precisely, 0 to 1 grading scale is represented for the results, viz., from the least important to the most important components.

The F-DEMATEL/MCDA method was utilized to determine the important criteria, ranking and likelihood together with the WLC and the sensitivity analysis in dissimilar implementation strategies evaluated by thirty-nine professionals' survey with a five-point Likert scale. Analysis on F-DEMATEL/MCDA offers comparable outcomes for single influence notwithstanding the markers' integer utilized on the assessment. The most significant criteria in sustainable science e-learning education systems was the implementation strategy A along with sustainability of 0.54 in the 0 to 1 appropriateness index. Furthermore, through the WLC and sensitivity analysis, the consequences revealed that the example generated great consistency and suitability. The professionals evaluated the individual conceptual developments; thus, this work clears up what

professionals' grander sample of contemplates are the possibilities of the six implemented stratagems as disclosed in Table 4 and Figures 4 and 5. The scenario A acquired a 31% very likely score (84% most likely and likely positive perception, respectively 31% and 53%), while the scenario F obtained a 6% very likely score (19% most likely and likely positively perception, respectively 6% and 13%). On the basis of criteria' weightings and rankings, and survey analysis, remarkably, it could be discovered that the scenario A was the most preferred and the scenario F was the slightest preferred. In the scenario A, particularly, environmental (0.57) was the most satisfactory variable with 77% positive perception (see Figure 5). Furthermore, the scenarios C and E had a difference, but they not had a meaningful difference. Consequently, for the effective sustainable science e-learning education system, the strategies were contemplated as practical in sustainability science education.

The attained results describe the innovative evidence on the significant criteria selection of distinctive conceivable impact and influence concentrated in e-learning system for sustainability science education. This work specifies a distinctive method for decision-support through the sustainable science e-learning education system and likelihood approaches with contribution through professional decision-makers and fulfills a gap of MCDA practices and multi-criteria analyses. The main conclusion of this work indicated in sustainable science e-learning education system that this method could show the most promising criterion for science e-learning systems for long-term learning programs, as well as stipulate their initial ranking. The results are revealed on a piece produced operating the WLC method and show the maximum consistency amongst them. Consequently, this process has a much further continuous and complete MCDA aspect. It could fulfil a niche and gap for MCDA methods for sustainable science e-learning education systems along with the intention and influence of professional decision-makers. Consequently, the most vital sustainable science e-learning education system can be acquired through the method implemented and applied in the context of comparable education circumstances. Also, it could be utilized for resolving MCDA problem owing to the proposed method's pliable and pertinent feature.

## Declarations

### Author contribution statement

D. Gonzalez-Gomez, J. S. Jeong: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

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### Competing interest statement

The authors declare no conflict of interest.

### Additional information

No additional information is available for this paper.

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