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Analyzing the factors influencing green software development using a hybrid fuzzy approach

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Abstract

Today, Environmental protection and sustainable development are two critical issues. Sustainability is now playing a significant role in almost every aspect of life. Information and communication technology is an integral element in the global economy and international development, with extensive applications in almost all industries. Similarly, software development is an essential component of a rapidly evolving technology community. It is also an important starting point for reducing resource consumption and carbon emissions. Nevertheless, compared to hardware, the software has received inconsiderable attention. The aim of this study is to identify, rank, and determine the importance of factors influencing green software development using a hybrid approach. Five criteria and four subcritical were identified from qualitative content analysis of relevant studies and interviews with twelve academic and industry experts. FDEMATEL was employed to determine the interaction and interrelationships among the identified criteria and sub-criteria while utilizing FANP to calculate the weights of the criteria and their relevant sub-criteria to determine their priorities. The following ranked first to fifth as the most influential factors: operational factor "0.2153", infrastructure factor "0.2046", technological factor "0.2006", individual factor "0.1945", and the organizational factor "0.1849". Among the criteria, knowledge, and awareness had the greatest weight of "0.2908", and ethical factors had the lowest weight of "0.2308". Given the insignificant difference between the highest and lowest factors, it can be concluded that all factors are almost equally effective. And it can be concluded developing green software requires the creation of a trusted ecosystem.

Keywords: Green Software, Green Software Development, Green Information Technology, qualitative, DANP
2020 MSC: 90C70, 90C33, 90C29, 90C32

1 Introduction

One of the most critical subjects in today's societies is the risk of climate change and environmental degradation [62]. Information Technologies have a dual role in the goals of sustainable development, both as an enabler and as a factor in excessive energy consumption [105]. The early research has focused on hardware its software aspect also should be considered [105, 19, 20, 82].

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Authors in[51] believe that sustainability affects all aspects of social life; it needs to be a major matter in software development. They argued that engineers focus more on the technical perspective of a software system. Sustainability is important for all software systems because each new system creates dependency as it becomes part of the technical infrastructure, and its continued use may place new responsibility on ecological social systems. The resources and power consumption controlled by hardware affected the software to begin the process that causes high emission of an energy resource [35]. Green and sustainable software has emerged as a new and very active field in the software business [19]. Given the vital role of software centralized systems in society, software engineers have a responsibility to consider sustainability as a goal and build the structure of the software system. Green studies in the field of information technology often focus on a specific topic. And consider limited aspects of the entire software development process, and little research has provided a global approach [86]. However, there is no practical guide that provides a tangible analysis of sustainability [93]. The main purpose of this study is to identify the factors influencing the development of green software and prioritize them.

2 Theoretical foundations

According [32] there are three perspectives on green development. The first one is related to the Chinese philosophy of "unity of nature and humanity" that has developed over thousands of years, the second one is related to the "Marxist dialectics of nature", which were developed more than 100 years ago and the third one is the current theory of sustainable development. Green development is an integration of these theories.

The software is difficult to describe because it is "abstract". Software is a collection of code that leads to a computer program. Software upgrades are in many cases easier and often cheaper than computer hardware. Software is often divided into three categories: system software, programming software, and application software [80]. The role of computer software has changed dramatically over the past 50 years. Software affects almost every aspect of life and has become an inevitable part of business, culture, and daily activities. This vision serves as the basis for modern scientific research and software engineering problem solving and guides business decision-making. Software systems are produced in different types: entertainment, office products, transportation, medicine, communications, industrial processes, and so on. Software systems can be considered as converters of information production, management, access, change, display, or data transfer. Software engineering enables connectivity to information networks around the world and enables access to information in all its forms [16]. software development is always an exercise in discovery and learning, and second, if we aim to be "efficient" and "economic," then our ability to learn must be sustainable. This means that we must manage the complexity of the systems that we create in ways that maintain our ability to learn new things and adapt to them [22]. In [69] authors divided the environmental impacts of software into three categories: Impacts that directly affect energy or resource consumption are called first-level or IT procurement effects, such as hardware, performance requirements, software product packaging, network bandwidth, and so on. The effects of using the services provided by the software are called second-level effects or the effects of consuming information technology. Effects from different conflicting systems that work together to produce reactive effects are called tertiary effects or systematic effects. Sustainable and green software has become critical in the software engineering society. A group of researchers has realized the direct and indirect effects of software programs on the energy consumption of the system and the environment. Their attempt includes developing software engineering techniques and promoting green software advances among software developers; The main goal of stability and greening at any stage of the software development process and to discuss it as a feature of quality of software or non-functional feature of software programs [20].

3 Research Methodology

In the first step, the library method has been used to gather information about the subject literature and the research background. In a second step, the semi-structured interview method has been applied to collect empirical information to deeply evaluate the perceptions, attitudes, interests, and desires of the subjects [41]. The interview questions were extracted from the theoretical framework developed in the first stage. Finally, the factors identified in the steps were examined using a pairwise questionnaire. The fuzzy approach is used to deal with the uncertainty and ambiguity in the verbal expressions of the respondents.

In general, in content analysis, the elements considered are collected, classified, and analyzed. Content analysis is a flexible method that has been widely used in the fields of knowledge and information science, and management [111]. It is a suitable method for analyzing texts through which the researcher can systematically examine the basic trends and properties of a text [104]. Using the content analysis method, the basic characteristics and properties of a text or article can be categorized or its properties can be matched with pre-defined categories and classes [15].

In recent decades, researchers' interest in using qualitative research methods for complex management problems has increased, and among these methods, content analysis as an intersection of quantitative and qualitative methods is of particular importance in solving management problems [25]. According to [19], the advantages of the content analysis method are: In managerial studies, content analysis is a repeatable method for dealing with individual and group concepts and constructs such as values, goals, attitudes, and perceptions [17]; therefore, it can be used for a wide range of organizational issues and phenomena.

Open coding is an analytical process through which concepts are identified and their characteristics and dimensions are discovered in data. It forms the primary categories of information about the phenomenon under study by categorizing the information. The researcher bases the categories on all collected data, such as interviews, observations, and events or self-contained notes [18]. The procedure of connecting categories to subcategories and integrating them at the level of attributes and dimensions is referred to as axial coding. "Axial" coding is a term used to describe coding that occurs around a category's "axis" During this step, the open coding aspects, attributes, and dimensions are established and implemented to gain more knowledge about the connection "Causal conditions," "contextual and intervening conditions," as well as "consequences." The fuzzy DANP method is one of the multi-criteria decision-making methods. Fuzzy DANP combines the fuzzy DEMATEL technique with the Analytical Network Process (ANP) and provides a survey of the case study to obtain relationship-related indicators. Fuzzy DANP can be used to obtain a fuzzy weighted supermatrix, which represents the degree of penetration between relationships. In addition, we consider the effects of other dimensions to obtain a fuzzy weighted supermatrix, which reflects the magnitude of the effect exerted by other dimensions. Many researchers and scientists used this technique in various fields and developed it by other MCDM methods. [109] Assessing the New Product Development Process for the Industrial Decarbonization of Sustainable Economies. [113] Evaluation of Government Data Sustainability choosing knowledge management strategy. [85] Proposing a digital identity management framework to determine the interactions between the factors. [61] Interrelations among Leadership Competencies of BIM Leaders. [21] Prioritizing the components of e-learning systems. [73] analyzing mobile app issues. [52, 11, 28] Using DANP in green supply chain management practices. [101] Identifying and prioritizing factors influencing the selection of the top suppliers of e-procurement.

4 Finding and results

The interviews operate in a semi-structured manner. In this section, twelve persons with different roles of software developer, product manager, project manager, IT consultant, software architect, researcher, business analyst, and software test manager were selected. The questions were also asked as follows

- Define green software development?
- What factors affect the development of green software?
- There was also an open-ended question in this section to express their opinion.

First, participants were asked about their views on green software, and then the definition of this research was presented to them from the process of green software development, and they were asked to use this definition to express their analysis and opinion. The interviews were conducted online and took between 30 and 40 minutes for each participant.

Interviewees knew the concept of green information technology from a hardware perspective. After defining the green software, people stated that some of these things are considered in carrying out projects.

A group of interviewees equated green software with sustainable software, and their definition of sustainability includes extensibility and effective response to change (especially changes related to technology and platforms), flexibility, compatibility, and integration with platforms and other software systems. (Definition of clear interfaces and non-dependence on the third-party system). This group considers sustainability as an important or very important feature in their current software development projects.

Another factor mentioned by the interviewees was the quality aspects and consideration of non-functional needs in software development. The factors presented by the interviewees are given in the table. of the main steps in any qualitative research is the use of coding tools. In qualitative methods, coding is done in two stages open coding, axial coding Tables 1 to 5 show the results of content analysis based on the identified dimensions extracted from the literature, theoretical studies, and interviews.

Table 1: Organizational factor

Open code	index	Concept	source
Governance	A1	-Supporting green innovations -Allocate resources and budgets -Defining rules and responsibilities	[99, 74, 75] [29, 39, 55] [27]
Strategy	A2	-Development of action plans consistent with sustainability goals by aligning green strategies with organizational strategies -Reduce energy consumption through user interactions with the user interface Reducing the direct and indirect negative effects of software development on the economy, society, humans, and the environment -Waste Management -Reduce Carbon emission	[107, 4, 7] [55, 60, 40] [27]
Assess Monitoring	A3	-Environmental effects of carbon emissions -Environmental risk reduction assessment -Assess Software Energy cost -Documentation and electronic publication -Monitoring resource consumption (processor, input and output devices, memory, data storage, servers) -Control of energy efficiency and power consumption of software systems -Measuring the performance of applications -Determining and measuring the key environmental index -Determining and measuring software quality indicators	[40, 24, 44] [12, 84, 78] [55],[14],[89] [55],[14],[90] [27]
Policy	A4	-Using automation to perform repetitive implementation tasks -Electronic waste management policy -paper removal -Documentation and electronic publication -Development of printing optimization -Environmental software purchase policy -Manage to shut down the computer (turning off on-off systems on which no processing is done automatically) and turning them on when needed -Defining the energy consumption threshold of memory and processor -Specify the scope of the project	[99],[89],[48] [7],[40],[43] [84],[78],[47] [55],[14],[90] [69],[89],[87]

Table 2: Individual factor

Open code	index	Concept	source
Attitude	B1	-Strengthen beliefs related to environmental and sustainable activities -Strengthen the attitude of optimal use of resources and energy consumption -mindset focusing on existing techniques and providing a useful measurement unit for estimating software energy consumption	[70, 33],[72] [40],[71]
Social-cultural	B2	-Compliance of business analysis with green regulations and domestic policies -Consideration of green criteria, evaluation tools, and methods by the business analyst	[62],[88]
Ethical	B3	Observing the principles of professional ethics of software programmers	[65, 67]
Knowledge & awareness	B4	Training programmers with green technologies for software development	[51],[44],[33, 36],[106],[30],[42]

Table 3: Infrastructure factor

Open code	index	Concept	source
hardware	C1	-Designing rooms to make maximum use of natural light for lighting -Installation of low-consumption lights -Use of low-consumption hard disk drives -Reuse of hardware in the project -Use of multi-core processors in an energy-efficient way -Energy management (electricity) of personal computer -Manage shutdown of the computer -Use of efficient transformers and uninterruptible power supply Virtualization for more hardware and cost-efficiency	[50, 56]
storage	C2	-Manage and control the life cycle of stored data to prevent data redundancy -Virtualization and integration of server/storage -Allocation of resources -Delete unused communication servers and databases	[66]
Network	C3	-Backup and recovery of servers, reducing the cost of network equipment -Virtualization to reduce maintenance and management costs of servers and services	[50],[66, 37]
Datacenter	C4	-Use of natural ventilation or replacement of environmentally friendly fans -Installation of airflow monitoring system and liquid cooling for software equipment -Establishment of the company's data center near clean/natural energy sources -Use of "green" data center infrastructure -Using dynamically changeable fans -Delete unused communication servers and databases -Configure the server to shut down dynamically if not in use -Deployment of blade servers and low-power processors -Virtualization for optimal use of physical space in data centers	[103, 53]

Table 4: Infrastructure factor

Open code	index	Concept	source
Knowledge management	D1	-Evaluate and document the software life cycle periodically for optimization -Documenting and managing knowledge of software-related resources for training and sharing within the organization and donating it to academic and research centers -Creating a knowledge base to provide the best practices, suggestions, guides, and recommendations -Sharing information between customers and developers at all stages of development -Environmental knowledge management: knowledge of the use of technology, mechanisms, policies, people, tools, processes, structures, and strategies to absorb, store, transfer and retrieve environmental knowledge to reduce the negative effects of the environment -The environmental knowledge circulation process, a combination of the concept of environmental management and knowledge circulation process, evaluates the performance of organizations in environmental knowledge management -Share knowledge with all stakeholders	[6, 91, 58] [48],[47],[1],[2]
Configuration management	D2	-Reuse of software modules and knowledge when coding -Identify different components and modules for use at the right time	[81],[38],[63] [63],[92]
Standardization	D3	-Standardization of methods, tools, technical solutions, etc -six sigma -CMMI(Capability Maturity Model Integration) -ISO / IEC 14001/ISO / IEC 12207/ISO / IEC 15504	[74],[75],[57]
Communication collaboration	D4	-Use of online collaboration infrastructure -Use video conferencing for everyday tasks -Active communication and cooperation between the development and implementation team -Receive regular feedback from the customer -Holding a meeting with stakeholders to guide the software project to the green project as an example (using online infrastructure) -Minimize travel and telecommuting -Compliance of business analysis with green internal regulations and policies -Remote planning and management -Proper interaction with the customer	[3],[110],[59]

Table 5: Technological factor

Open code	index		Concept	source
Tool	E1		-Using machine learning tools to build a model for predicting energy-efficient data structure based on dynamic workload -Using neural network models to classify energy-efficient data structures based on features such as number of elements, iteration range, user interface -Using the tool to generate and automatically review the code -Use a tool to estimate the amount of energy consumption at the program code level -Tools for measuring energy	[60],[77],[26] [56],[8]
method	E2		-Lean -Agile (XP, scrum, . . .) -DevOps	[4],[89],[37] [84],[46],[34] [31],[114],[79]
Framework	E3		-Extensions and compatibility with various platforms and other systems -Quality aspects and consideration of non-functional needs -Support for updating to newer versions of products -Defining clear relationships, being independent of third-party components, and adapting to technology and changing platforms -Integration with other systems -Assess the characteristics of programming languages for less energy consumption -Identify energy saving opportunities in dynamic data structure -Considering energy efficiency in module design, conceptual design, data structure, and software architecture -Simple design -Reusable design -Use design patterns -Refactoring -Use of algorithm efficiency Algorithm & Programming language	[35],[86],[103] [93],[107],[64] [97],[68] [9],[83] [100],[45] [14],[95]
Emerging trend	E4	Artificial intelligence	-Make better decisions for developers and help improve the overall quality of software -Enable the analysis of emotional analysis and conversion of non-structural data into structural data -Use as a tool for more effective tests of quality assurance professionals	[43],[10]
		Machine learning	-Continuous system learning of workflow information to improve efficiency and effectiveness when running processes -Build a model for predicting energy-efficient data structure based on dynamic workload -Classify energy-efficient data structures based on features such as number of elements, iteration range, and user interface	[60],[12],[96]
		cognitive	-Use cognitive capabilities to extract meaningful patterns to help better predict or even shape changes in the future -Using cognitive computing to achieve strategic priorities through new and unimaginable methods in the past -Process automation uses cognitive systems to make correct decisions based on past and offline analysis -Using the power of cognitive computing systems to develop and enhance human expertise	[102]
		blockchain	-Use of Blockchain technology to create more potential to help green processes -Use blockchain design to increase the power of technology to manage data independently and securely to identify and track the value of ideal environmental transactions	[49],[54]
		IOT	-Respond without human supervision and automatically for a specified period to information received through the sensor via the Internet of Things	[53],[94],[98],[115],[5]
		Cloud computing	-Using the cloud to distribute software -Cloud structure with green computing -Coordination between teams	[108],[112] [76]

4.1 The Fuzzy DEMATEL based on ANP (DANP) data analysis

Step 1: Calculate the direct-influence matrix by scores(D)
In this step, the respondents were asked to show the effect of criterion i on criterion j using Table 2. To take into account the opinion of all experts according to Equation (4.1), an arithmetic mean is taken from them.

$$\tilde{z} = \frac{\tilde{x}^1 \oplus \tilde{x}^2 \oplus \tilde{x}^3 \oplus \ldots \oplus x^p}{p} \tag{4.1}$$

In this formula, p is the number of experts and $\tilde{x}^1$, $\tilde{x}^2$, $\tilde{x}^p$ The pairwise comparison matrix of expert 1 , expert 2 , and expert p, respectively and $\tilde{z}$ is a Triangular fuzzy number in the form $\tilde{z}_{ij} = (l'_{ij}, m'_{ij}, u'_{ij})$.

Table 6: Linguistic scales for the influential degree of criteria

Linguistic scale value	Triangular fuzzy number
No impact	$(0.0, 0.0, 0.25)$
Very low impac	$(0.0, 0.25, 0.5)$
low impact	$(0.25, 0.5, 0.75)$
High impact	$(0.5, 0.75, 1)$
Very high impact	$(0.75, 1, 1)$

Step 2: Normalise the direct-influence matrix
To normalize the matrix obtained from the previous step, use formulas (4.2) and (4.3) and call it the H matrix.

$$\tilde{H}_{ij} = \frac{\tilde{z}_{ij}}{r} = \left(\frac{l'_{ij}}{r}, \frac{m'_{ij}}{r}, \frac{u'_{ij}}{r}\right) = \left(l''_{ij}, m''_{ij}, u''_{ij}\right) \tag{4.2}$$

Where r is obtained from the following relation:

$$r = \max_{1 \leq i \leq n} \left(\sum_{j=1}^{n} u'_{ij'} \sum_{i=1}^{n} u'_{ij} \right) \tag{4.3}$$

Step 3: Attain a total-influential matrix Tc
After calculating the normal matrix, the fuzzy total-influential matrix is obtained according to formulas (4.4) to (4.7).

$$T = \lim_{k \to +\infty} \left(\tilde{H}^1 \oplus \tilde{H}^2 \oplus \ldots \oplus \tilde{H}^k \right) \tag{4.4}$$

Each element is a fuzzy number $\tilde{t}_{ij} = \left(l^t_{ij}, m^t_{ij}, u^t_{ij}\right)$ and is calculated by the following formulas:

$$[l^t_{ij}] = H_l \times (I - H_l)^{-1} \tag{4.5}$$

$$[m^t_{ij}] = H_m \times (I - H_m)^{-1} \tag{4.6}$$

$$[u^t_{ij}] = H_u \times (I - H_u)^{-1} \tag{4.7}$$

In these formulas, the I matrix is identity and H_l, H_m , H_u Each matrix is n × n Its constituents are the lower number, the middle number, and the upper number of the triangular fuzzy numbers of the H matrix, respectively.
Step 4: Calculate the total-influential matrix
First, the T_D matrix must be extracted from the total-influential matrix of the Tc criteria. Therefore, each T_D matrix element can be calculated as follows:
If we know every T_D matrix element is t_{ij} every t''_{ij} is obtained from the mean of every T_C^{ij}.
Step 5: Calculate the intensity and direction of the effect
According to equations (4.8) and (4.9), the r_i and c_j indices are calculated. The r_i index represents the sum of the I th row and the c_j index represents the sum of the j^{th} column of the T_c matrix for the corresponding dimension. Similarly, we calculate the values of the index $\tilde{R}$ and $\tilde{D}$. The R_i index represents the sum of the i^{th} row and the C_j index represents the sum of the j^{th} column of the T_D matrix. To draw and analyze the chart, we need two indicators

of impact intensity and effectiveness and direction of impact, which are obtained using r_i and c_j. For each $i = j$ we will have:

$$\tilde{D} = (\tilde{D}_i)_{n\times 1} = [\sum_{j=1}^{n} \tilde{T}_{ij}]_{n\times 1} \tag{4.8}$$

$$\tilde{R} = (\tilde{R}_i)_{1\times n} = [\sum_{j=1}^{n} \tilde{T}_{ij}]_{1\times n} \tag{4.9}$$

Where $\tilde{D}$ and $\tilde{R}$ are $n \times 1$ and $1 \times n$ matrices respectively.
The next step characterized the importance of the indicators($\tilde{D}_i+\tilde{R}_i$) And the relationship between criteria $\left(\tilde{D}_i - \tilde{R}_i\right)_i$
If $\tilde{D}_i - \tilde{R}_i > 0$, the relevant criterion is effective, and if $\tilde{D}_i - \tilde{R}_i < 0$ the relevant criterion is effective.
$r_i + d_j$ = Intensity of impact and effectiveness (In other words, the higher the value of $r_i + d_j$, the more it interacts with other factors in the system.) $r_i - d_j$ = Direction of impact and effectiveness (Thus, if $r_i - d_j > 0$, the relevant criterion is the cause, and if $r_i - d_j < 0$, the relevant criterion is the effect).
According to the calculated values The values of the ri $+d_j$ and $r_i - d_j$ indexes for the criteria and also the index $\tilde{D}_i + \tilde{R}_i$ and $\tilde{D}_i - \tilde{R}_i$ are obtained for the dimensions are obtained And then defuzziation using Equation (4.10):

$$defuuzy = \frac{((u-l)+(m-l))}{3} + l \tag{4.10}$$

Step 6: Network Relationships Map (NRM)
To determine the network relationship map (NRM), the threshold value must be calculated. In this way, partial relationships can be omitted and a network of significant relationships can be drawn. Only relationships that value in the T_C and T_D matrices are greater than the threshold value will be displayed in the NRM.
To calculate the value of the relationship threshold, Using the opinion of experts or the average values, for each T_C^{ij} (in the T_C matrix) and also the average values of the T_D matrix (to map the dimension relationship) are calculated. After the threshold intensity is determined, all values that are smaller than the threshold are zero, that causal relationship is not considered. For this purpose, the complete relation matrix of dimensions and criteria is de-fuzzy using Equation (4.10).
Step 7: Normalization of the total-influential matrix ($T_D^{\propto}$) According to Equation (4.11), we proceed to normalize the TD matrix, by calculating the sum of each row of the TD matrix according to the relevant dimension, then dividing the element of each row by the sum of the elements of the same row, and at the end of the row and We change the column.

$$\boldsymbol{T}_D = \begin{bmatrix} t_{11}^{D_{11}} & \cdots & t_{1j}^{D_{1j}} & \cdots & t_{1m}^{D_{1m}} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ t_{i1}^{D_{i1}} & \cdots & t_{ij}^{D_{ij}} & \cdots & t_{im}^{D_{im}} \\ \vdots & \vdots & & \vdots & \vdots \\ t_{m1}^{D_{m1}} & \cdots & t_{mj}^{D_{mj}} & \cdots & t_{mm}^{D_{mm}} \end{bmatrix} \begin{matrix} \longrightarrow d_1 = \sum_{j=1}^{m} t_{1j}^{D_{1j}} \\ \\ \longrightarrow d_i = \sum_{j=1}^{m} t_{ij}^{D_{ij}}, d_i = \sum_{j=1}^{m} t_{ij}^{D_{ij}}, i = 1, \dots, m \\ \\ \longrightarrow d_m = \sum_{j=1}^{m} t_{mj}^{D_{mj}} \end{matrix} \tag{4.11}$$

$$\boldsymbol{T}_D^{\alpha} = \begin{bmatrix} t_{11}^{D_{11}}/d_1 & \cdots & t_{1j}^{D_{1j}}/d_1 & \cdots & t_{1m}^{D_{1m}}/d_1 \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ t_{i1}^{D_{i1}}/d_i & \cdots & t_{ij}^{D_{ij}}/d_i & \cdots & t_{im}^{D_{in}}/d_i \\ \vdots & \vdots & & \vdots & \vdots \\ t_{m1}^{D_{m1}}/d_m & \cdots & t_{mj}^{D_{mj}}/d_m & \cdots & t_{mm}^{D_{mm}}/d_m \end{bmatrix} = \begin{bmatrix} t_D^{\alpha 11} & \cdots & t_D^{\alpha 1j} & \cdots & t_D^{\alpha 1n} \\ \vdots & & \vdots & & \vdots \\ t_D^{\alpha i1} & \cdots & t_{D_D}^{\alpha ij} & \cdots & t_D^{\alpha in} \\ \vdots & & \vdots & & \vdots \\ t_D^{\alpha n1} & \cdots & t_D^{\alpha rj} & \cdots & t_D^{\alpha an} \end{bmatrix}$$

Step 8: Normalization of total-influential matrix $T_C^{\propto}$ Criteria and formation of an unbalanced supermatrix We normalize the T_C matrix using relations (4.12) to (4.14); In this step, the sum of each row T_C^{ij} is calculated according to the relevant dimension and then in each T_C^{ij}, each element is divided by the sum of the elements of the corresponding row. By transposing the matrix $T_C^{\propto}$ an unbalanced supermatrix is obtained.

$$T_C^{\alpha} = \begin{array}{cc} & \\ D_1 & \begin{array}{c} c_{11} \\ \vdots \\ c_{1m_1} \end{array} \\ \vdots & \vdots \\ D_i & \begin{array}{c} ci1 \\ \vdots \\ c_{im_i} \end{array} \\ \vdots & \vdots \\ D_n & \begin{array}{c} c_{n1} \\ \vdots \\ c_{nm_n} \end{array} \end{array} \overset{\begin{array}{ccc} D_1 & D_j & D_n \\ c_{11}\dots c_{1m_1} \cdots & c_{j1}\dots c_{jm_j} \cdots & c_{n1}\dots c_{nm_n} \end{array}}{\begin{bmatrix} T_c^{\alpha 11} & \cdots & T_c^{\alpha 1j} & \cdots & T_c^{\alpha 1n} \\ \vdots & & \vdots & & \vdots \\ T_c^{\alpha i1} & \cdots & T_c^{\alpha ij} & \cdots & T_c^{\alpha in} \\ \vdots & & \vdots & & \vdots \\ T_c^{\alpha n1} & \cdots & T_c^{\alpha nj} & \cdots & T_c^{\alpha nn} \end{bmatrix}} \tag{4.12}$$

$$d_{ci}^{11} = \sum_{j=1}^{m_1} t_{cij}^{11}, i = 1, 2, \dots, m_1 \tag{4.13}$$

$$\mathbf{T}_C^{\propto 11} = \begin{bmatrix} t_{c11}^{11}/d_{c1}^{11} & \cdots & t_{c1j}^{11}/d_{c1}^{11} & \cdots & t_{c1m1}^{11}/d_{c1}^{11} \\ t_{ci1}^{11}/d_{ci}^{11} & \cdots & t_{cij}^{11}/d_{ci}^{11} & \cdots & t_{cim1}^{11}/d_{ci}^{11} \\ \vdots & & \vdots & & \vdots \\ t_{cm11}^{11}/d_{cm1}^{11} & \cdots & t_{cm1j}^{11}/d_{cm1}^{11} & \cdots & t_{cm1m1}^{11}/d_{cm1}^{11} \end{bmatrix} = \begin{bmatrix} t_{c11}^{\propto 11} & \cdots & t_{c1j}^{\propto 11} & \cdots & t_{c1m1}^{\propto 11} \\ \vdots & & \vdots & & \vdots \\ t_{ci1}^{\propto 11} & \cdots & t_{cij}^{\propto 11} & \cdots & t_{cim1}^{\propto 11} \\ \vdots & & \vdots & & \vdots \\ t_{cm11}^{\propto 11} & \cdots & t_{cm1j}^{\propto 11} & \cdots & t_{cm1m1}^{\propto 11} \end{bmatrix} \tag{4.14}$$

Step 9: Formation of a balanced supermatrix
In this step, we multiply the matrix $T_D^{\propto}$ by the matrix W. In this way, each $T_D^{\propto ij}$ is multiplied by W_{ij}. **Step 10: Limit the rhythmic supermatrix**
According to Equation (4.15), bring the rhythmic supermatrix to power (consecutive odd numbers) so that all the numbers in each row converge.

$$\lim_{z\to\infty} (W^{\propto l})^Z, \qquad \lim_{z\to\infty} (W^{\propto m})^Z, \qquad \lim_{z\to\infty} (W^{\propto u})^Z \tag{4.15}$$

Table 1 to 5 shows the research factors, which include 20 subcritical and 5 criteria. First, based on the opinion of 12 experts and based on the fuzzy spectrum of Table 6, the degree of influence of the criteria on each other was determined Then, using Equation (4.1), a direct communication matrix was formed. The results are given in Table 7. Table 8 also shows the direct communication matrix T and the values $D + R$ and $D - R$ are given. $D + R$ indicates the degree to which one criterion relates to other criteria. The larger the number, the more relevant that criterion is. The D_R index indicates the cause and effect of a criterion. If positive, it indicates that the factor The cause and if it is negative, show that the factor is effect, that the criteria of Organizational factor and technological factor are the nature of the cause and the rest of the criteria are of the nature of the effect. Also, for the main dimensions of the research, the TD matrix was formed, which is given in Table 5. Then the relationship between the criteria was drawn, which is shown in Figure 1. At the end, the weight of the criteria was determined. The results show that among the main criteria of operational factor weighing "0.2153", Infrastructure factor weighing "0.2046", Technological factor weighing "0.2006", Individual factor weighing "0.1945", and Organizational factor weighing "0.1849" Ranked first to fifth. Among the sub-criteria of organizational factor monitoring weighing "0.2861", policy weighing "0.2482", Strategy weighing "0.2332" and Governance weighing "0.2325". Among the sub-criteria of Individual factor Knowledge and awareness weighing "0.2908", Social-cultural weighing "0.244" Attitude weighing "0.2344" and Ethical weighing "0.2308". Among the sub-criteria of Infrastructure factor Data center weighing "0.2635", Storage weighing "0.2572" Physical weighing "0.2472" and Network weighing "0.2322". Among the sub-criteria of operational factor Knowledge management weighing "0.2604", Configuration management weighing "0.257" Standardization weighing "0.2463" and Communication and collaboration weighing "0.2362". Among the sub-criteria of Technological factor Tool weighing "0.2553", method weighing "0.2536" Standardization Framework "0.252" and Emerging trend weighing "0.239". Among the criteria, knowledge, and awareness have a maximum weight "0.2908"and ethical factors have minimum weight "0.2308".

Table 7: The fuzzy direct-relation average matrix $\tilde{A} = [\tilde{a}_{ij}]_{n \times n}$

	A1	A2	A3	A4	...	E2	E3	E4
A1	(0, 0, 0.25)	(0.636, 0.886, 1)	(0.636, 0.886, 1)	(0.568, 0.818, 0.932)	...	(0.682, 0.932, 1)	(0.636, 0.886, 1)	(0.614, 0.864, 1)
A2	(0.136, 0.341, 0.568)	(0, 0, 0.25)	(0.591, 0.841, 0.977)	(0.568, 0.818, 0.955)	...	(0.568, 0.818, 1)	(0.614, 0.864, 1)	(0.636, 0.886, 1)
A3	(0.455, 0.705, 0.909)	(0.386, 0.636, 0.886)	(0, 0, 0.25)	(0.295, 0.5, 0.705)	...	(0.318, 0.568, 0.818)	(0.432, 0.682, 0.886)	(0.409, 0.659, 0.864)
A4	(0.455, 0.705, 0.909)	(0.455, 0.705, 0.886)	(0.568, 0.818, 0.955)	(0, 0, 0.25)	...	(0.636, 0.886, 0.977)	(0.659, 0.909, 1)	(0.545, 0.795, 0.977)
B1	(0.364, 0.614, 0.841)	(0.455, 0.705, 0.864)	(0.545, 0.795, 0.909)	(0.386, 0.636, 0.864)	...	(0.523, 0.773, 0.955)	(0.409, 0.659, 0.864)	(0.591, 0.841, 0.977)
B2	(0.568, 0.818, 0.909)	(0.341, 0.591, 0.841)	(0.273, 0.523, 0.773)	(0.409, 0.659, 0.909)	...	(0.591, 0.841, 0.955)	(0.568, 0.818, 0.955)	(0.568, 0.818, 0.955)
B3	(0.568, 0.818, 0.977)	(0.227, 0.477, 0.727)	(0.545, 0.795, 0.955)	(0.614, 0.864, 0.955)	...	(0.568, 0.818, 0.977)	(0.409, 0.659, 0.886)	(0.5, 0.75, 0.932)
B4	(0.614, 0.864, 0.955)	(0.591, 0.841, 1)	(0.523, 0.773, 0.977)	(0.591, 0.841, 0.977)	...	(0.636, 0.886, 0.977)	(0.568, 0.818, 0.977)	(0.614, 0.864, 0.977)
C1	(0.182, 0.432, 0.682)	(0.409, 0.659, 0.886)	(0.568, 0.818, 0.977)	(0.568, 0.818, 0.932)	...	(0.636, 0.886, 0.977)	(0.659, 0.909, 0.977)	(0.545, 0.795, 0.909)
C2	(0.273, 0.523, 0.773)	(0.25, 0.5, 0.75)	(0.636, 0.886, 1)	(0.364, 0.614, 0.864)	...	(0.386, 0.636, 0.864)	(0.159, 0.386, 0.636)	(0.136, 0.341, 0.591)
C3	(0.25, 0.455, 0.705)	(0.159, 0.409, 0.659)	(0.591, 0.841, 1)	(0.25, 0.5, 0.75)	...	(0.477, 0.727, 0.886)	(0.25, 0.5, 0.75)	(0.227, 0.477, 0.727)
C4	(0.159, 0.341, 0.591)	(0.25, 0.5, 0.75)	(0.523, 0.773, 0.955)	(0.25, 0.5, 0.75)	...	(0.636, 0.886, 1)	(0.523, 0.773, 0.955)	(0.182, 0.432, 0.682)
D1	(0.364, 0.614, 0.864)	(0.205, 0.455, 0.705)	(0.636, 0.886, 1)	(0.159, 0.409, 0.636)	...	(0.659, 0.909, 1)	(0.705, 0.955, 1)	(0.591, 0.841, 1)
D2	(0.523, 0.773, 0.955)	(0.545, 0.795, 0.977)	(0.591, 0.841, 1)	(0.614, 0.864, 1)	...	(0.568, 0.818, 1)	(0.614, 0.864, 1)	(0.636, 0.886, 1)
D3	(0.136, 0.341, 0.591)	(0.045, 0.227, 0.477)	(0.182, 0.364, 0.614)	(0.136, 0.318, 0.568)	...	(0.545, 0.795, 1)	(0.545, 0.795, 0.909)	(0.591, 0.841, 0.977)
D4	(0.227, 0.477, 0.705)	(0.25, 0.5, 0.727)	(0.341, 0.591, 0.841)	(0.205, 0.455, 0.705)	...	(0.636, 0.886, 1)	(0.614, 0.864, 1)	(0.523, 0.773, 0.932)
E1	(0.636, 0.886, 1)	(0.545, 0.795, 1)	(0.568, 0.818, 1)	(0.636, 0.886, 1)	...	(0.614, 0.864, 1)	(0.614, 0.864, 1)	(0.659, 0.909, 1)
E2	(0.614, 0.864, 1)	(0.614, 0.864, 1)	(0.636, 0.886, 1)	(0.614, 0.864, 1)	...	(0, 0, 0.25)	(0.659, 0.909, 1)	(0.5, 0.75, 0.932)
E3	(0.273, 0.523, 0.773)	(0.432, 0.682, 0.864)	(0.591, 0.841, 0.932)	(0.432, 0.682, 0.886)		(0.568, 0.818, 1)	(0, 0, 0.25)	(0.614, 0.864, 1)
E4	(0.568, 0.818, 1)	(0.591, 0.841, 1)	(0.591, 0.841, 1)	(0.591, 0.841, 1)	...	(0.545, 0.795, 1)	(0.614, 0.864, 1)	(0, 0, 0.25)

Table 8: The fuzzy total-influence matrix $\tilde{T}$ and the sum of influences given/received for dimensions

	A1	A2	A3	A4	...	E2	E3	E4
A1	(0.023, 0.1, 0.483)	(0.055, 0.145, 0.529)	(0.064, 0.167, 0.582)	(0.054, 0.148, 0.536)	...	(0.068, 0.175, 0.596)	(0.064, 0.169, 0.58)	(0.061, 0.162, 0.569)
A2	(0.029, 0.112, 0.483)	(0.021, 0.095, 0.474)	(0.059, 0.157, 0.561)	(0.053, 0.142, 0.52)	...	(0.059, 0.162, 0.576)	(0.06, 0.16, 0.56)	(0.06, 0.156, 0.55)
A3	(0.04, 0.116, 0.467)	(0.037, 0.114, 0.473)	(0.023, 0.099, 0.488)	(0.034, 0.112, 0.474)	...	(0.041, 0.132, 0.53)	(0.045, 0.134, 0.518)	(0.042, 0.129, 0.508)
A4	(0.046, 0.134, 0.513)	(0.046, 0.135, 0.52)	(0.059, 0.162, 0.576)	(0.025, 0.106, 0.499)	...	(0.065, 0.171, 0.591)	(0.064, 0.167, 0.576)	(0.057, 0.157, 0.564)
B1	(0.036, 0.112, 0.461)	(0.04, 0.117, 0.47)	(0.05, 0.138, 0.518)	(0.039, 0.119, 0.479)	...	(0.05, 0.141, 0.533)	(0.043, 0.132, 0.514)	(0.051, 0.138, 0.51)
B2	(0.046, 0.121, 0.458)	(0.035, 0.111, 0.462)	(0.037, 0.125, 0.504)	(0.04, 0.12, 0.475)	...	(0.054, 0.144, 0.526)	(0.051, 0.14, 0.511)	(0.05, 0.136, 0.502)
B3	(0.047, 0.123, 0.465)	(0.029, 0.107, 0.46)	(0.05, 0.139, 0.517)	(0.05, 0.13, 0.48)	...	(0.053, 0.145, 0.531)	(0.044, 0.133, 0.512)	(0.047, 0.134, 0.505)
B4	(0.053, 0.14, 0.514)	(0.052, 0.14, 0.524)	(0.057, 0.158, 0.575)	(0.055, 0.146, 0.533)	...	(0.064, 0.169, 0.589)	(0.059, 0.161, 0.573)	(0.06, 0.159, 0.562)
C1	(0.028, 0.109, 0.463)	(0.04, 0.121, 0.481)	(0.054, 0.147, 0.534)	(0.049, 0.134, 0.493)	...	(0.059, 0.155, 0.547)	(0.059, 0.153, 0.532)	(0.052, 0.143, 0.518)
C2	(0.026, 0.093, 0.416)	(0.025, 0.092, 0.422)	(0.049, 0.126, 0.476)	(0.032, 0.102, 0.436)	...	(0.038, 0.118, 0.481)	(0.026, 0.103, 0.457)	(0.023, 0.097, 0.446)
C3	(0.029, 0.103, 0.448)	(0.025, 0.101, 0.453)	(0.052, 0.14, 0.516)	(0.031, 0.111, 0.467)	...	(0.048, 0.139, 0.523)	(0.036, 0.125, 0.502)	(0.033, 0.119, 0.491)
C4	(0.023, 0.089, 0.419)	(0.027, 0.097, 0.434)	(0.046, 0.126, 0.487)	(0.029, 0.102, 0.442)	...	(0.052, 0.135, 0.501)	(0.046, 0.127, 0.485)	(0.028, 0.107, 0.463)
D1	(0.038, 0.12, 0.484)	(0.03, 0.114, 0.484)	(0.059, 0.155, 0.548)	(0.03, 0.117, 0.491)	...	(0.061, 0.16, 0.562)	(0.062, 0.159, 0.546)	(0.055, 0.148, 0.536)
D2	(0.049, 0.136, 0.516)	(0.05, 0.138, 0.525)	(0.06, 0.162, 0.579)	(0.056, 0.148, 0.537)	...	(0.061, 0.166, 0.593)	(0.062, 0.164, 0.576)	(0.061, 0.16, 0.566)
D3	(0.022, 0.088, 0.412)	(0.017, 0.083, 0.413)	(0.029, 0.105, 0.463)	(0.023, 0.092, 0.426)	...	(0.048, 0.13, 0.493)	(0.047, 0.127, 0.475)	(0.048, 0.125, 0.47)
D4	(0.029, 0.107, 0.463)	(0.03, 0.109, 0.472)	(0.041, 0.132, 0.525)	(0.03, 0.112, 0.48)	...	(0.057, 0.151, 0.546)	(0.055, 0.147, 0.531)	(0.049, 0.138, 0.518)
E1	(0.055, 0.144, 0.523)	(0.051, 0.141, 0.532)	(0.06, 0.164, 0.585)	(0.058, 0.152, 0.542)	...	(0.064, 0.172, 0.599)	(0.063, 0.168, 0.583)	(0.063, 0.165, 0.572)
E2	(0.053, 0.14, 0.514)	(0.053, 0.141, 0.523)	(0.062, 0.164, 0.575)	(0.056, 0.148, 0.533)	...	(0.032, 0.125, 0.551)	(0.064, 0.166, 0.573)	(0.054, 0.154, 0.559)
E3	(0.036, 0.123, 0.499)	(0.044, 0.131, 0.512)	(0.059, 0.16, 0.567)	(0.046, 0.137, 0.523)	...	(0.06, 0.165, 0.584)	(0.03, 0.119, 0.53)	(0.059, 0.158, 0.557)
E4	(0.052, 0.141, 0.527)	(0.053, 0.143, 0.535)	(0.062, 0.166, 0.589)	(0.056, 0.15, 0.546)	...	(0.061, 0.169, 0.603)	(0.063, 0.168, 0.586)	(0.03, 0.12, 0.538)

Table 9: The fuzzy total-influence matrix $\tilde{T}$ and the sum of influences given/received for dimensions

	Di	Ri	$(Di)^{defuzzy}$	$(Ri)^{defuzzy}$	$Di + Ri$	$Di - Ri$
A1	(0.197, 0.561, 2.13)	(0.138, 0.462, 1.946)	0.963	0.8491.811	0.114	
A2	(0.161, 0.506, 2.037)	(0.159, 0.489, 1.997)	0.902	0.881	1.783	0.020
A3	(0.134, 0.441, 1.903)	(0.205, 0.586, 2.207)	0.826	0.999	1.825	−0.173
A4	(0.176,0.536,2.108)	(0.166,0.508,2.028)	0.940	0.901	1.841	0.039
B1	(0.178,0.497,1.957)	(0.177,0.494,1.951)	0.877	0.874	1.751	0.003
B2	(0.18,0.498,1.929)	(0.184,0.512,1.97)	0.869	0.889	1.758	-0.020
B3	(0.186,0.508,1.944)	(0.182,0.495,1.912)	0.880	0.863	1.743	0.017
B4	(0.198,0.569,2.16)	(0.199,0.572,2.156)	0.975	0.976	1.951	0.000
C1	(0.174,0.529,2.049)	(0.142,0.459,1.922)	0.917	0.841	1.758	0.076
C2	(0.118,0.409,1.806)	(0.164,0.494,1.95)	0.778	0.869	1.647	-0.091
C3	(0.174,0.507,1.986)	(0.116,0.418,1.843)	0.889	0.792	1.681	0.096
C4	(0.133,0.437,1.86)	(0.177,0.511,1.985)	0.810	0.891	1.701	-0.081
D1	(0.197,0.555,2.095)	(0.176,0.525,2.045)	0.949	0.915	1.865	0.034
D2	(0.196,0.578,2.207)	(0.189,0.536,2.056)	0.994	0.927	1.921	0.067
D3	(0.142,0.437,1.821)	(0.186,0.532,2.063)	0.800	0.927	1.727	-0.127
D4	(0.182,0.52,2.036)	(0.167,0.498,1.995)	0.913	0.886	1.799	0.026
E1	(0.225,0.635,2.321)	(0.226,0.642,2.358)	1.060	1.075	2.136	-0.015
E2	(0.211,0.612,2.276)	(0.218,0.631,2.338)	1.033	1.062	2.095	-0.029
E3	(0.213,0.611,2.261)	(0.22,0.621,2.272)	1.028	1.038	2.066	-0.009
E4	(0.222,0.633,2.336)	(0.207,0.596,2.225)	1.063	1.009	2.072	0.054

Table 10: The fuzzy total-influence matrix $\tilde{T}$ and the sum of influences given/received for dimensions

	A	B	C	D	E	$(Di)^{defuzzy}$	$(Ri)^{defuzzy}$	$Di+Ri$	$Di-Ri$
A	(0.042,0.128,0.511)	(0.054,0.147,0.534)	(0.055,0.152,0.549)	(0.054,0.149,0.544)	(0.058,0.158,0.565)	2.703	2.494	5.197	0.209
B	(0.045,0.128,0.493)	(0.046,0.13,0.499)	(0.042,0.132,0.516)	(0.038,0.127,0.508)	(0.053,0.146,0.536)	2.552	2.553	5.105	-0.001
C	(0.035,0.112,0.462)	(0.035,0.114,0.469)	(0.037,0.118,0.481)	(0.043,0.125,0.484)	(0.044,0.13,0.501)	2.397	2.639	5.036	-0.242
D	(0.037,0.12,0.489)	(0.041,0.127,0.501)	(0.053,0.143,0.524)	(0.045,0.131,0.51)	(0.056,0.149,0.539)	2.562	2.609	5.172	-0.047
E	(0.054,0.147,0.539)	(0.056,0.153,0.55)	(0.06,0.161,0.569)	(0.06,0.159,0.563)	(0.054,0.156,0.575)	2.796	2.715	5.511	0.080

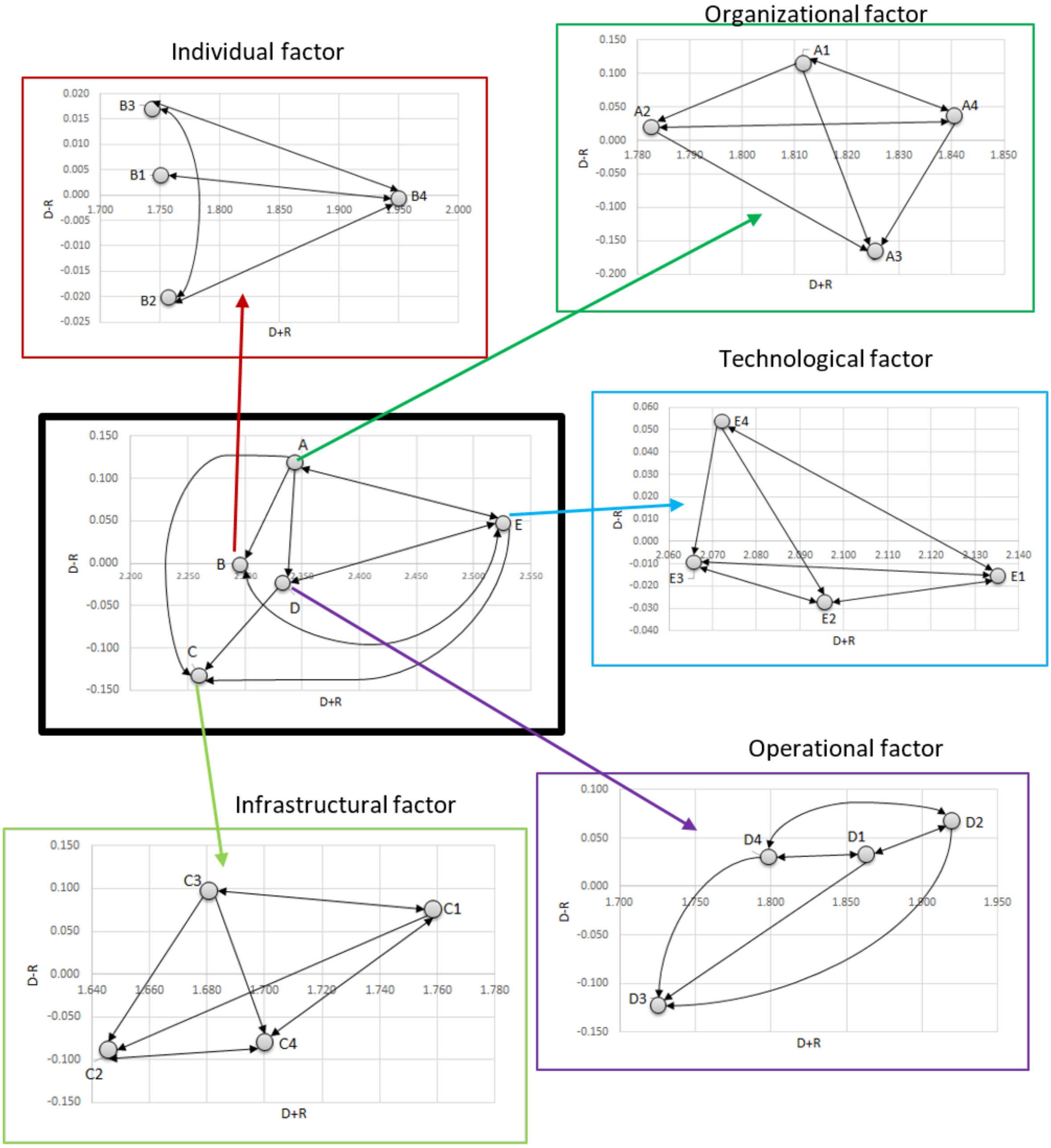

Figure 1: Fuzzy scope influential network relation map

Table 11: Global Factors weight

Factors	Code	Local Weight	Global Weight
Organizationalfactor	**A**	**0.1849**	
Governance	*A*1	0.2325	0.0430
Strategy	*A*2	0.2332	0.0431
Monitoring	*A*3	0.2861	0.0529
Policy	*A*4	0.2482	0.0459
	B	**0.1945**	
Attitude	B1	0.2344	0.0456
Social-cultural	B2	0.2440	0.0475
Ethical	B3	0.2308	0.0449
Knowledge & awareness	B4	0.2908	0.0566
Infrastructurefactor	**C**	**0.2046**	
Physical	C1	0.2472	0.0506
Storage	C2	0.2572	0.0526
Network	C3	0.2322	0.0475
Datacenter	C4	0.2635	0.0539
Operationalfactor	**D**	**0.2153**	
Knowledge management	D1	0.2604	0.0561
Configuration management	D2	0.2570	0.0553
Standarization	D3	0.2463	0.0530
Communication& collaboration	D4	0.2362	0.0509
Technologicalfactor	**E**	**0.2006**	
Tool	E1	0.2553	0.0512
method	E2	0.2536	0.0509
Framework	E3	0.2520	0.0506
Emerging trend	E4	0.2390	0.0480

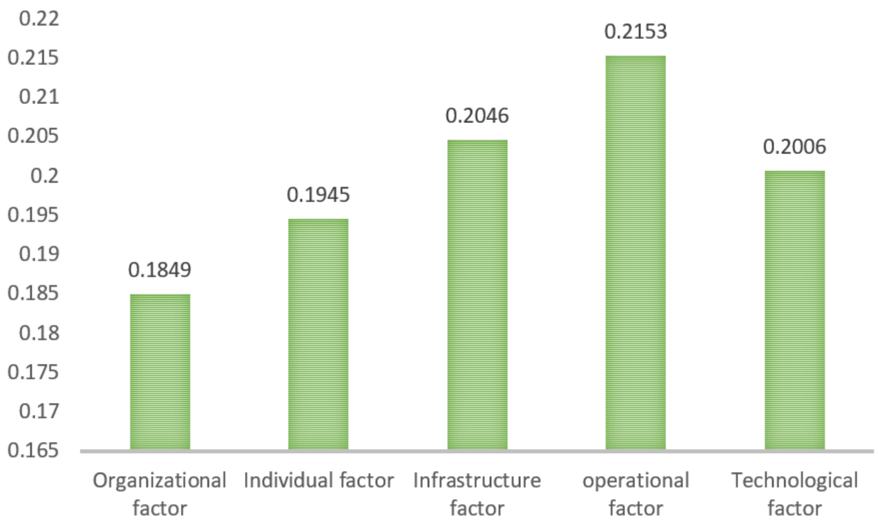

Figure 2: Criteria Weight and Priorities

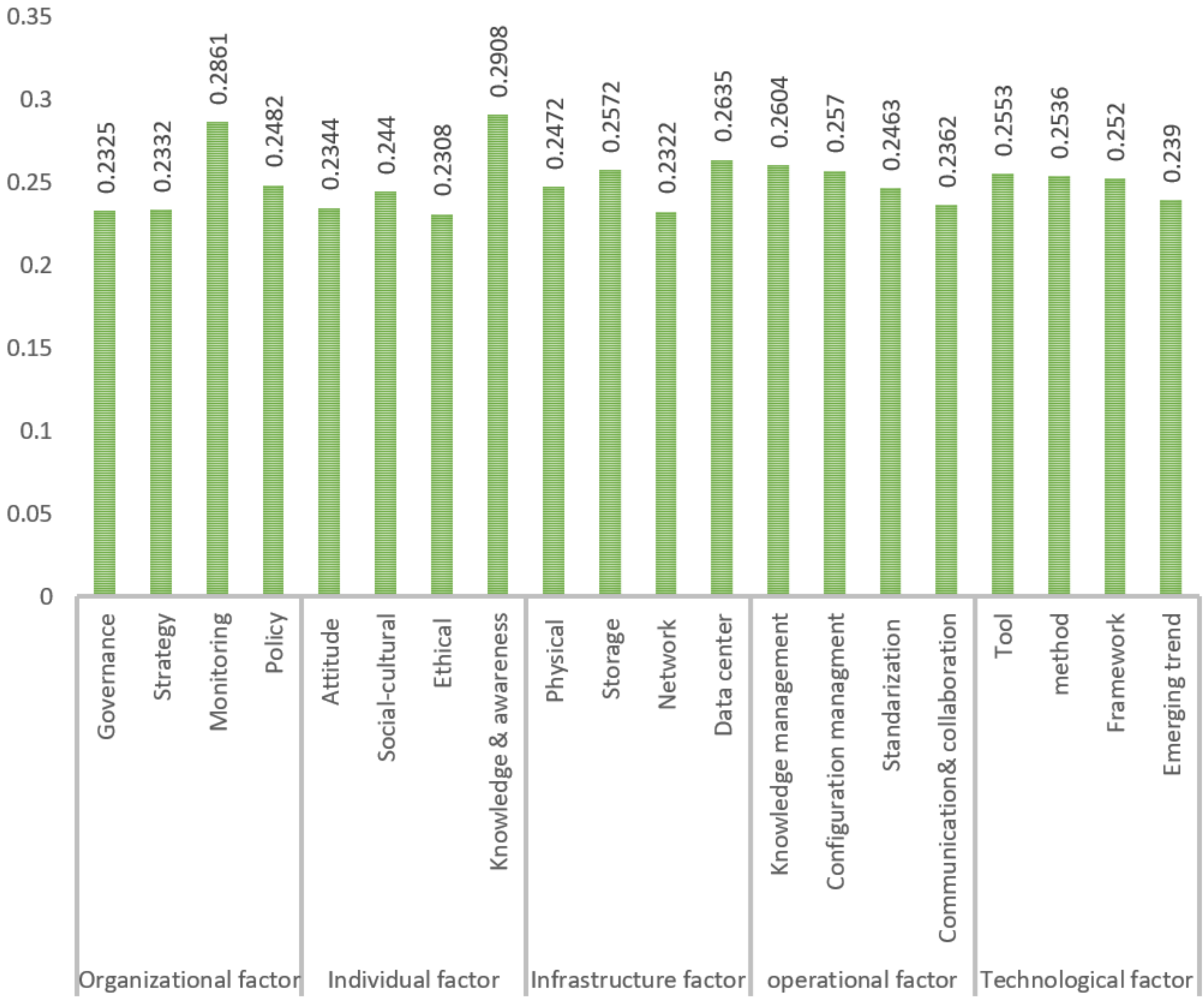

Figure 3: Sub Criteria Weight and Priorities

5 Conclusion

As a component of information technology, software plays a dual role in the environment; Undoubtedly, the software is the backbone of smart solutions that help and support climate change. On the other hand, with the increase of digital technology and its applications, it acts as one of the environmental problems. However, the software itself does not consume energy and has no harmful effects. The problem lies in software development and implementation. Companies can reduce energy and carbon emissions by observing some software development factors.

The main goal of this study was to identify the criteria influencing green software development. The factors were identified from qualitative content analysis of the literature and interviews with Industry and academic experts. Five criteria and four subcritical for each criteria were identified. Next, the factors were evaluated and analyzed using the FDEMATEL based on analytic network process (ANP) and interrelationships and interactions of criteria on each other were determined.

The results showed that the organizational and technological factors are affecting factor and “individual factor”, “operational factor” and “infrastructural factor” are influential factors.

Also, among the main criteria of “operational factor”, “Infrastructure factor”, “Technological factor”, “Individual factor”, and “Organizational factor” ranked first to fifth.

Among the sub-criteria, “knowledge and awareness” had greatest weight, and “ethical” had lowest weight. Regarding the small difference between the highest and the lowest factors "0.06", it can be concluded that all factors are almost equally effective. And we can conclude developing green software requires the creation of a trusted ecosystem that includes organizational factors (governance, strategy, monitoring, policy), individual factors (attitude, social-cultural, ethical, knowledge & awareness), infrastructure factors (physical, storage, network, datacenter), operational factors (knowledge management, configuration management, standardization, communication & collaboration) and technological factors (tool, method, framework, emerging trend).

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