Blockchain Technology Evaluation with Linguistic Variables: A Case for Smart Agriculture

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Abstract

Blockchain (BC) technology is developing in every sector, and it guarantees to solve many problems concerning security, privacy, and trust. BC is not a separate technology; it combines technologies in computer science and financial applications. When BC technology is assessed concerning agri-food processes, it is stated that it can be a quality solution to support transparency and help to build trust in the agri-food sector. Concerning all the benefits and paradigm changes in the agri-food chain, understanding the BC technology is the first step before including it in the existing environments. Knowing the key factors affecting the BC efficiency and application may be an excellent way to start and investigate the developing technology. Accordingly, this paper aims to create an assessment methodology for the BC technology from the smart agriculture (SA) perspective. The 2-Tuple linguistic (2-TL) model is used with multi-criteria decision-making (MCDM) tools. The 2-TL model is a linguistic-based analytical approach that can eliminate information loss during the translation stage. While evaluating emerging technology, a linguistic-based methodology could be more understandable for practitioners and researchers. The DEMATEL method is utilized in this study's framework thanks to its ability to check the interdependence among the proposed criteria and extract their interrelationships. Evaluating these relationships can help companies increase the efficiency of their own evaluation processes. A case study to test the plausibility of the suggested framework is also given with detailed results and discussions.

Keywords
2-Tuple linguistic model, Blockchain, DEMATEL, Smart Agriculture, Technology Evaluation.

1. Introduction
Blockchain (BC) is developing in every sector, and it guarantees to solve many problems concerning security, privacy, and trust. Notwithstanding its reputation and the great attention obtained from public and private sides, the technology is still far from being well comprehended. It is enclosed by a great deal of overemphasis and hype. BC is not a separate technology; it is the combination of technologies in computer science and financial applications (Ajwani-Ramchandani et al., 2021). Technologies involved in these areas contain public/private key cryptography, cryptographic hash functions, database technologies, primarily distributed databases, consensus algorithms, and decentralized processing. In a nutshell, BC's principal aim is to attain database reliability and integrity with distributed decentralized database background (Alicke et al., 2017).

When BC technology is assessed concerning agri-food processes, it is stated that it can be a quality solution to support transparency and help to build trust in the agri-food sector. Today, in the agri-food industry, the data is audited by third parties. The data is stored instead by paperwork or in the central data center. These two approaches are away from being well-organized due to the errors, corruption, and inefficiency of paperwork. BC technology offers a solution that the existing transparency and trust mechanisms cannot handle. These information problems pose a severe threat to food safety, food quality, and sustainability, which shows that remaining transparency and trust systems cannot solve and sometimes even worsens the problems of low transparency and trust in agri-food chains (Borsellino et al., 2020). BC technology provides a means to guarantee record persistence and potentially simplify data sharing between diverse actors in a food value chain. This potential could lead to thrilling paradigm modification that enables transparency and trust in food chains ensuring food integrity (Lin et al., 2018).

Concerning all the benefits and paradigm changes in the agri-food chain, understanding the BC technology is the first step before including it in the existing environments. Knowing the key factors affecting the BC efficiency and application may be a good way to start and investigate the developing technology. Accordingly, this paper aims to create an assessment methodology for the BC technology from the smart agriculture (SA) perspective. SA and BC are both novel notions that emerged in the last decade, they are still emerging, and their necessities are shaped as they are used and researched. Therefore, they both have some uncertainties and haziness in application and technology.

In this suggested BC technology assessment methodology, conceiving the uncertainties, a framework based-on fuzzy linguistic measures (Büyüközkan et al., 2021) are presented. The 2-Tuple linguistic (2-TL) model is chosen to be used with multi-criteria decision-making (MCDM) tools. The 2-TL model is a linguistic-based analytical approach that can eliminate information loss during the translation stage (Herrera et al., 2001). While evaluating emerging technology, a linguistic-based methodology could be more comprehensible for practitioners and researchers. Plus, it can also create decision-making environments closer to the human cognitive process. Understanding such a critical technology can also be an advantage that can change the usual business models.

1.1 Objectives

As stated in the literature, BC technology is seen as a path-breaking technology for all sectors. BC is still an emerging technology, yet it is critical to create some knowledge about its components and facilitators for constructing a robust emerged ecosystem. Accordingly, this paper's main objectives are as follows:

- Creating an index for BC assessment,
- Creating a technology evaluation methodology based-on linguistic assessments,
- Creating a flexible and comfortable environment for DMs to learn and assess the BC technology.

This paper proposed a 2-TL-DEMATEL (Quader et al., 2016) methodology for BC technology assessment for SA by considering these objectives. The remainder of this paper is organized as follows: Section 2 gives the theoretical background with a literature review and technology evaluation criteria. Section 3 presents the methodological background with 2-TL-DEMATEL methodology details. Section 4 provided the case study to test the plausibility of the suggested methodology. Section 5 gives the results and discussion, and finally, Section 6 provides the conclusions.

2. Literature Review

This section will explain the theoretical background of BC technology and its use in SA.

2.1 Blockchain and Agriculture

When the recent articles about BC and SA are examined, according to the co-occurrences of keywords (more than 30 times), Figure 1 is obtained. Figure 1 presents the network visualization map[1] for keywords used in academic studies in recent years.

This map also shows us the major emphasized areas of the BC in SA and their relations with each other. As can be seen from the map, there are two groups: red and green. The green cluster is related to the enabler technologies for BC, and the red one is highly related to the application areas of BC technology in agriculture. Internet of things (IoT) is the essential enabler and facilitator for BC implications (Saxena et al., 2021). The literature also supports this approach, and IoT and BC co-occurrences are high (Bandara et al., 2021; Xu et al., 2021; Ferrag et al., 2020; Lin et al., 2018). As the map shows, BC applications in SA mostly concentrate on supply chain traceability. With the COVID-19 situation, food traceability drew all the attention because of health concerns (Duncan et al., 2019). To obtain a fully traceable system, today BC solutions stand-alone to supply effective solutions. The development of BC technology is critical to have all-inclusive farming systems in the future (Zhao et al., 2019). In the reviewed materials, BC technology is reviewed from the cost-effectiveness aspect (Harshavardhan Reddy et al., 2019). However, it has a promising benefit, such as social, economic, and environmental to maintain sustainability in the agricultural aspect. Also, BC-based systems are large ecosystems in which collaboration is critical. For the future of SA, collaborative

[1] https://www.vosviewer.com

platforms will be preferred to reach stable and inclusive growth in the sector (Harshavardhan Reddy et al., 2019) (Figure 1).

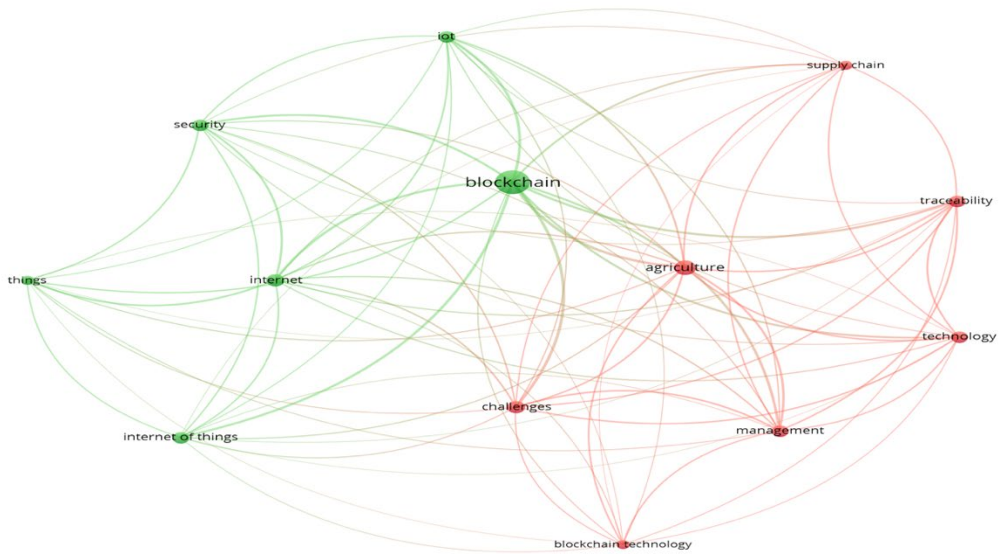

Figure 1. Network map visualization of BC-SA studies

2.2 Blockchain Technology Evaluation Criteria

Based on the academic literature and the industrial reports related to the SA, technology evaluation dimensions and sub-criteria are derived. Table 1 here shows the two-levelled evaluation criteria.

As stated in Table 1, the main dimensions are determined as: Cost, Security, Speed, Operation, and Vendor-related issues (Deloitte, 2020; McKinsey and Co., 2020).

The Cost dimension is highly emphasized in the academic literature and industrial reports. In the literature, Cost is seen as one of the main barriers to BC technology with interoperability and data confidentiality.

Another dimension is Security. The security dimension is seen as the most potent enabler for BC technology, yet there are some trust issues and some question marks about data sharing in the literature. The resistance to attacks, user anonymity, and data confidentiality are assigned as the sub-criteria for the security dimension (Duncan et al., 2019).

Speed is also the main dimension since transaction speed is highly critical in this era. Thanks to the vital importance of real-time data sharing, the speed dimension is presented with encryption speed, transaction speed, and latency.

The operation dimension is selected due to the interoperability issues of BC technology. Its compatibility with existing technologies and its efficient operation with other technologies to be added is a widely discussed dimension in the academy for BC (World Economic Forum, 2020). Finally, as BC is provided by a supplier or a vendor, and the BC ecosystem is built together with providers, vendor-related issues are also one of the main dimensions for technology assessment.

Table 1. BC technology evaluation dimensions and sub-criteria (Vangala et al., 2021; Pincheira et al., 2021; Ferrag et al., 2020; Zhao et al., 2019; Harshavardhan Reddy et al., 2019)

Dimensions	Criteria	
Cost (C)	Purchase cost	C1
	Maintenance cost	C2
	Additional cost	C3

Security (S)	Resistance to attacks	S1
	User anonymity	S2
	Data confidentiality	S3
Speed (SP)	Encryption speed	SP1
	Transaction speed	SP2
	Latency	SP3
Operation (O)	Interoperability	O1
	Process capability (capacity)	O2
	Functionality	O3
Vendor-related issues (V)	Trust	V1
	Effective Coordination	V2
	Availability	V3

3. Methods
This section will provide the methodological background for the technology assessment framework. This section will give the MCDM methodology and its components as preliminaries.

3.1 Suggested MCDM Methodology for Technology Assessment
Technology is seen as a critical enabler to obtain a competitive advantage in today's uncertain and high-speed environments (Dong et al., 2021).The procurement of fundamental technology is particularly vital for advanced product manufacturing. The technology's know-how must be transmitted to the user for competent use. Therefore, estimated outcomes such as productivity, income generation, and return on investment can be reached.

The selection of proper technology, barriers and drivers' association, and the appropriate supplier evaluation are fundamental processes to reach a successful technology transfer. During these processes, MCDM helps overcome limited knowledge, multiple variables, and complexity rising from multiple actor participation. Hence, MCDM methods have turned into a key tool to simplify technology transfer processes. This tool can be handy for developing countries since their changeability accepts the development of research processes around policymaking, the definition of transfer models, prioritization of technologies for countries and companies, identification of barriers and facilitators, and construction of efficient transfer strategies. Plus, MCDM methods also permit ambiguity, imprecision, uncertainty, and subjectivity reduction in human-based judgments.

Concerning all the benefits of MCDM models in technology transfer and assessment, this paper suggests an MCDM-based linguistic technology assessment framework with the 2-TL model and DEMATEL tool. Figure 2 presents the general suggested framework for technology evaluation (Figure 2).

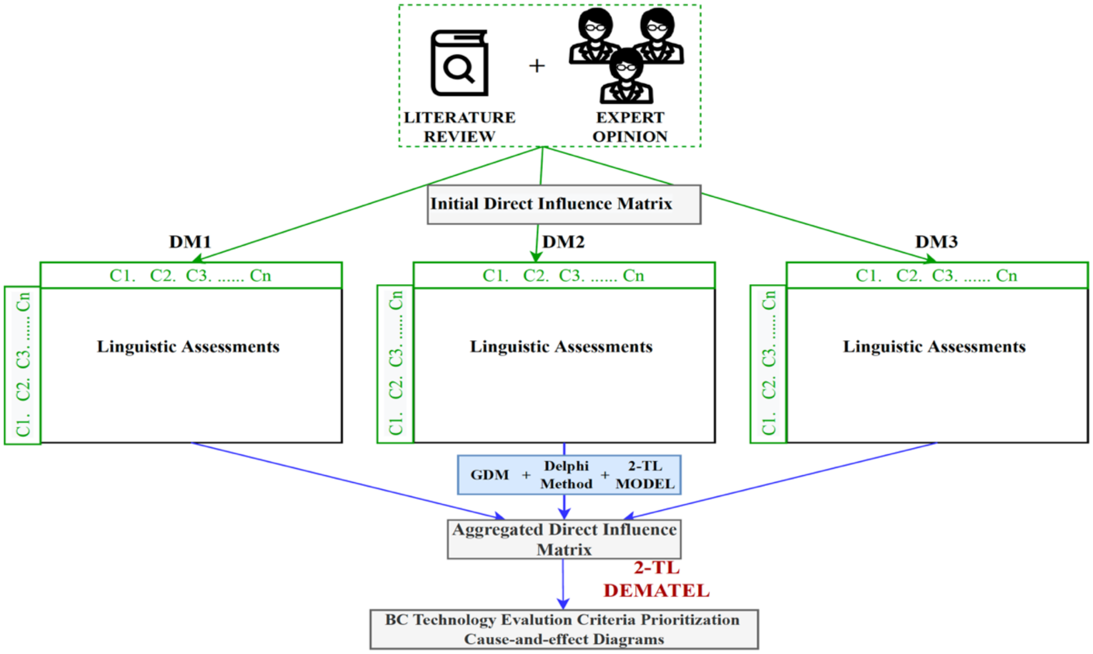

Figure 2. The suggested framework for the BC technology evaluation

3.2 2-Tuple Linguistic Model

The 2-Tuple linguistic model is a fuzzy logic-based model (Zadeh, 1965).It reduces information loss while transforming linguistic data into numerical form. The 2-Tuple fuzzy linguistic representation model makes it possible to represent linguistic information with a 2-Tuple form of *(s, α)*, where *'s'* is a linguistic label and *'α'* is a numerical value representing this symbolic translation's value (Herrera et al., 2000). For the necessary and basic definitions, readers can refer to (Martínez et al., 2015). The leading translation equation of 2-TL is given as follows:

$$\Delta_s : [0, g] \rightarrow \bar{S}$$
$$\Delta_s(\beta) = (S_i, \alpha), with \begin{cases} i = round(\beta) \\ \alpha = \beta - i \end{cases} \quad (1)$$
$$S_i \in S \Rightarrow (S_i, 0)$$

Linguistic Hierarchies

A *Linguistic Hierarchy (LH)* is the union of all levels *t,* where each level *t* corresponds to a linguistic term set symmetrically distributed with an odd granularity (Martínez et al., 2015). The transformation function to translate a linguistic term set with granularity *n(t)* to a linguistic term set having granularity *n(t')* is as follows:

$$TF_{t'}^{t} = \left(S_i^{n(t)}, \alpha^{n(t)}\right) = \Delta\left(\frac{\Delta^{-1}\left(\left(S_i^{n(t)}, \alpha^{n(t)}\right) \times (n(t') - 1)\right)}{n(t) - 1}\right) \quad (2)$$

The transformation function enables multi-granular information to become one linguistic domain.

3.3 Dematel

DEMATEL (Gabus et al., 1972) is an accurate MCDM tool that depicts the importance of related criteria. It also makes it possible to determine the causal relationships between evaluation criteria (Büyüközkan et al., 2010) and is suggested for the criteria weighting process. It is utilized in this study's framework because of its ability to check the interdependence among the proposed criteria and extract their interrelationships. Evaluating these relationships can help companies increase the efficiency of their own evaluation processes. Evaluation dimensions are determined according to an extensive literature search and additional interviews with industrial experts.

3.4 Group Decision Making

MCDM aims to discover the most appropriate alternative by conceiving multiple criteria concurrently. Group Decision Making (GDM) may be adequate to reach an objective solution in this procedure. GDM involves various decision-makers (DMs) having different backgrounds or points of view and handling the decision process distinctive from others. However, each DM has a shared awareness for cooperating with each other to achieve collective decision. Particularly while having haziness and uncertainty, reaching consensus for a decision in a group with different opinions turns out to be more critical. Generally, GDM problems are solved by utilizing classic approaches, such as the majority rule, minority rule, or total agreement. Yet, these techniques do not assure an acceptable solution for all DMs (Büyüközkan et al., 2015).

In this paper, a consensus-reaching process is followed by the Delphi approach. Delphi is a communication instrument that facilitates group decision-making. The Delphi process is very efficient for supporting a group of individuals to handle complicated problems as a group (Büyüközkan, 2004).The method is based on expert knowledge, and the group is principally formed with knowledgeable and expert contributors.
The assessment made by DMs depends on their judgement and is subjective. Accordingly, instead of crisp numbers, the linguistic variables are given to the DMs to represent the uncertain and subjective nature of their data.

3.5 2-TL DEMATEL Technique for Blockchain Technology Evaluation

The DEMATEL technique can convert the interrelations between factors into an intelligible structural model of the system and divide the interrelations into cause-and-effect groups. Hence, it is an appropriate and valuable tool to analyze and rank the interdependent relationships among factors in a complex system for long-term strategic decision-making and indication of improvement scopes. The formulating steps of the 2-TL integrated DEMATEL method can be summarized as follows (Quader et al., 2016):

Step 1. Constructing the average matrix (*A*).
In this step, DMs give their evaluations,$\left(S_{ij}, \alpha_{ij}\right)$. They evaluate the direct effect between criteria *i* and *j*.

Step 2. Calculating the initial direct influence matrix (*D*).
In this step, the matrix D is obtained by normalizing the matrix A with the following relation:

$$D = s.A$$
$$s = min\left[\frac{1}{max_{1\le i\le n}\sum_{j=1}^{n}\left|\Delta^{-1}\left(S_{ij}, \alpha_{ij}\right).\right|}, \frac{1}{max_{1\le j\le n}\sum_{i=1}^{n}\left|\Delta^{-1}\left(S_{ij}, \alpha_{ij}\right).\right|}\right] \tag{3}$$

Step 3. Calculating the total direct/indirect influence matrix (*T*).
The total direct/indirect influence matrix is defined as the following relation:

$$T = D(I - D)^{-1} \tag{4}$$
$$T = \left[\Delta^{-1}\left(S_{ij}, t_{ij}\right)\right]\ i, j = 1,2 \dots n$$

In this relation, *I* is the identity matrix. In the *T* matrix, *d* and *r* values can be derived to determine the direct/indirect relationships between criteria. *d* refers to the dispatcher, and *r* indicates the receiver. These values can be obtained by using the following relation:

$$d = d_{n\times 1} = \left[\sum_{j=1}^{n} \Delta^{-1}(S_{ij}, t_{ij})\right]_{n\times 1}$$
$$r = r_{n\times 1} = \left[\sum_{i=1}^{n} \Delta^{-1}(S_{ij}, t_{ij})\right]_{1\times n} \quad (5)$$

r_i gives the summation of the direct and indirect effects of criterion on the others. If c_i is the sum of the *jth* column of the matrix *T*, then it refers to the sum of the direct and indirect effects that the criterion receives from others. In addition, when $j=i$,, $(d_i + r_i)$ gives an index of the strength of influences given and received, it refers to the degree of importance of criterion *i* in the problem. Also, if $(d_i\text{-}r_i)<0$, then criterion *i* is being affected by other criteria (Tzeng *et al.*, 2007). Moreover, if $(d_i\text{-}r_i)>0$, it means that the degree of affecting others is stronger than the degree of being affected.

Step 4. Analyzing the cause-and-effect diagrams.
In this step, influence diagrams are obtained to investigate the cause-effect relations between criteria. Comprehensive details of the recommended methodology for BC technology evaluation are presented in Figure 3.

4. Case Study

This section gives the real case application for the BC technology assessment. For that purpose, one decision-making group is formed from three different experts with different background about SA and smart technologies. The case study is applied to test the plausibility of the suggested framework. One of the experts from the decision-making group is an academician who works about SA and its technologies. The second one is a consultant whose interest is mainly focused on smart systems and agriculture. Finally, the third expert is also an academician who works about smart systems and technologies. Considering the diverse background of experts about the subject, different granulated linguistic sets are provided to them. Thanks to the 2-TL model five scaled evaluation set is provided to the academician who works on smart systems. Nine scaled evaluation set is suggested to the other two experts who are more experienced on the SA area. Different sets are provided so that the experts would feel comfortable and avoid uncertainty while making evaluations and reach a more objective conclusion. The linguistic sets are provided in Table 2. And case study steps are provided followingly.

Table 2. Five and nine scaled linguistic evaluation sets

2-TL linguistic sets	
S^5	*None (N)-Low(L)- Medium (M)- High(H)-Perfect(P)*
S^9	*None (N)-Low (L)-Medium Low (ML)-Almost Medium (AM)- Medium (M)-Almost High (AH)-High(H)- Very High (VH)-Perfect(P)*

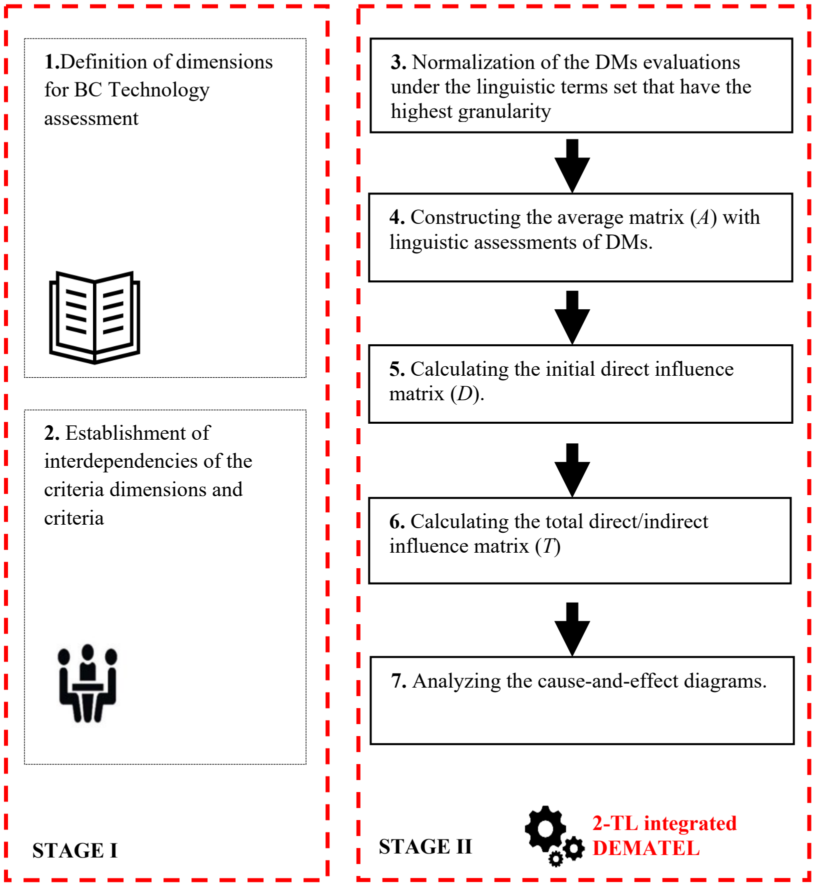

Figure 3. Suggested methodology for BC technology evaluation

As a first step, while constructing the average matrix, each DM gave their evaluations, (S_{ij}, α_{ij}). They evaluate the direct effect between criteria *i* and *j*. After collecting each DMs assessment, the different scaled assessments are first unified under nine scaled set since it has the highest granularity by using Eq. (2). Then, the assessments are aggregated with the Weighted Aggregation Operator of 2-TL (Martínez et al., 2015). Here Table 3 gives the aggregated ultimate average matrix for dimensions.

Table 3. Aggregated average matrix for dimensions

	C	**S**	**SP**	**O**	**V**
C	0.00	(L, -0.30)	(L ,0.28)	(AM, -0.20)	(ML, -0.17)
S	(AM, -0.47)	0.00	(ML, 0.10)	(AM, -0.35)	(ML, 0.10)
SP	(L 0.13)	(ML, -0.30)	0.00	(ML, 0.10)	(ML, -0.17)
O	(ML, 0.10)	(ML, -0.42)	(ML, -0.30)	0.00	(ML, -0.40)
V	(ML, -0.28)	(ML, 0.40)	(ML, 0.40)	(ML, -0.17)	0.00

According to the aggregated ultimate average matrix, the steps provided in Section 3.5 are followed. The exact process is followed for each sub-criteria group, and finally, relations between dimensions and the sub-criteria importance are obtained. The following section will present the results of the case study.

5. Results and Discussion

After applying the 2-TL-DEMATEL steps, the prioritization of dimensions and sub-criteria and interrelation of dimensions and sub-criteria are obtained. Here Figure 4 shows the importance of dimensions. The same process is applied for sub-criteria as well. Their details will be presented and discussed during the presentation.

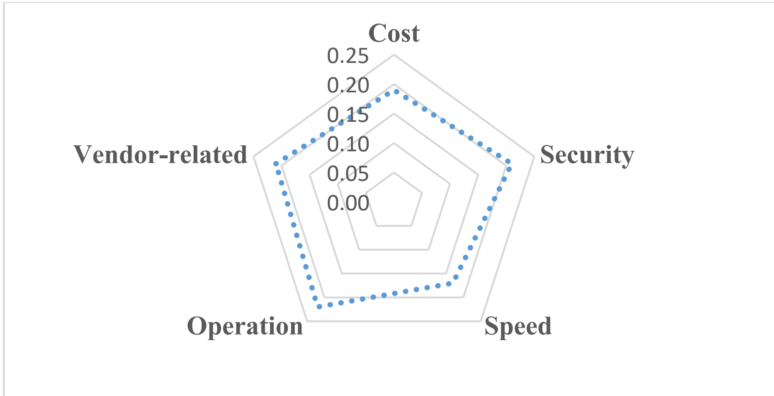

Figure 4. Importance of dimensions obtained from 2-TL-DEMATEL methodology

The *d+r* and *d-r* values are also provided to investigate the cause-effect relations between dimensions. The exact process is obtained for each sub-criteria group as well. Here, Figure 5 shows the *d+r* and *d-r* values for dimensions.

Figure 5. *d+r* and *d-r* values for dimensions

If $(d_i\text{-}r_i)>0$, it means that the degree of affecting others is more substantial than the degree of being affected. Accordingly, when the results are examined, only Operation and Vendor-related issued dimensions are the most critical ones while evaluating the BC technologies for SA.

5.1. Managerial Implications

The suggested methodology for BC technology evaluation for SA may be a handy tool to generate future strategies for today's farms. Especially in emerging economies like Turkey, this methodology may be a robust tool for planning and organizing the technology transfer. The framework also proposes cause-effect relations between the significant factors affecting BC technology.

As a first step, the assessment dimensions and sub-criteria may be advantageous for understanding BC technology. After applying the 2-TL-DEMATEL methodology, a suitable supplier could be selected according to the farms' needs. This could also help the farm to build its own BC environment with trustable and strategically parallel stakeholders.

The suggested linguistic-based technology assessment framework is also validated in this case study, and it also showed its plausibility.

The examination of cause-and-effect relations allows the possibility of better analyzing the technology and its enablers. It also allows creating a roadmap to follow during the technology transfers. Highly affecting dimensions are needed to be considered when choosing the right supplier. In our case study, Operation and the Vendor Related Issues, the interoperability of BC technology and the vendor's specialties possess critical importance for BC technology.

6. Conclusion

This paper aims to create a linguistic information based MCDM model for BC technology evaluation for SA. As aforementioned, BC is seen as a ground-breaking technology for various sectors. Agriculture is one of the fields where the need for secure and traceable products is rising; therefore, this paper targeted the agriculture sector for BC technology integration.

Since BC is an emerging technology, the impreciseness about the notion still exists for practitioners. So, this paper first targets to create an index for important dimensions and sub-criteria for BC technology. The same methodology also allows us to see the cause-and-effect relations between these dimensions; thus, this framework guides practitioners to precisely understand BC technology. Moreover, the same framework may also guide the policymakers or DMs in the organizations to select the most appropriate technology supplier according to their needs.

In this paper, three different DMs are used during the case study. The number of DMs could be a limitation for this paper, yet according to the literature, the number is enough to reach an objective solution (Büyüközkan et al., 2021). Yet, for future studies, the number of DMs could be increased. Also, an appropriate technology supplier selection framework can be integrated with the existing one. The same 2-TL approach could be integrated into the supplier selection stage as well.

Moreover, the same 2-TL-DEMATEL methodology could be applied to other smart technologies to understand better their purpose, enablers, and drivers.

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Biography

Gülçin Büyüközkan is the Dean of the Engineering and Technology Faculty, Galatasaray University, Turkey. She also works as a professor in the Industrial Engineering Department of the same university. Her current studies mainly focus on smart systems, smart technologies, digital transformation, sustainability, supply chain management, multi-criteria decision making, and the application of intelligent techniques on these areas. Prof. Büyüközkan is the author of numerous journal and conference papers.

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