mathematics

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Analysis and Evaluation of Barriers Influencing Blockchain Implementation in Moroccan Sustainable Supply Chain Management: An Integrated IFAHP-DEMATEL Framework

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Citation: Boutkhoum, O.; Hanine, M.; Nabil, M.; EL Barakaz, F.; Lee, E.; Rustam, F.; Ashraf, I. Analysis and Evaluation of Barriers Influencing Blockchain Implementation in Moroccan Sustainable Supply Chain Management: An Integrated IFAHP-DEMATEL Framework. *Mathematics* **2021**, *9*, 1601. https://doi.org/10.3390/math9141601

Academic Editor: Jan Lansky

Received: 3 June 2021
Accepted: 2 July 2021
Published: 7 July 2021

Abstract: Blockchain technology has received wide attention during recent years, and has huge potential to transform and improve supply chain management. However, its implementation in the SSCM (Sustainable Supply Chain Management) strategy is sophisticated, and the challenges are not explored very well, especially in the Moroccan context. To this end, the chief objective of the current endeavor is to investigate the barriers that hinder the adoption of blockchain technology in SSCM from the Moroccan industry and service sectors' perspective. Based on a comprehensive literature search and the use of experts' viewpoints, the barriers affecting the successful implementation of blockchain are classified into three categories called TEO: technological and system, environmental, and intra-organizational dimensions. In this context, a fuzzy group decision-making framework is organized by combining DEMATEL (Decision-Making Trial and Evaluation Laboratory) and IFAHP (Intuitionistic Fuzzy Analytic Hierarchy Process). The IFAHP technique helps to determine the importance/priorities of barriers affecting blockchain adoption, while the DEMATEL technique forms the cause–effect interconnections between these barriers and classifies them concerning the degree of importance and relationships. The results reveal that 'government policy and support' and 'challenges in integrating sustainable practices and blockchain technology through SCM' are significant adoption barriers of blockchain in Moroccan SSCM. The proposed solution can support industrial decision makers to form flexible short- and long-term decision-making strategies to efficiently manage a sustainable supply chain.

Keywords: blockchain; sustainable supply chain; multicriteria decision-making analysis; IFAHP; DEMATEL

1. Introduction

Today, emerging technologies under the auspices of Industry 4.0 are generating substantial financial and business opportunities for supply chain networks. With the increasing awareness of sustainability and consumer preoccupations about energy consumption, materials depletion, data security, privacy, etc., organizations are confronted with the challenge of implementing appropriate measures through technology integration. According to the CompTIA (Computing Technology Industry Association), the top ten emerging technologies in 2020 are artificial intelligence, 5G networks, Internet of Things, serverless computing, biometrics, augmented/virtual reality, blockchain, robotics, natural language processing, and quantum computing [1]. Blockchain is technology well-positioned for innovative business models and has the potential to pioneer such advancements [2]. Conventionally, blockchain is referred to as a secure record of historical transactions, gathered into blocks, branched in chronological order, and spread across several different servers to create efficient provenance [3]. It supports peer-to-peer exchange and provides considerable improvements to transparency, accountability, security, efficiency, and cost minimization [4]. Moreover, blockchain technology ensures data immutability, traceability, and smart contracts, which creates high trust environments without involving any intermediaries [5].

Both academia and industry focus on using technology to improving the processes and operations of business and society. Nonetheless, the way that emerging technologies address sustainability challenges has attracted wide attention. Blockchain technology has influenced a variety of sectors, such as real-time IoT operating systems, secure sharing of medical data, cryptocurrency exchange, traced foods, logistics monitoring, and supply chain sustainability. Supply chain management is regarded as one of the most important blockchain applications concerning the recent demand and growing complexity of supply chain networks [6].

Indeed, supply chain sustainability presents an important competitive and strategic challenge wherein the process of the supply chain and its products are analyzed for meeting sustainability certifications and criteria [7]. Traceability is becoming an equally important requirement and a key differentiator for many industrial supply chains. Moreover, the lack of transparency in the supply value of an article makes it impossible to verify and validate the actual value of that article. In the same context, the associated cost in manipulating the intermediaries and their transparency makes traceability difficult to manage. With its ability to enhance transparency, durability, security, and integrity, blockchain technology may be well suited to resolving these issues [8]. Indeed, blockchain technology plays a pivotal role in sustainability, thanks to its capacity for (i) supporting new forms of producer–consumer collaboration, (ii) helping people to adopt more sustainable manners of living, and (iii) assisting businesses in enhancing their procurement and recycling practices [9]. On the other hand, the extraction of information in the blockchain context is among the issues to which researchers are trying to find solutions to improve supply chain management. Among these solutions, we quote the contribution of [10], which suggests a protocol based on peer prediction with a non-linear scaling system for decentralized oracles to help confidently retrieve external information.

Despite the potential and capabilities of blockchain technology for bringing important reconstitution in the SSCM, its real-world implementation is still in its infancy and requires novel and intuitive models [2,11]. Morocco, like many other developing countries, seeks to leverage the potential of blockchain for meeting the growing demands in SSCM. However, with this desire comes the need for further research and investigation for understanding blockchain implementation. It also requires identifying the barriers influencing its adoption decision in SSCM from the Moroccan industry's and service sectors' perspective. This is so because the literature lacks a comprehensive study on fuzzy group decision-making frameworks combining MCDM (Multi-Criteria Decision-making Methods), especially the DEMATEL method, with IFS (Intuitionistic Fuzzy Set) theory to assist decision makers in evaluating the major blockchain adoption barriers in Moroccan SSCM. Indeed, certain frameworks and methodologies have been proposed for evaluating factors, barriers, and criteria concerning blockchain adoption in SCM and SSCM. The most used methods, as mentioned in related works section, are ANP (Analytic Network Process) [12], integrated ISM (Interpretive Structural Modeling)-DEMATEL [11,13], AHP-VIKOR [14] and DEMATEL [5,15]. However, there are some limitations in these contributions related to several influence constraints, such as uncertain and imprecision preferences and incomplete information, which are often not taken into consideration in the decision-making process. Additionally, decision makers need to form flexible short- and long-term decision-making strategies. Therefore, the group decision-making framework based on IFAHP and DEMA-

TEL methods is proposed in this study because of (1) its ability to help interpret decision makers' thinking when making decisions by formulating mathematical rules for working with linguistic terms, which are easier for understanding human reasoning [16], and (2) its decision support process, which can be continuously improved from short and long period perspectives. Hence, the prime objective of the current study is to propose a collective multicriteria decision support solution based on the integration of IFAHP and DEMATEL for the sufficient identification, evaluation, and ranking of the barriers with the most significant impact on the adoption of blockchain in Moroccan SSCM. The IFAHP technique is applied to rank the various barriers concerning their importance/priorities based on expert opinions. On the other hand, DEMATEL is used to extract the cause–effect relationships among the barriers as well as their intensity. It also helps to classify them as per the degree of importance and relationships.

This study aims at identifying the barriers from the existing literature on blockchain and expert proposals. The identified barriers and sub-barriers are taken into consideration, and similar barriers or barriers with similar processes are eliminated during the validation phase. These barriers and sub-barriers are analyzed and ranked. Briefly, we address the following research questions:

- Why has blockchain technology not been widely adopted in Moroccan supply chains for sustainability purposes?
- What are the barriers that impede the Moroccan industry and service sectors from investing and adopting blockchain technology?
- What are the significant cause-and-effect relationships between those barriers?
- Should companies tackle one barrier to mitigate the effects of the others?

The rest of the paper is structured as follows. Section 2 discusses important research works related to the current study. The proposed research methodology is presented in Section 3. Section 4 covers the proposed fuzzy group decision framework and its application. This is followed by the discussion of the results in Section 5. In the end, the conclusion is given in Section 6.

2. Related Works

This section focuses on the academic research papers treating blockchain technology and its impact on sustainable supply chain management. Despite the large number of research papers on blockchain, most of these papers dealt with the challenges, opportunities, and barriers related to the application of blockchain technology. Although blockchain originally concentrated on cryptocurrencies, its transformative characteristics encouraged other sectors for its adoption. Businesses adopt new technologies, such as blockchain, if they believe that they can enhance the efficacy of their business processes and increase revenue.

With globalization, blockchain technology has become an important part of sustainable supply chain management; its several adaptations can be found in the literature. For instance, Ref. [17] presented an overview of how, increasingly, the literature deals with blockchain efficiency to relieve global supply chain issues, including improving transparency, integrity, compliance, and stakeholder management. In this context, the authors explained that the safety and authenticity of the data can be ensured by blockchain technology [18]. It can also help to minimize the cost of preventing data from volatile alterations that increase risks in the supply chain and decrease business reliability. Moreover, as part of mineral supply chains, Ref. [19] introduced the notion of "digital extraction" based on blockchain traceability for more precise and reliable monitoring and end-to-end traceability in mineral supply chains. In the food supply chain context, the authors in [20] proposed a novel solution based on a sustainable blockchain framework for the halal food supply chain, which can be employed to improve the integrity of the supply chain in the Malaysian context. Along the same lines, Ref. [21] proposed a novel model to assess blockchain maturity in the agricultural supply chain domain. Similarly, Ref. [7] examined blockchain technology and smart contracts with a potential application to supply chain management. The capability of blockchain to address the supply chain sustainability problem is discussed in detail. In addition, insights to overcome adoption barriers are provided through the proposition of future research propositions and directions.

Due to the importance of blockchain technology, many research papers examined factors and barriers affecting the implementation of blockchain technology in different sectors and proposed different decision support solutions. Of the solutions, works focusing on multicriteria decision support methods are cited here. For instance, ref. [12] developed a modeling framework based on the ANP (Analytic Network Process) to evaluate and rank the significant factors that influence the adoption of blockchains. For this purpose, the opinions of managers in the Nigerian freight logistics industry were used. Another research study along the same lines is [11], which utilized an integrated ISM (Interpretive Structural Modeling)-DEMATEL approach to model the significant barriers investigated for the implementation of blockchain technology in the Indian agriculture supply chain and interrogate the interrelationship amongst these identified barriers. Finally, the intensity of the relationship between these barriers was analyzed. Similarly, Ref. [13] proposed an integrated methodology based on ISM and DEMATEL to evaluate and establish the relationships between the identified enablers of blockchain technology adoption in the agriculture supply chain. Ref. [14] presented a decision framework based on AHP and VIKOR under IFT (Intuitionistic Fuzzy Theory) to investigate the feasibility of blockchain technology in a large-scale logistics company located in Turkey.

Several other research works devised frameworks for investigating the barriers associated with blockchain technology. For instance, the authors developed a framework for the successful adoption of blockchain in industry and service sectors in [15]. In this regard, the literature and experts were consulted for successful DLT (Distributed Ledger Technology) adoption. Later, barriers were examined and ranked based on the DEMATEL technique for the successful implementation of blockchain in industries other than cryptocurrencies. However, the main focus of [15] is the external problems related to cryptocurrencies in a public blockchain. Barriers influencing blockchain implementation in the supply chain domain and sustainability are not covered. A similar method was used by [5] for examining barriers and relationships amongst those barriers that affect blockchain implementation in a sustainable supply chain. The DEMATEL technique was used to structure the causal relationships among the identified barriers and identify each barrier's prominence. Further, diverse studies [22–25] tried to discuss and identify the applications and contributions of blockchain in logistics and supply chain systems.

In essence, blockchain technology has lots of potential to introduce reconstitution in SSCM. As Moroccan SCMs and SSCMs have several limitations and are very complex, unorganized, and involve many intermediaries, they require an appropriate consolidation platform, where certain technologies, such as blockchain, could play a significant role. Indeed, as [26] argued, developing countries can benefit from the important features of blockchain technology, such as helping with the disintermediation and decentralization of existing markets and modes of governance and business to enforce sustainability standards. The Moroccan strawberry supply chain, for example, has experienced potential improvement proposals [27,28]. One of the objectives of these proposals is to measure the challenges and opportunities of implementing blockchain technology, focusing on remote auditing during the 2020 harvest season [27]. Due to increased awareness, people demand more sustainable compliance. Hence, the adoption of blockchain technology has become imperative to guarantee such activities for real-world practices. Nevertheless, blockchain implementation is still in the naive stage [2]. Therefore, addressing the barriers that influence blockchain adoption in Moroccan SSCM is urgently needed. Currently, it is evident from the available literature review that no study has investigated the blockchain adoption barriers in SSCM by applying the fuzzy group decision-making framework based on IFAHP and DEMATEL, particularly in the Moroccan context. This paper makes contributions in this direction. The methodology followed and its application are briefly introduced in the following sections.

3. Proposed Research Methodology

The manifold nature of the barriers influencing the adoption of blockchain technology in SSCM makes it a multicriteria decision problem. Analyzing a large number of interrelated barriers can be overwhelming. It is, therefore, necessary to define the relative impact of each barrier on the decision problem. In this context, MCDM methods are developed to tackle decisions that involve multiple, and usually conflicting, objectives. Such decisions often require trade-offs that can be assisted by these methods. These methods have characteristic strengths and weaknesses. However, certain features are common among these methods, such as conflicts between criteria and incomparable units, etc. [29].

Barrier analysis for blockchain adoption is a difficult problem to solve, especially when the number of barriers is large and the interactions are complex. Among the available MCDM techniques, one of the most important approaches is IFAHP integrating IFS to AHP (Analytical Hierarchy Process) [30], which is an extension of FAHP (Fuzzy AHP) and traditional AHP. In addition, DEMATEL (Decision Making Trial and Evaluation Laboratory) is also largely used [31]. The IFAHP technique is used to structure and assess factors systematically and rationally concerning their importance based on expert opinions. On the other hand, DEMATEL analyzes the interconnections between these factors and classifies them into cause and effect groups.

3.1. Intuitionistic Fuzzy AHP

Despite the popularity and simplicity of FAHP for handling fuzzy multicriteria decision-making problems, it is often criticized for its limitation of the fuzzy set itself. In fact, in fuzzy set theory, the membership function is a single-valued function that cannot be used to simultaneously express support, objection, and hesitation evidence in many practical situations [30]. For this reason, ref. [32,33] extended Zadeh's fuzzy set to IFS (Intuitionistic Fuzzy Set) for modeling human perception and cognition more comprehensively by integrating a membership, non-membership, and hesitancy function. In addition, other fuzzy set extensions have been proposed to remedy limitations, such as normalized interval-valued triangular fuzzy numbers [34], intuitionistic 2-tuple linguistic sets [35] and hesitant fuzzy sets [36]. In this study, an integrated IFS is presented as discussed in the following sub-section.

3.1.1. Intuitionistic Fuzzy Sets

This sub-section briefly examines the basic concept of the IFS and introduces the arithmetic operations in IFS, which are used throughout the rest of this study. IFS theory was proposed by [32] based on fuzzy set theory invented by Zadeh [37]. It considers the membership function and non-membership functions to describe any x in X. It is suitable for real-life problems, where complexity, hesitancy, vagueness, and uncertainty exist. In what follows, the basic definitions of IFS are specified [38,39].

Let $X \neq O$ be a given set, and A be an IFS in X, the object A can be given by the following:

$$A = [(x, \mu_a(x), v_a(x)) | x \,\epsilon\, X)] \tag{1}$$

where functions $\mu_A : X \longrightarrow [0,1]$ and $v_A : X \longrightarrow [0,1]$ represent the membership and non-membership degree of the element $x \,\epsilon\, X$ to the set A, respectively, and for all $x \,\epsilon\, X$:

$$\begin{array}{lc} & 0 \leq \mu_A(x) + v_A(x) \leq 1 \\ if & \{\langle x, \mu_A(x), 1 - \mu_A(x)\rangle | x \,\epsilon\, X\}; \\ & \pi_A(x) = 1 - \mu_A(x) - v_A(x), \end{array} \tag{2}$$

where $\pi_A(x)$ is the membership uncertainty degree of element $x \,\epsilon\, X$ to set A. Concerning ordinary fuzzy sets, $\pi_A(x) = 0$ for all $x \,\epsilon\, X$, some arithmetic operations in IFS are given below:

$$A_1 + A_2 = \{[x, \mu_{A_1}(x) + \mu_{A_2}(x) - \mu_{A_2}(x) * \mu_{A_2}(x), v_{A_1}(x) * v_{A_2}(x)] | x \,\epsilon\, X\}; \tag{3}$$

$$A_1 * A_2 = \{[x, \mu_{A_1}(x) * \mu_{A_2}(x), v_{A_1}(x) + v_{A_2}(x) - v_{A_1}(x) * v_{A_2}(x)] | x \epsilon X\}; \quad (4)$$

$$\lambda * A = \{\left[x, 1 - (1 - \mu_A(x))^{\lambda}, (\nu_A(x))^{\lambda}\right] | x \epsilon X\}; \quad (5)$$

3.1.2. Intuitionistic Fuzzy AHP Steps

In the current study, IFAHP is applied to compute the importance weight of all identified barriers that influence blockchain adoption. The steps of the IFAHP methodology are described below. The adopted methodology is a modified form of the concept provided in [30,39].

Step 1: Construct the structure of the hierarchy for the evaluation of the problem based on linguistic pairwise comparison matrices. Presumably, there are kth DMs and n criteria (barriers) to be assessed. The DMs fulfill these matrices, using the linguistic scale of Table 1 (linguistic data are transformed into an IF matrix) as defined below.

$$R^{(k)} = (r_{ij}^{(k)})_{n \times n} = \begin{pmatrix} r_{11}^{(k)} & r_{12}^{(k)} & \ldots & r_{1n}^{(k)} \\ r_{21}^{(k)} & r_{22}^{(k)} & \ldots & r_{2n}^{(k)} \\ \ldots & \ldots & & \ldots. \\ r_{n1}^{(k)} & r_{n2}^{(k)} & \ldots & r_{nn}^{(k)} \end{pmatrix} \quad (6)$$

where $r_{ij}^{(k)} = (\mu_{ij}^{(k)},\ v_{ij}^{(k)},\ \pi_{ij}^{(k)})$

Step 2: Estimate the importance weights of each DM. The expert's importance level is considered to be a linguistic variable (all DMs may not have the same assessment in the decision process). Let $D_k = [\mu_k, v_k, \pi_k]$ be an IFN for evaluating the k^{th} DM (see Table 2) and λ_k be the influence weight of each DM, the weight of the k^{th} DM can be computed using Equation (7).

$$\lambda_k = \frac{\mu_k + \pi_k(\frac{\mu_k}{\mu_k + v_k})}{\sum_{k=1}^{t}(\mu_k + \pi_k(\frac{\mu_k}{\mu_k + v_k}))} \quad (7)$$

where $\sum_{k=1}^{t} \lambda_k = 1, \lambda_k \epsilon [0, 1]$

Table 1. Linguistic terms and corresponding IFN for pairwise comparison. (modified from [39])).

Linguistic Terms/Variables	Abbreviations	IFNs (μ, v, π)	Reciprocal
Extreme poor/Extreme low	EP/EL	(0.05, 0.95, 0.00)	(0.95, 0.05, 0.00)
Very poor/Very low	VP/VL	(0.15, 0.8, 0.05)	(0.8, 0.15, 0.05)
Poor/Low	P/L	(0.25, 0.65, 0.1)	(0.65, 0.25, 0.1)
Medium poor/Medium low	MP/ML	(0.35, 0.55, 0.1)	(0.55, 0.35, 0.1)
Fair/Medium	F/M	(0.5, 0.4, 0.1)	(0.4, 0.5, 0.1)
Medium good/Medium high	MG/MH	(0.65, 0.25, 0.1)	(0.25, 0.65, 0.1)
Good/High	G/H	(0.75, 0.15, 0.1)	(0.15, 0.75, 0.1)
Very good/Very high	VG/VH	(0.85, 0.1, 0.05)	(0.1, 0.85, 0.05)
Extreme good/Extreme high	EG/EH	(0.95, 0.05, 0)	(0.05, 0.95, 0)

Table 2. Linguistic variables to evaluate the importance weights of decision makers [14].

Linguistic Variables	IFNs (μ, v, π)
Very important	(0.9, 0.05, 0.05)
Important	(0.75, 0.2, 0.05)
Medium	(0.5, 0.4, 0.1)
Unimportant	(0.25, 0.6, 0.15)
Very unimportant	(0.1, 0.8, 0.1)

Step3: Build the aggregated IF judgment matrix based on DMs opinions using IFWA (Intuitionistic Fuzzy Weighted Averaging) operator proposed by [40]. Let $R^{(k)} = (r_{ij}^{(k)})_{n\times n}$ be an IF decision matrix of the *kth* DM.

$$r_{ij} = IFWA_\lambda(r_{ij}^{(1)}, r_{ij}^{(2)}, \ldots, r_{ij}^{(t)}) = \lambda_1 r_{ij}^{(1)} \oplus \lambda_2 r_{ij}^{(2)} \oplus, \ldots, \lambda_t r_{ij}^{(t)}$$

$$= \left(1 - \Pi_{k=1}^{t}(1-\mu_{ij}^{(k)})^{\lambda_k}, \Pi_{k=1}^{t}(1-v_{ij}^{(k)})^{\lambda_k}, \Pi_{k=1}^{t}(1-\mu_{ij}^{(k)})^{\lambda_k} - \Pi_{k=1}^{t}(1-v_{ij}^{(k)})^{\lambda_k}\right) \quad (8)$$

The aggregated IF decision matrix can be defined as below:

$$R = \begin{pmatrix} r_{11} & r_{12} & \ldots & r_{1n} \\ r_{21} & r_{22} & \ldots & r_{2n} \\ \ldots & \ldots & & \ldots. \\ r_{n1} & r_{n2} & \ldots & r_{nn} \end{pmatrix} \quad (9)$$

where $r_{ij} = (\mu_{ij}, v_{ij}, \pi_{ij}), \mu_{ij} = 1 - \prod_{k=1}^{t}(1-\mu_{ij}^{(k)})^{\lambda_k}, v_{ij} = \prod_{k=1}^{t}(1-v_{ij}^{(k)})^{\lambda_k}$,
$\pi_{ij} = \prod_{k=1}^{t}(1-\mu_{ij}^{(k)})^{\lambda_k} - \prod_{k=1}^{t}(1-v_{ij}^{(k)})^{\lambda_k}, i, j \in N$

Step 4: Compute the criteria IF entropy weights, using Equations (10) and (11).

$$H_j = -\frac{1}{nln2}\sum_{i=1}^{n}[\mu_{ij}ln\mu_{ij} + v_{ij}lnv_{ij} - (1-\pi_{ij})ln(1-\pi_{ij}) - \pi_{ij}ln2] \quad (10)$$

Then W can be obtained as follows:

$$W_j = \frac{(1-H_j)}{(n - \sum_{i=1}^{n} H_j)} \quad (11)$$

Step 5: Rank the TEO barriers according to their priority weighting. The barriers' overall weights are obtained using the weights of the main dimensions multiplied by the local weights in the hierarchical structure.

3.2. DEMATEL

Being the most popular multi-criteria decision support methods in the literature, AHP, FAHP, and IFAHP are well-established approaches to structure and assess several defined factors and rank them concerning their priorities. Even so, they fail to address the interactions and relationships among these factors. Hence, we introduce the DEMATEL method as one of the most used multicriteria decision support techniques for assessing the complex interrelationships between evaluation factors.

The DEMATEL technique was first proposed in the Science and Human Affairs Program [31] of the Battelle Memorial Institute of Geneva. This technique aimed to settle the complicated and intertwined problem group [41]. It is a structural modeling technique that analyzes and diagnoses the inter-dependent relationships and the strengths of the influence between the significant factors (in this paper, barriers) through developing a cause-and-effect diagram known as a diagraph [42]. Many researchers apply the DEMATEL technique to examine and analyze complex problems in different domains.

The DEMATEL technique is summarized in the following steps [43,44]:

Step 1: Construct the initial direct-relation matrix and average matrix.

In this step, the experts are invited to assess the direct influence between any two barriers, using the scale given in Table 3. Let each expert's initial direct-relation matrix be given by $[a_{ij}^k]_{n*n}$, where 'a_{ij}' represents the degree to which the expert conceives barrier i to affect barrier j; then, the average direct influence matrix is given by Equation (12).

$$A = [b_{ij}] = \frac{\sum_{k=1}^{H} a_{ij}^k}{H} \tag{12}$$

where $i, j \epsilon \{1, 2, 3, ..., (n-1), n\}$, n represents the total number of barriers in the study, k is a number of an expert with $1 \leq k \leq H$ and H represents the total number of experts.

$$A = \begin{pmatrix} 0 & b_{12} & ... & b_{1(n-1)} & b_{1n} \\ b_{21} & 0 & ... & b_{2(n-1)} & b_{2n} \\ ... & ... & ... & ... & ... \\ b_{(n-1)1} & b_{(n-1)2} \; b_{(n-1)1} & ... & 0 & b_{(n-1)n} \\ b_{n1} & b_{n2} & ... & b_{n(n-1)} & 0 \end{pmatrix} \tag{13}$$

Step 2: Calculate the normalized initial direct relation matrix N using Equations (14) and (15).

$$N = A * S, \tag{14}$$

$$S = min\left[\frac{1}{max \sum_{j=1}^{n} |b_{ij}|}, \frac{1}{max \sum_{i=1}^{n} |b_{ij}|}\right] \tag{15}$$

where $i, j \epsilon \{1, 2, 3, \ldots, (n-1), n\}$, "$n$" denotes the number of barriers in the study.

Step 3: Develop the total relation matrix $T = [t_{ij}]_{n*n}$ using Equation (16).

$$T = N + N^2 + N^3 + ... + N^h = N(I - N)^{-1} \tag{16}$$

where $h \longrightarrow \infty$ and $'I'$ represents the identity matrix.

$$T = \begin{pmatrix} 0 & t_{12} & ... & t_{1(n-1)} & t_{1n} \\ t_{21} & 0 & ... & t_{2(n-1)} & t_{2n} \\ ... & ... & ... & ... & ... \\ t_{(n-1)1} & t_{(n-1)2} \; t_{(n-1)1} & ... & 0 & t_{(n-1)n} \\ t_{n1} & t_{n2} & ... & t_{n(n-1)} & 0 \end{pmatrix} \tag{17}$$

Step 4: Formulate the 'influence relationship'.

Let $R = [r_i]_{n*1} = [\sum_{j=1}^{n} t_{ij}]$ be the vector representing the sum of rows of matrix T and $C = [c_j]_{1*n} = [\sum_{i=1}^{n} t_{ij}]$ be the vector representing the sum of the columns. Using the values of $(R + C)$ and $(R - C)$, a degree of influence and a degree of relationship with others is defined. In fact, the sum $(r_i + c_j)$ presents the total effects given and received by barrier i (the higher this sum, the stronger the relationship with the other barriers and vice versa), and the difference $(r_i - c_j)$ presents the net effect that barrier i contributes to the system. More precisely, barrier i is a net cause group (has higher influence on others) on the condition that the value of $(r_i - c_j)$ is positive, whereas factor i is a net receiver group (tends to be influenced more from others) if $(r_i - c_j)$ is negative.

Step 5: Calculate the threshold value and construct the digraph.

Setting a threshold value helps the decision maker to determine the influence level and obtain an appropriate causal map. It can be determined by computing the average of the elements of the total-relation matrix T as threshold α, which is given by Formula (18). The elements, having an influence level in matrix T higher than the threshold α, are converted into the impact digraph (causality map or influence relationship map). This diagraph is reached by plotting the $(R + C, R - C)$ data set, where $(R + C)$ is taken as the x axis and $(R - C)$ as the y axis for each barrier.

$$\alpha = \frac{1}{n^2} \sum_{i=1}^{n} \sum_{j=1}^{n} t_{i,j} \tag{18}$$

Table 3. Influence scores for expert judgments (see [15]).

Linguistic Term/Variable	Influence Score
Very high influence	4
High influence	3
Low influence	2
Very low influence	1
No influence	0

4. Proposed Fuzzy Group Decision-Making Framework and Its Application

The EPI (Environmental Performance Index) [45], which is a global metric for the environment that ranks each country's performance on sustainability issues, proposes a quantitative basis to analyze, compares and comprehends the environmental performance of 180 countries. The rank is calculated using the environmental performance of each country with the available data. According to the EPI 2020 report, Morocco is ranked in the 100th position with an EPI score of 42.3 and a 10-year change score of 13.3, which reveals that there are significant chances of possible improvement in the Moroccan environmental sector [46]. Despite the lack of knowledge and competency in the Moroccan industry and service sectors for SSCM implementation, blockchain technology can decrease barriers toward achieving the sustainability goal of closing the lifecycle of the product [47]. Blockchain technology plays a notably important sustainability role by offering four capabilities to support sustainable supply chains [47]:

- Instigate ecological behavior;
- Enhance visibility all over the lifecycle of the product;
- Enhance systems and operations efficiency;
- Improve reporting and monitoring of sustainability.

The selection problem of blockchain technology is a highly critical and costly decision for businesses. Therefore, decision makers need to consider whether or not it should be applied. In this work, modeling the barriers influencing the implementation of blockchain technology in the Moroccan SSCM context is analyzed. The study proposes a fuzzy group decision-making framework, integrating IFAHP and DEMATEL techniques to assist decision makers in identifying, evaluating, and ranking the blockchain implementation barriers in SSCM of the Moroccan industry and service sectors. Although not completely inclusive, the proposed fuzzy group decision-making framework can offer a comprehensive collection of barriers that hinders the adoption of blockchain for Moroccan SSCM. Eventually, it brings out the interactions and relationships among those barriers. The reasons for combining IFAHP and DEMATEL in this contribution include the following:

- The interdependence of many barriers in the decision-making context.
- The difficulty to measure the subjectivity of barriers.
- The hybrid technique allows the barriers to be numerically measured.
- It tackles the inherent uncertainty and vagueness of certain decision-making problems.
- Based on the critical analysis of the literature, it is clear that the combined IFAHP-DEMATEL technique to analyze and assess the barriers that influence the blockchain adoption in SSCM has not been applied in the Moroccan industry and service sectors context.

Other details regarding the proposed fuzzy group decision-making framework are discussed in the following sub-sections.

4.1. Proposed Group Decision-Making Framework

The proposed fuzzy group decision-making framework combines IFAHP and DEMATEL techniques to identify and evaluate the blockchain implementation barriers. The proposed approach consists of three steps.

Step 1: Identify and select the main barriers and sub-barriers from literature resources and a pilot discussion with a group of experts. **Step 2:** Prioritize and assess the importance of each barrier by using the IFAHP technique. This prioritization would help to evolve the short-term decision-making strategies. **Step 3:** Analyze the causal interaction relationship between the different identified barriers, which would help to work out the long-term decision-making strategies.

The road map of the proposed fuzzy group decision-making framework is illustrated in Figure 1.

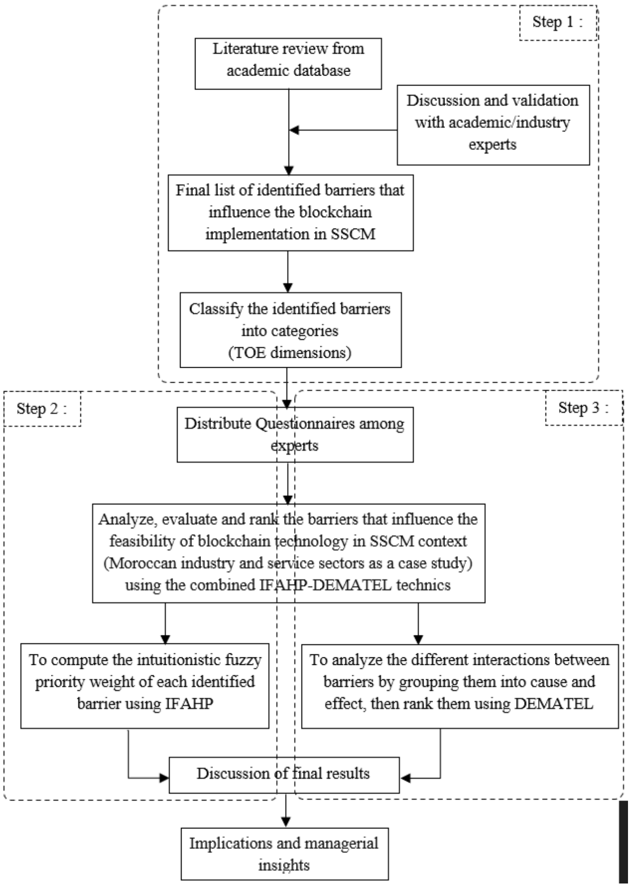

Figure 1. Proposed fuzzy group decision-making framework.

4.2. Data Collection

The novelty of blockchain and the rarity of real adoption of both blockchain technology and SSCM limit a large-scale study. Hence, a convenience specimen of respondents is selected, including those in industry and academics knowledgeable in blockchain technology and sustainable supply chain management, to help in identifying and evaluating the barriers that influence blockchain implementation in Moroccan SSCM.

The data collected for this study are based on a questionnaire [48] that is distributed to managers and academics deemed competent to complete it effectively, and whose minimum experience in the field of Moroccan supply chain management exceeded four years. For the questionnaire, a closed-questions strategy follows, where each question is followed by a set of MC (multiple choice) from which only one choice could be selected. This strategy helps to determine the response of managers concerning the influence score defined in Table 3. This questionnaire is designed for data collection and constructed based on a set of identified TEO barriers from a comprehensive literature search. These barriers are finalized through the viewpoints of experts from industry and academia (see Table 4 and Figure 2), who are asked to recommend the addition or removal of a barrier.

Table 4. Summary of main barriers and sub-barriers for blockchain adoption and related references.

Main Barriers	Sub-Barriers	References
Technological and System (TB)	Lack of scalability and system speed (TB1)	[2,15,49]
	Availability of specific blockchain tools (TB2)	[4,50]
	The complexity of blockchain-based system design (TB3)	[49,51]
	Security and privacy concern (TB4)	[4,50,52]
Environmental (EB)	Government policy and support (EB1)	[15,52,53])
	High sustainability costs (energy consumption and materials depletion) (EB2)	[54,55]
	Challenges in integrating sustainable practices and blockchain technology through SCM (EB3)	[53,56]
Intra-Organizational (OB)	SCM-Stakeholder resistance to blockchain culture (OB1)	[11], Experts opinion.
	Top management support and capability of human resources (OB2)	[2,52]
	Lack of new organizational policies for using blockchain technology (OB3)	[57,58]

Before data collection, the purpose and usefulness of the research is explained to each respondent. Additionally, the potential benefits of the research are highlighted. Later, experts are invited to assess the barriers that influence blockchain adoption in SSCM based on linguistic variables already presented in Tables 1–3. The current study used a non-probabilistic method for selecting the respondents. Managers from the top 20 firms were invited to fill the questionnaire. For this purpose, 20 people were invited from 7 industries working in the field of freight logistics and agriculture SCM, and 10 academicians, out of which only four (from three organizations) and three academicians accepted to participate with their anonymous opinion in our study. In this context, the questionnaire was as simplified as possible to assist the experts during the identification and evaluation process. For example, the experts were asked to assess the influence between each barrier by posing questions, such as what is the degree of influence that 'the complexity of blockchain-based system design' has on the 'availability of specific blockchain tools', taking into consideration the linguistic terms presented in Table 3?

The objective during the identification process is to reach a consensus between different experts regarding the barriers taken for the evaluation process. As a result, the expert responses were collected and examined carefully, which led to the finalization of ten crucial barriers considered to be the main TEO barriers to implementing blockchain technology in SSCM from the Moroccan industry and service sector perspective. The details of the identified barriers are presented in Table 4.

4.3. *Empirical Analysis*

4.3.1. IFAHP Process: Computing Relative Importance of Identified Barriers Using IFAHP

The implementation of blockchain technology in SSCM is challenging because it is very critical for an industrial company to identify and recognize real factors and barriers influencing its implementation. There are various uncertainties and risks in the evaluation of these barriers. Therefore, in this study, a linguistic evaluation scale is used to capture the uncertainty in integration with an intuitive fuzzy aspect of the IFAHP.

The main objective of the IFAHP process is to prioritize the identified barriers influencing the blockchain adoption in Moroccan SSCM, according to their relative importance weight. For this purpose, a hierarchical decision structure is established to analyze the problem. It is composed of three levels as shown in Figure 2. The highest level is occupied by the main objective, which also consists of three main barriers located at the second level, while the third level contains ten sub-barriers. For this, expert opinions are used regarding the rating of each barrier, compared to the other barriers through the proposed scale in Table 1.

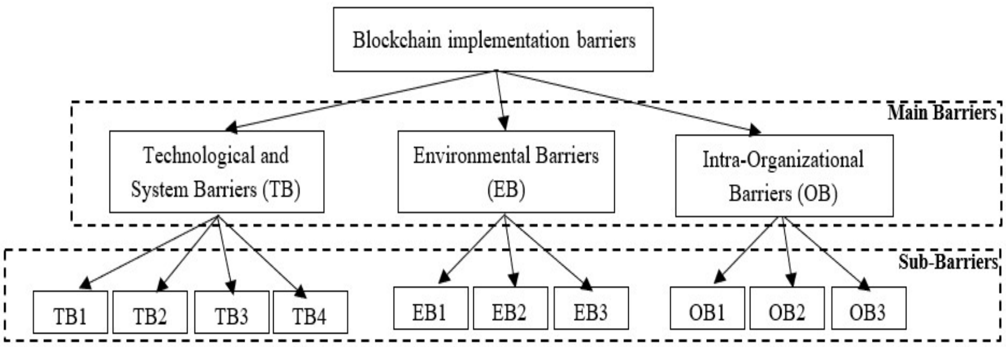

Figure 2. The hierarchical analysis model of the problem.

The barrier assessment procedure, using IFAHP, includes the following steps (where the focus is on the assessment of the main barriers located at the second level of the hierarchical structure presented in Figure 2).

Step 1. Compute the decision makers' weights based on the linguistic variables given in Table 2 . These weights are obtained using the Formula (7) as shown in Table 5.

Table 5. Importance of decision makers.

Decision Makers (D_k)	μ	**v**	π	λ_k
D1	0.75	0.2	0.05	0.146899
D2	0.9	0.05	0.05	0.176279
D3	0.5	0.4	0.1	0.103373
D4	0.75	0.2	0.05	0.146899
D5	0.75	0.2	0.05	0.146899
D6	0.5	0.4	0.1	0.103373
D7	0.9	0.05	0.05	0.176279

Step 2. Establish the aggregated IF judgment matrix based on all DMs' opinions and their weights, according to Equations (8) and (9).

(2a) The DMs' opinions on the relative importance of each criterion, using linguistic variables of Table 1, are presented in Table 6.

Table 6. The DMs judgments for the main barriers, using linguistic variables.

	D1			D2			D3			D4			D5			D6			D7		
Main Barriers	TB	EB	OB	TB	EB	OB	TB	EB	OB	TB	EB	OB	TB	EB	OB	TB	EB	OB	TB	EB	OB
TB	M	VH	EH	M	H	VH	M	MH	EH	M	H	VH	M	H	H	M	MH	H	M	EH	H
EB		M	H		M	VH		M	MH		M	M		M	H		M	MH		M	H
OB			M			M			M			M			M			M			M

(2b) The aggregated IF judgment matrix presented below is obtained by transforming linguistic variables of all DMs' opinions to IF numbers, then using Equations (8) and (9) as presented in Table 7.

Table 7. The aggregated IF judgment matrix.

Aggregate Matrix (r_{ij})									
Main Barriers	**TB**			**EB**			**OB**		
	μ	v	π	μ	v	π	μ	v	π
TB	0.5000	0.6000	−0. 1000	0.8300	0.8609	−0. 6909	0.8500	0.8874	−0.7374
EB	0.1391	0.1700	0.6909	0.5000	0.6000	−0.1000	0.7450	0.8089	−0.5539
OB	0.1126	0.1500	0.7374	0.1911	0.2550	0.5539	0.5000	0.6000	−0.1000

Step 3. Compute the IF entropy weights and final entropy weight of the main barriers, using Equations (10) and (11) as shown in Table 8. The illustrative priority distribution of the main barriers is shown in Figure 3.

Table 8. IF entropy weights and final entropy weight for main barriers.

IF Entropy Weight			**Final Entropy Weight**	
H1	0.9958	...	W1	0.3588
H2	0.9955	...	W2	0.3850
H3	0.9970	...	W3	0.2562

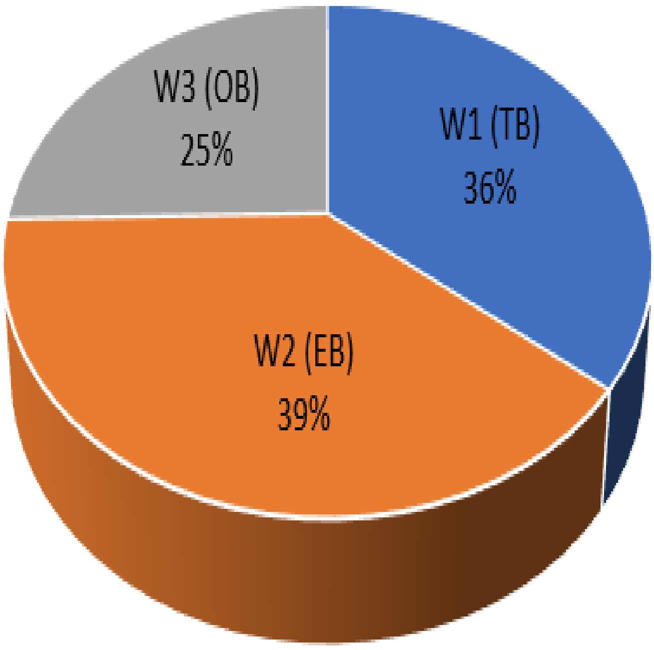

Figure 3. Priority distribution for main barriers.

By continuing the same calculation steps of the IFAHP process (steps 1, 3 and 4) for all sub-barriers, the final obtained results are presented in Table 9 (see Appendix A, Tables A1–A9 for all sub-barriers evaluation steps).

Table 9. Final importance weights of all barriers.

Main Barriers	Relative Weights	Sub-Barriers	Relative Weights	Global Weights	Final Rank
Technological and system	0.3581	TB1	0.2232	0.0799	9
		TB2	0.2489	0.0891	8
		TB3	0.2696	0.0965	5
		TB4	0.2583	0.0925	7
Environmental	0.3883	EB1	0.4335	0.1683	1
		EB2	0.2621	0.1018	4
		EB3	0.3044	0.1182	2
Intra-organizational	0.2536	OB1	0.3743	0.0949	6
		OB2	0.2135	0.0541	10
		OB3	0.4122	0.1045	3

4.4. DEMATEL Process: Determining Interdependence among Identified Barriers

To establish the interdependence between the identified barriers influencing the blockchain adoption about a causal effect relationship, the DEMATEL method is used. To begin with the process, the same experts are asked to assess the blockchain adoption barriers on a scale of 0–4 (Table 3).

The main barriers are evaluated initially. After receiving the expert's responses, the initial direct-relation matrix $[a_{ij}^k]_{n*n}$ is constructed (see Table A10 Appendix B). As illustrated in Table 10, the average matrix $(A = [b_{ij}])$ is built, using Formula (12) based on the calculation of the average of the expert's reply. Next, the normalized initial direct-relation matrix (N) (see Table 11) is developed based on Equations (14) and (15). Further, we obtain the total relation matrix (T) by applying Equation (16) as shown in Table 12. Next, based on Table 12, a causal digraph and a relationship diagram is created in $(r_i + c_i, r_i - c_i)$ as illustrated in Figure 4.

Table 10. Average direct-relation matrix (main barriers).

Main Barriers	TB	EB	OB
TB	0.0000	2.8571	2.0000
EB	3.0000	0.0000	2.2857
OB	2.0000	1.8571	0.0000

Table 11. Normalized direct-relation matrix (N).

	TB	EB	OB
TB	0.0000	0.5405	0.3784
EB	0.5676	0.0000	0.4324
OB	0.3784	0.3514	0.0000

Table 12. Total relation and direct–indirect influence matrix (main barriers).

	TB	EB	OB	Sum Ri	Ri + Ci	Ri−Ci	Group
TB	2.6211	2.8757	2.6137	8.1104	16.3207	−0.0998	effect
EB	3.1221	2.6585	2.7634	8.5440	16.4517	0.6363	cause
OB	2.4671	2.3735	1.9599	6.8005	14.1374	−0.5365	effect
Sum Cj	8.2102	7.9077	7.3369	Threshold α:		2.6061	

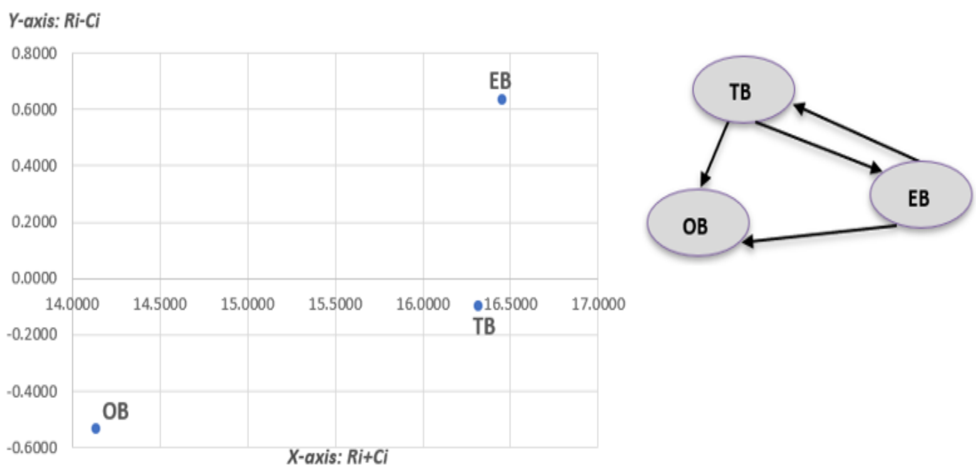

Figure 4. The causal digraph and relationship diagram (main barriers).

Similarly, the same DEMATEL calculation steps are executed for all sub-barriers as presented in Tables 13–15. In Appendix B, the causal effect graphs for the sub-barriers are also displayed in Figures A1–A3.

Table 13. Total relation and direct–indirect influence matrix for environmental sub-barriers.

	EB1	EB2	EB3	Sum Ri	R + C	R−C	Group
EB1	2.3536	2.6107	2.3576	7.3220	14.3956	0.2484	cause
EB2	2.2967	1.9060	1.9780	6.1807	12.9473	−0.5859	effect
EB3	2.4232	2.2498	1.8217	6.4947	12.6520	0.3375	cause
Sum Cj	7.0736	6.7666	6.1573	α:		2.2219	

Table 14. Total relation and direct–indirect influence matrix for technological and system sub-barriers.

	TB1	TB2	TB3	TB4	Sum Ri	R−C	R-C	Group
TB1	0.6474	0.9942	0.8662	0.7116	3.2194	6.3020	0.1367	cause
TB2	0.4650	0.3944	0.4113	0.3749	1.6456	5.3222	−2.0309	effect
TB3	0.9717	1.1127	0.7075	0.8391	3.6311	6.6172	0.6449	cause
TB4	0.9986	1.1753	1.0011	0.6386	3.8136	6.3778	1.2493	cause
Sum Cj	3.0827	3.6766	2.9861	2.5642	α:		0.7694	

Table 15. Total relation and direct–indirect influence matrix for intra-organizational sub-barriers.

	OB1	OB2	OB3	Sum Ri	R + C	R−C	Group
OB1	1.4191	1.4748	1.7626	4.6565	9.4784	−0.1655	effect
OB2	1.4119	1.0504	1.4748	3.9371	8.1817	−0.3076	effect
OB3	1.9910	1.7194	1.6403	5.3507	10.2284	0.4730	cause
Sum Cj	4.8219	4.2446	4.8777	α:		1.5494	

5. Results and Discussion

This section presents the application results of the proposed fuzzy group decision-making framework. Then, the implications and managerial insights of these results are presented, and effective ways to mitigate those barriers are suggested.

5.1. IFAHP Results

The objective of the IFAHP process is to compute the priorities of barriers affecting blockchain adoption and help decision-makers devise flexible short-term decision-making measures by considering the imprecision with the innate linguistic nature of the problem. As given in Table 9, the global importance weights of the main barriers and sub-barriers are calculated. The sub-barriers global weights are computed by multiplying their relative importance weights with the importance weights of their respective main barriers.

The potential rank reversal phenomenon is an inconsistency that occurs in many MCDM methods, especially AHP, which gives a wrong viewpoint concerning the impending decision. After conducting several experiments as a sensitivity analysis, it is observed that the proposed group decision-making framework does not incur any rank reversal during the analysis process.

The results of the IFAHP process (Table 9 and Figure 3) indicate that the environmental main barrier (EB) obtains the highest priority, as it holds the first rank with the most important weight of ‘0.3883’ among the other main barriers. This explains that the decision makers give more attention to the impacts of environmental and governmental barriers. The global importance weights of the three environmental sub-barriers ‘EB1: 0.1683’, ‘EB2: 0.1018’ and ‘EB3: 0.1182’ explain this concern. The second priority rank is occupied by the technological main barrier (0.3581), which is focused on concerns regarding the availability, complexity, security, and privacy of blockchain adoption in Moroccan SSCM. The priority distribution for the four technological and system sub-barriers ‘TB1: 0.0799’, ‘TB2: 0.0891’, ‘TB3: 0.0965’ and ‘TB4: 0.0925’ illustrates this preoccupation. The intra-organizational main barrier holds the last rank, and so, occupies the lowest priority (0.2536), due to the sustainable nature of our case study, even though the global weight of the single intra-organizational sub-barrier ‘OB3: Lack of new organizational policies for using blockchain technology’ is more important, compared to the technological sub-barriers global weights, as it holds the third global rank with an importance weight of ‘0.1045’.

5.2. DEMATEL Results

The DEMATEL method can trace the degree of influence and relationship between the identified barriers, which is not possible in the IFAHP method, as it only computes the importance/priorities of barriers affecting blockchain adoption.

Depending on the DEMATEL process results (Table 12 and Figure 4), the environmental main barrier (EB) tends to cause group barriers, as the score of $(r - c)$ is positive and equals 0.6363. Accordingly, its influence on the other main barriers is very important. EB turns out to be a decisive barrier for the implementation of blockchain technology in the Moroccan SSCM context. The three sub-barriers linked to this main barrier arranged regarding their $(r + c)$ score (see Table 13) are 'EB1: Government policy and support' $>$ 'EB2: High Sustainability Costs [Energy consumption and materials depletion]' $>$ 'EB3: Challenges in integrating sustainable practices and blockchain technology through SCM'. Further, depending on the values of $(r - c)$, sub-barriers EB1 and EB3 relate to the cause group, whereas EB2 appertains to the effect group. Hence, it is essential to concentrate on the barriers of the cause group that has the potential to immediately affect the other barriers.

According to the findings of the current study, the technological and system main barrier (TB) is placed in the effect group barriers. Within this main barrier, there are four sub-barriers arranged based on their $(r + c)$ score, namely 'TB3: The complexity of blockchain-based system design' $>$ 'TB4: Security and privacy concern' $>$ 'TB1: Lack of scalability & System Speed' $>$ 'TB2: Availability of specific blockchain tools' as shown in Table 14. The sub-barriers TB1, TB3, and TB4 are classified in the cause group barriers, which means that they have a high influential impact over the other sub-barrier, TB2, in the effect group.

The third rank, according to the $(r + c)$ score of the main barriers, is occupied by the intra-organizational main barrier (OB), also placed in the effect group barriers. Within this main barrier, which is highly influenced by the other barriers, as shown in the causal digraph and relationship diagram (Figure 4), there are three sub-barriers also arranged based on their $(r + c)$ score. The barriers are 'OB3: Lack of new organizational policies for using blockchain technology' $>$ 'OB1: SCM-Stakeholder resistance to blockchain culture' $>$ 'OB2: Top management support and capability of human resources' (see Table 15). Sub-barrier O3 appears in the cause group with an important influence on the sub-barriers OB1 and OB2 appertaining to the effect group.

As already presented in Table 12, the significant influence (influence level) of the main barriers is illustrated, using a threshold value, i.e., an average of elements in the 'total influence matrix' as explained in step 5 of Section 3.1.2. This value, in our study, was 2.6061 for the main barriers. The most significant relationship is the one with the influence value that is more important than this threshold value (see Table 12 and Figure 4).

5.3. Implications and Managerial Insights

The investigated barriers in this study for blockchain implementation in SSCM are exploratory; yet, they provide policymakers and supply chain managers opportune information to start organizing plans to settle barriers allied to the adoption of blockchain technology.

As blockchain technology is in the naive phase, its implementation rate in SSCM is lower than other areas[2,31]. The results of this study revealed that 'government policy and support' and 'challenges in integrating sustainable practices and blockchain technology through SCM' are significant barriers to the adoption of blockchain in SSCM, which is in line with the survey carried out on blockchain technology in 2020 by Deloitte [49]. In this context, it is recommended to define an appropriate government regulation concerning the adoption of blockchain. In the Moroccan context, as the country still bans cryptocurrencies, it is beginning to support professional or institutional blockchains [59]. However, the Moroccan government must put in place more efforts at the national and international levels to help public and professional organizations accept this emerging technology. On the business side, the findings of this study advise managers of the need to recruit associates and partners in their supply chains to ensure broad and more efficient blockchain adoption. It is necessary to convince, encourage and find creative approaches and solutions to support partners to join consortia or collaborate, such as the example of 'Messem International' company [60], which is the fruit of a partnership bringing together Morocco with partners in the Netherlands. This company plans to implement blockchain technology to trace its frozen strawberry products made in Morocco, which are then sent to the Netherlands for storage before being shipped worldwide [28].

The expanded international use of blockchain technology can be a catalyst for adoption; notably so since most sustainable supply chains are not geographically insulated but are connected to the world via trade, which can help SC-stakeholders to gain trust in using blockchain and mitigate the uncertainty about this emerging technology. In the same context, as blockchain technology is very immature and needs time for development, blockchain technical developers are expected to come with a solution to settle all security and privacy issues to reduce blockchain complexity and increase consumer satisfaction.

6. Conclusions and Future Work

This study proposes a support solution for helping decision makers to analyze and evaluate the feasibility of blockchain technology in SSCM from the Moroccan industry and service sector perspective. This solution consists of a fuzzy group decision-making framework based on the integration of IFAHP and DEMATEL to identify, categorize and assess blockchain adoption barriers for SSCM. Given the overall interest in blockchain technology, the proposed fuzzy group decision-making framework can be utilized as an evaluation tool for future blockchain initiatives in the Moroccan SSCM.

As the first step to constructing this framework, a comprehensive literature search and experts' viewpoints on the most significant blockchain adoption barriers (a total of ten barriers were identified) are leveraged. Currently, it is clear from the available literature review that no study has investigated the blockchain adoption barriers in the Moroccan SSCM context apart from cryptocurrencies, and none has applied the fuzzy group decision-making framework based on the integration of IFAHP and DEMATEL. The current study makes contributions in this direction.

According to the analysis and evaluation results, the obtained IFAHP results are often considered to form short-term decision-making strategies by determining the importance/priorities of the identified barriers affecting blockchain adoption. On the other hand, the DEMATEL results based on the analyzed causal diagrams might enhance the decision-making effects for a longer period, which is achieved by evaluating the complex interrelationships among the barriers and classifying them as cause and effect clusters.

The main benefit of combining IFAHP and DEMATEL is that the decision support process can be continuously improved from short and long period perspectives. Consequently, these results can be compared, for example, to other solutions and approaches dealing with blockchain adoption barriers as presented in the literature review section, such as [11–13].

However, this paper was not exempt from limitations since it used a limited number of experts; this paves the way for future studies to use a significant number of decision makers to confirm the validity of the study. In addition, the DEMATEL method can be extended to Intuitionistic Fuzzy (e.g., type-2 fuzzy sets, hesitant fuzzy sets, neutrosophic sets) DEMATEL to model human perception and cognition more comprehensively when evaluating blockchain adoption barriers in the context of the DEMATEL analysis process. Moreover, future research may consider extending the proposed framework by including more significant sustainable barriers, and the results can then be compared with this study.

As another perspective, we are developing a web-based IFGDM framework integrating all the functionalities of the proposed framework to assist the participants involved in this decision-making process and simplify the decision-making task. Finally, this study concludes that, while various opportunities and benefits are provided by blockchain technology, several challenges remain unresolved, demanding more technical developments and appropriate government regulations before governments can embark on such a project.

Author Contributions: Conceptualization, O.B. and M.H.; data curation, E.L. and F.E.B.; formal analysis, E.L. and I.A.; funding acquisition, E.L.; investigation, F.E.B., M.H. and M.N.; methodology, F.R., O.B. and M.N.; project administration, F.R.; resources, F.E.B.; software, F.R. and M.N.; supervision, I.A.; visualization, O.B.; writing—original draft, M.H.; writing—review and editing, I.A. All authors have read and agreed to the published version of the manuscript.

Funding: This research was supported by the Florida Center for Advanced Analytics and Data Science funded by Ernesto.Net (under the Algorithms for Good Grant).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

Appendix A

Appendix A.1. Computation Steps (in Order) for Environmental Sub-Barriers

Table A1. The DMs judgments for the environmental sub-barriers using linguistic variables.

	D1			**D2**			**D3**			**D4**			**D5**			**D6**			**D7**		
Sub-Barriers (EB)	EB1	EB2	EB3	EB1	EB2	EB3	EB1	EB2	EB3	EB1	EB2	EB3	EB1	EB2	EB3	EB1	EB2	EB3	EB1	EB2	EB3
EB1	M	H	VH	M	MH	H	M	MH	EH	M	H	VH	M	L	H	M	MH	H	M	EH	H
EB2		M	H		M	VH		M	MH		M	L		M	ML		M	MH		M	H
EB3			M			M			M			M			M			M			M

Table A2. The aggregated IF judgment matrix.

	Aggregate Matrix (rij)								
Sub-Barriers (EB)	EB1			EB2			EB3		
EB1	0.5346	0.6000	−0.1346	0.7484	0.7253	−0.4736	0.8178	0.8744	−0.6922
EB2	0.3045	0.2516	0.4439	0.5000	0.6000	−0.1000	0.6688	0.6689	−0.3377
EB3	0.1356	0.1822	0.6822	0.3311	0.3312	0.3377	0.5000	0.6000	−0.1000

Table A3. IF entropy weights and final entropy weight for environmental sub-barriers.

IF Entropy Weight		**Final Entropy Weight**	
H1	0.9962	W1	0.43348822
H2	0.9977	W2	0.26206987
H3	0.9974	W3	0.30444191

Appendix A.2. Computation Steps (in Order) for Technological and System Sub-Barriers

Table A4. The DMs judgments for the technological and system sub-barriers using linguistic variables.

	D1				**D2**				**D3**				**D4**				**D5**				**D6**				**D7**			
Sub Barriers	TB1	TB2	TB3	TB4	TB1	TB2	TB3	TB4	TB1	TB2	TB3	TB4	TB1	TB2	TB3	TB4	TB1	TB2	TB3	TB4	TB1	TB2	TB3	TB4	TB1	TB2	TB3	TB4
TB1	M	VH	M	MH	M	H	MH	H	M	EH	ML	H	M	H	M	MH	M	VH	MH	MH	M	VH	H	MH	M	EH	H	MH
TB2		M	L	VL		M	VL	L		M	ML	MH		M	L	L		M	ML	L		M	MH	M		M	H	MH
TB3			M	L			M	M			M	M			M	H			M	MH			M	MH			M	M
TB4				MH				M				M				M				M				M				M

Table A5. The aggregated IF judgment matrix.

	Aggregate Matrix (rij)											
Sub Barrier	**TB1**			**TB2**			**TB3**			**TB4**		
TB1	0.9759	0.9358	0.4323	1.0000	0.4425	0.2536	0.9947	0.8639	0.4323	0.9979	0.7428	0.4323
TB2	0.4425	1.0000	0.2960	0.9802	0.9273	0.4323	0.9542	0.9896	0.4025	0.9403	0.9903	0.4076
TB3	0.8639	0.9947	0.4323	0.9870	0.9542	0.4025	0.9759	0.9358	0.4323	0.9881	0.9254	0.4323
TB4	0.7428	0.9979	0.4323	0.9903	0.9403	0.4076	0.9254	0.9881	0.4323	0.9759	0.9358	0.4323

Table A6. IF entropy weights and final entropy weight for technological and system sub-barriers.

IF Entropy Weight		Final Entropy Weight	
H1	0.250402	W1	0.2231907
H2	0.164059	W2	0.2488988
H3	0.094578	W3	0.2695867
H4	0.132405	W4	0.2583238

Appendix A.3. Computation Steps (in Order) for Intra-Organizational Sub-Barriers

Table A7. The DMs judgments for the intra-organizational sub-barriers using linguistic variables.

	D1			D2			D3			D4			D5			D6			D7		
Sub Barrier	OB1	OB2	OB3	OB1	OB2	OB3	OB1	OB2	OB3	OB1	OB2	OB3	OB1	OB2	OB3	OB1	OB2	OB3	OB1	OB2	OB3
OB1	M	M	VL	M	ML	L	M	MH	H	M	H	M	M	MH	L	M	MH	M	M	M	EL
OB2		M	L		M	ML		M	MH		M	M		M	VL		M	MH		M	L
OB3			M			M			M			M			M			M			M

Table A8. The aggregated IF judgment matrix.

	Aggregate Matrix (rij)								
Sub-Barriers	OB1			OB2			OB3		
OB1	0.5000	0.6000	−0.1000	0.5831	0.6496	−0.2326	0.4021	0.2975	0.3004
OB2	0.3504	0.4169	0.2326	0.5000	0.6000	−0.1000	0.4005	0.4270	0.1725
OB3	0.7025	0.5979	−0.3004	0.5730	0.5995	−0.1725	0.5000	0.6000	−0.1000

Table A9. IF entropy weights and final entropy weight for intra-organizational sub-barriers.

IF Entropy Weight		Final Entropy Weight	
H1	0.9944	W1	0.37428037
H2	0.9968	W2	0.21351668
H3	0.9938	W3	0.41220295

Appendix B

Table A10. The initial direct-relation matrix for main barriers using influence scores of Table 3.

Main Barrires	TB							EB							OB						
	D1	D2	D3	D4	D5	D6	D7	D1	D2	D3	D4	D5	D6	D7	D1	D2	D3	D4	D5	D6	D7
TB	0	0	0	0	0	0	0	2	3	3	2	3	4	3	2	2	3	1	2	2	2
EB	3	2	4	3	3	4	2	0	0	0	0	0	0	0	3	2	2	2	2	3	2
OB	2	2	3	2	1	1	3	1	2	2	1	2	3	2	0	0	0	0	0	0	0

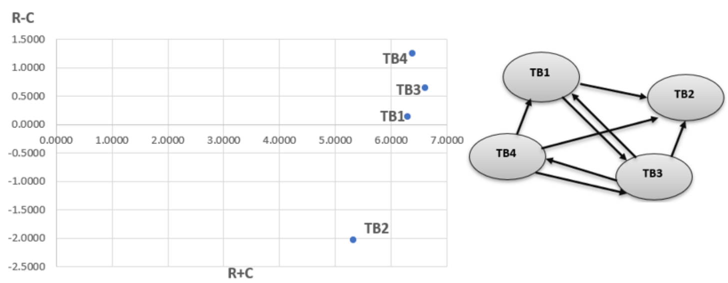

Figure A1. The causal effect graph for the technological and system sub-barriers.

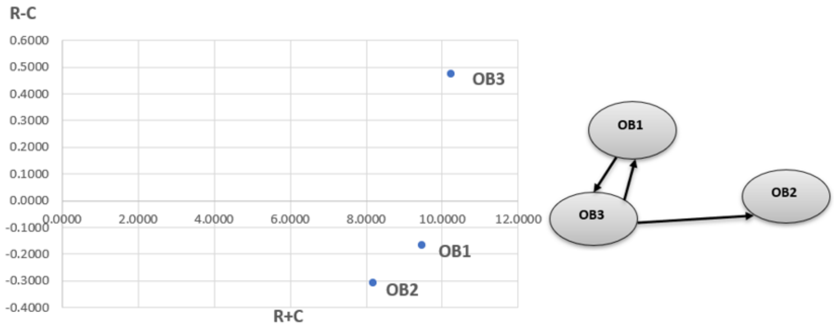

Figure A2. The causal effect graph for the intra-organizational sub-barriers.

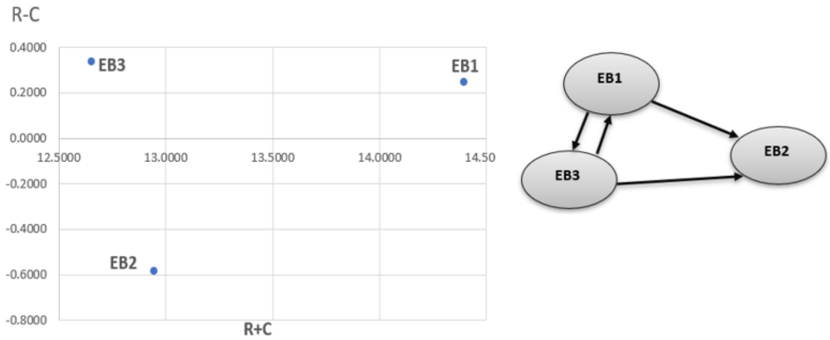

Figure A3. The causal effect graph for the environmental sub-barriers.

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