Sustainable Management of the Supply Chain Based on Fuzzy Logic

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Abstract

Companies face a number of management challenges, and decision makers must adopt new approaches that consider sustainable development in their operations. In this context, the article aims to address sustainable supply chain manage-ment and propose solutions based on a fuzzy logic. Three dis-tance measurement algorithms are applied to evaluate and classify suppliers in a consumer goods industry. The results demonstrate the usefulness of the algorithms in decision-mak-ing and bring a contribution to the sustainable development of companies. Furthermore, it supports future studies on sus-tainable management, the supply chain, and the application of algorithms to sustainability.

Keywords

Adequacy Ratio; decision-making process; fuzzy logic; Hamming Distance; OWA Operators; supply chain; sustainability; sustainable management

Introduction

In 1987, it was established that "the sustainable development must meet the current needs without compromising the future of the next generations" (World Commission on Environment and Development (WCED)) 1987). The need to promote sustainable economic development (Dhahri and Omri 2018) is a challenge for private corporations. Companies that seek to include corporate social responsibility (CSR) (Song, Wang, and Zhu 2018) in their strategies must focus on managing issues such as human rights, labor relations, the environment, and the fight against corruption, not only within their organizations in their supply chain (Mota et al. 2018).

In recent years, the supply chain (Barbosa-Póvoa, da Silva, and Carvalho 2018; Castillo et al. 2018; Dania, Xing, and Amer 2018) is one of the areas that are the most exposed to the stakeholders"awareness (Freeman et al.

2010; Porter & Kramer 2011), especially in the way in which products and services are considered, and the social and environmental impacts of their activity (Soundararajan and Brown 2016). Companies are also aware of their responsibility for their chain of value creation (Hart and Milstein 2003) and the importance of this in their responsible and sustainable behavior (Yin, Qian, and Singhapakdi 2018). They are extending the scope of application of their codes of conduct to their suppliers (Egels-Zandén 2017).

In this context, the challenge for organizations to manage their suppliers taking sustainable development as a reference when buying products and services. Additionally, the stakeholder theory states that a company to generate value and wealth sustainable over time, its determined by relationships with stakeholders (Freeman et al. 2010) which reinforces the importance of supplier management.

This article aims to address the sustainable management of the supply chain and to propose solutions based on fuzzy logic. In addition, the manuscript broadens the discussion on the importance of the supply chain, CSR, and brings solutions toward sustainable development. One motivation is to present alternatives tools for decision-making can improve the management of companies, increase transparency, productivity, and achieve sustainable development.

The contribution of this document includes a bibliometric study and identifies a gap in the literature regarding the link between "fuzzy logic" and "sustainability." Therefore, the objective is to reduce this gap, advance the frontier of knowledge, and collaborate with applied science. It also shows tools for decision-making to consider supply chain sustainability criteria to evaluate and select suppliers. In addition, the paper supports future studies on sustainable management, supply chain, fuzzy logic, and sustainability. The methodology of the study is based on applied research, with a quantitative approach modeling and simulation (Will M. Bertrand and Fransoo 2002).

This paper is organized as follows. First of all, it presents the criteria for evaluating suppliers. Second, it shows a study on supply chain impact. Third, it presents a bibliometric study on fuzzy logic and sustainability. Fourth, it explains the origin of Fuzzy Logic and its importance for applied science. Fifth, it describes three models based on Fuzzy Logic: Hamming Distance, Adequacy Ratio, and OWA Operators. Sixth, it applies the algorithms to evaluate suppliers in a consumer goods industry, considering the ten GC's principles. Finally, it presents the conclusions of the study, followed by references.

Criteria for Evaluating Suppliers

In this section, we present a theoretical framework on the criteria for evaluating suppliers, including the importance of GC's Principles and the algorithms of fuzzy logic as a tool in decision-making.

According to Barcellos de Paula (2011) sustainable purchasing refers to the strategy of acquiring goods or services in which various ethical, labor, economic, social, and environmental aspects are taken into account in the supply chain. The purchasing department must verify the utility of the acquisition in which the products are chosen under specific environmental and social requirements. On the other hand, the choice of suppliers must go beyond the selection and evaluation based solely on economic performance and integrate into this decision-making compliance with sustainability requirements that it considers appropriate and that exceed the applicable legal requirements. In this sense, the company encourages its suppliers to adopt common values in the process of continuous improvement toward sustainable development.

In the other hand, existing standards guide companies on the management tools used to ensure sustainable development planning. Therefore, compliance with standards is also part of the organizations' strategy (A. Gil-Lafuente and Barcellos de Paula 2011). Companies should analyze their strategy and decide which criteria they will use to select their suppliers. As indicated by the same authors, there is a set of standards that are published by official standards organizations that include ISO 14000 (environment), ISO 9000 (quality), EC EMAS (environment), BS 8800 (working conditions), and BS 8855 (environment). On the other hand, there is a set of standards that the market encourages its creation in areas such as safety and working conditions, social responsibility, among others. In this case, the ISO 26000 (social responsibility), SA 8000 (social rights), OHSAS 18001 (risks/accidents), ISO 45001 (health and safety at work), and AA 1000 (responsibility) are the most important (A. Gil-Lafuente and Barcellos de Paula 2011).

Several companies set criteria for selecting their suppliers. In general, companies certified with ISO 9000, ISO 14000, OSHAS 18001, ISO 45001, and SA8000 are valued. In addition, companies use other parameters to manage their supplier chain, such as the ISO 26000, the Global Compact Principles, the 17 Sustainable Development Objectives, the Global Reporting Initiative (GRI) sustainability reports. Depending on the sector in which a company operates, it can demand from its supplier specific certificates such as fair trade, organic product, and Kosher. In this way, companies seek to guarantee the quality of their raw materials, food safety, legal, and ethical compliance. As a result, "the sustainable management of suppliers leads to improve quality, competitiveness, cost reduction, technological advances, increase control over risk in the supply chain, and favor corporate reputation” (L. B. d. Paula and Rocha 2017).

For Porter and Kramer (2011), the creation of shared value is the policies and practices that strengthen the competitiveness of the company and improve the economic and social conditions of the communities they operate. According to the same authors, shared value is created through the redesign of products and markets, redefinition of productivity in the value chain, and development of support policies for clusters at the company’s locations. This sustainability strategy brings economic, social and environmental benefits, both for the company and for its stakeholders that is, the suppliers and the community. To create shared value, the company must evaluate its suppliers and integrate in this decision making the compliance with the appropriate sustainability requirements that exceed the applicable legal requirements. To achieve these goals, the company must establish a system for diagnosing and classifying suppliers according to the different levels of risk. Likewise, the organization establishes a supplier evaluation methodology based on the previously identified and defined responsible purchasing criteria that progressively cover the different risk groups detected. The company that develops a code of conduct to evaluate and select its suppliers can take into account environmental aspects, human rights, health and safety at work, labor standards, and employment practices.

Several companies currently adopt the 10 principles of the Global Compact (GC) (Hermansen, Mølmen-Nertun, and Pollestad 2008) by establishing the code of conduct for their suppliers. In this approach, “companies are asked to adopt, support and discuss, within their sphere of influence, a set of values within the areas of Human Rights, Labor Relations, Environment and Fight against Corruption” (United Nations 2008). The challenge for the company is to know the degree of compliance with the code of conduct by suppliers in each area and, based on the results, to decide what actions and initiatives to follow and the best way to manage them. This process of supplier management highlights the need to establish relationships between different concepts for different levels of compliance with the analyzed variables and to obtain the corresponding affinities between the different suppliers in relation to the degree of compliance with the code of conduct of the same.

For these reasons, this article includes a useful tool to help decision makers to evaluate their suppliers based on the GC’s principles (Vasavada and Kim, 2017). The use of fuzzy logic is proposed as a tool, and for this study we apply three algorithms: Hamming Distance, Adequacy Ratio and OWA Operators. The purpose for using these algorithms is reinforced by the excellent results obtained in other studies (Gil-Aluja 1999; Merigó and Gil-Lafuente 2011), and also by the gap identified in this issue.

It is essential to mention that this manuscript is an extended version and comes from a previous study (Barcellos de Paula and Gil-Lafuente 2018). According to the results, the company will be able to know its leading suppliers through a performance ranking and develop a supplier development plan. In this way, the company is expected to achieve a sustainable management of its supply chain. Some authors have recommended the use of fuzzy logic to evaluate and select suppliers (Özkır and Başlıgil 2013). In fact, fuzzy logic has assisted researchers to choose a more practical approach to the selection of green suppliers (Yu and Hou 2016), facilitate management and decision making in the supply chain (Sari 2013), helping to reduce costs and risks (Kayvanfar et al. 2018).

A Study on Supply Chain Impact

This section shows a study on the impact of the supply chain of a consumer goods industry. The results reinforce the motivation of this manuscript and indicate its importance for companies, society and academia.

Until a few years ago, the way companies operated were restricted to offer a good and safe product, but now sustainable consumption is pushing forward the industry and transforming the way business is done. Consumers want to know the manufacturing and distribution process, and mainly, they value the principles of social and environmental responsibility. In recent years, the market demands more transparency and, therefore, the visibility and importance of the role of supply chains within companies increased.

In this context, companies have to improve control methods because the impacts and the most significant sustainability problems are in the supply chain. Climate change, water scarcity, food waste, child labor, and inequality are some of the challenges that oblige a new attitude in how businesses operate. Therefore, new strategies become essential for long-term value creation. Retailers and manufacturers must collaborate to improve supplier operations, with better information and more transparency. In this way, they can create programs to reduce impacts and rethink production and consumption throughout the value chain (The Sustainability Consortium 2016).

Essential institutions, concerned with this issue in the supply chains of consumer goods, help companies to manage the main environmental and social problems of their products. For example, since 2009, a global non-profit organization called The Sustainability Consortium (TSC) has been working with multi-stakeholder groups, consisting of companies,

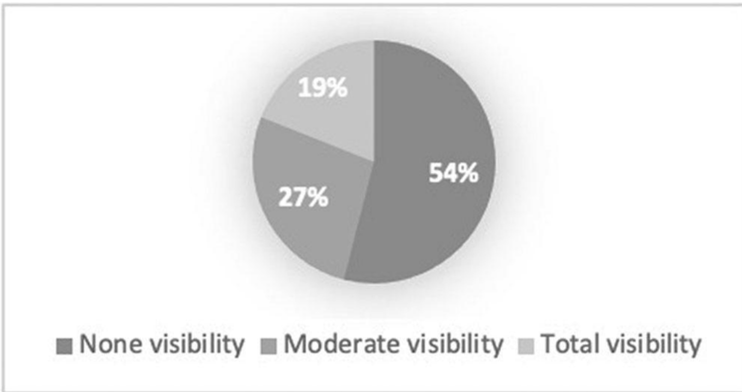

Figure 1. Visibility into supply chains. Source: Own elaboration based on TSC (2016).

governments, universities and nongovernmental organizations (NGOs) to transform the goods industry of consumption toward sustainable development through science. In 2016, TSC issued its Impact Report to understand how much visibility companies have into their supply chains. A survey with 2,500 participants and 1,700 suppliers indicates, though, that most manufacturers have limited visibility into their supply chains and their related sustainability risks, as displayed in Figure 1.

According to the study, the lack of visibility of most manufacturers was identified as the most critical barrier to improvement. Transparency plays a fundamental role, as it allows knowing the reality of companies, establishing metrics, identifying problems, and focusing the efforts where they will have the most significant impact on organizations transform blind spots into hotspots to action, they propose three steps to get greener global supply chains. "First, retailers should commit to a common platform to measure and track consumer product sustainability. Second, manufacturers should drive supply chain visibility and performance, which will enhance their own business outcomes and reduce risk. Third, stakeholders should partner to align and drive scale: companies, NGOs, and other organizations work together to create scale by harmonizing existing metrics and tools, and drive continued momentum by collaborating on shared initiatives to address key hotspots" (The Sustainability Consortium 2016).

Even though the Consumer Goods Industry brings a lot of benefits to society, it also has a high impact on sustainability, as shown in Figure 2.

As a result, improving sustainability can help mitigate the impacts and reduce the costs and risks of the supply chain. Likewise, it can increase revenues and growth by opening new markets for more innovative and ecological products. Finally, managing critical CSR issues, such as labor rights, can also reduce costs incurred because of the loss of reputation. The report also warns of a trend of economic growth in the coming decades, with an increase of close to 2.5 billion people to the consumer class and an increase of around 5% in the global consumer goods industry. These are the reasons

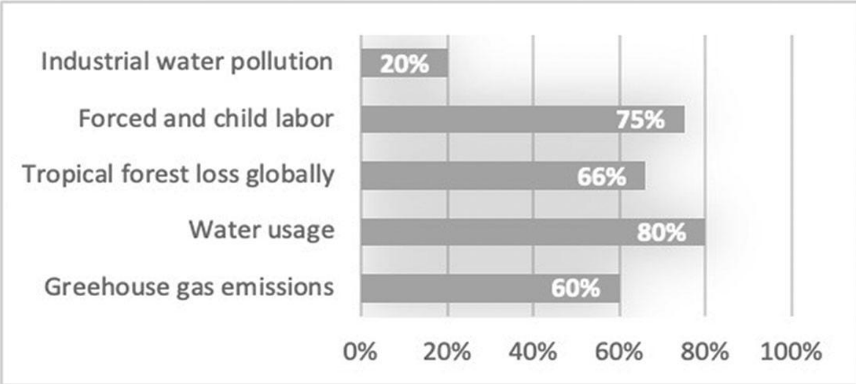

Figure 2. Consumer Goods Industry impact on sustainability. Source: Own elaboration based on TSC (2016).

why the challenges will be even more significant. Nevertheless, there is a huge potential for large-scale improvements, which means every change in that supply chain is able to produce significant results.

The primary motivation to elaborate this manuscript is that managing a supply chain is not an easy task for companies. Understand, measure, and track the immense variety of products, and its life cycle's impacts can be a challenge due to size and complexly of the system. There is a necessity to develop tools that allow managers to use them easily and broadly to collaborate in day-to-day decision-making process, improve stakeholder's transparency, especially suppliers, and in this way, help them effectively to achieve better results. This study has an essential value in deepening issues that can have a positive impact on companies, society, and academia.

A Bibliometric Study on Fuzzy Logic and Sustainability

This section presents a scientific study on the correlation between fuzzy logic and sustainability and identifies the existing research gaps. Also, it shows research studies that use fuzzy logic applied to sustainability.

It should be noted that the study was conducted on October 8, 2020 through the Web of Science, and the obtained information may vary over time because, when published, its number increases continuously, the topics are expanded while, at the same time, interdisciplinary connections are produced. It is also highlighted that the search performed may present small deviations since not all the papers that match the words "Fuzzy logic" and "Sustainabilit*" will be useful in our research. First, we separated our research into two parts: in the first part we use the keywords fuzzy logic and sustainability separately. In the second part, we choose the combination using the keywords "Fuzzy logic" and "Sustainabilit*". The results will be detailed next.

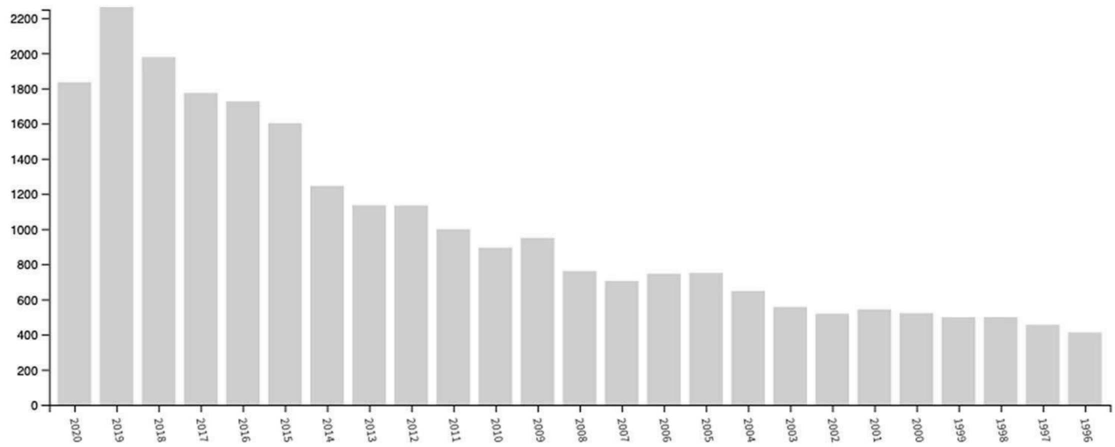

Figure 3. Bibliometric study using the keywords "Fuzzy logic". Source: Web of Science (2020).

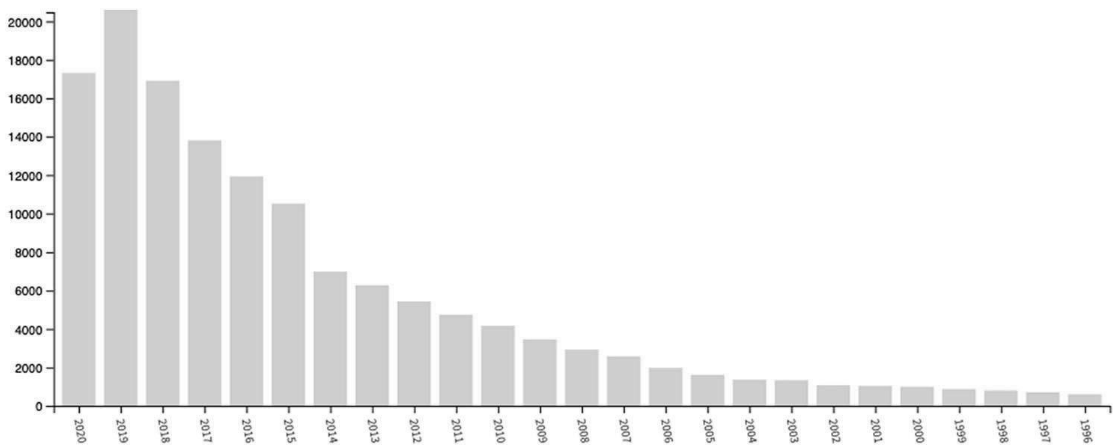

Figure 4. Bibliometric study using the keywords "Sustainabilit*". Source: Web of Science (2020).

In our search using the keywords "Fuzzy logic", we found 24,795 records. Figure 3 shows the distribution by year of papers published from 1996 to 2020.

In our search using the keywords "Sustainabilit*", we found 136,843 records. Figure 4 displays the distribution by year of papers published from 1996 to 2020.

Finally, Figure 5 shows the results of the publications (301 works) and citations (5,445 references) using the keywords "Fuzzy logic" and "Sustainabilit*". The distribution by year of articles published from 1997 to 2020. There are no records before 1997, which shows that this is a line of recent research.

In summary, the bibliometric study indicates that there are 24,795 records for "Fuzzy Logic," 136,843 records for "Sustainabilit*," and 301 records for "Fuzzy Logic" and "Sustainabilit*." The study also indicates that there is a trend of growth of research lines over time, and an increase in published manuscripts and citations between "Fuzzy Logic" and "Sustainabilit*," which reinforces the interest in this topic and allows

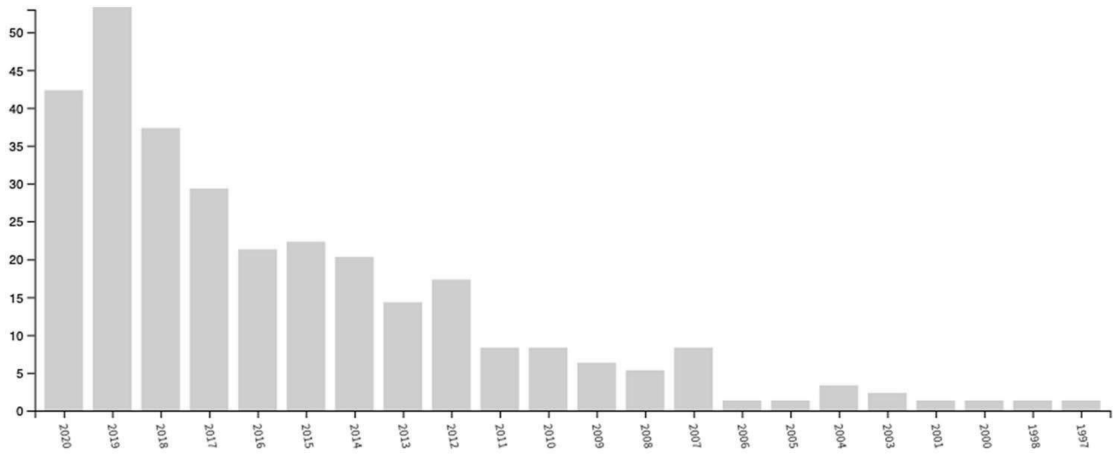

Figure 5. Bibliometric study using the keywords "Fuzzy logic" and "Sustainabilit*". Source: Web of Science (2020).

advancement the frontier of knowledge in these lines of research. In addition, it is observed that there is a research gap that can be developed using fuzzy logic applied to sustainability. For example, research lines should focus on the decision-making related to the supply chain, the stakeholder's management, the definition of relevant issues or materiality, the choice and definition of sustainability projects, among others.

However, there are recent research studies that use fuzzy logic and sustainability. These showed that the topic is relevant and offered many possibilities for research in different fields such as transport (L. d. Paula and Marins 2018), energy (Gamalath et al. 2018), supply chain (S. Singh et al. 2018), bank (Beheshtinia and Omidi 2017), CSR (Bhattacharya 2017), industry (Bottani, Gentilotti, and Rinaldi 2017), among others.

The Fuzzy Logic and Its Importance for Applied Science

This section introduces the methodologies used in this article. From the literature review, knowledge gaps have been identified in this field and, for this reason it is justified to present alternatives tools to manage the supply chain of a company sustainably. Next, the origin of Fuzzy Logic and its importance for applied science is explained, and finally, the methodologies are presented.

In 1937, Max Black introduced the notion of vague sets in "Vagueness: An exercise in logical analysis" (Black 1937). In this article, Max Black analyzed main ideas, one of which is the nature and observation of vagueness and the other is the relevance that vagueness can have for logic. This work was the first attempt to give a precise mathematical theory for the sets with a membership curve.

The difference between classical logic and fuzzy logic lies in what Aristotle calls the "Principle of the Third Exclusion". The theory of fuzzy subsets questions this principle by establishing a characteristic function of belonging for phenomena description. Fuzzy logic generalizes classical logic by incorporating a whole series of possibilities that could be contemplated by the latter. It is born at the moment when scientists realize that, when considering facts only as true or false, they are making a mistake since we can hardly find phenomena in the social sciences that represent the whole or nothing.

In reality, there are few facts that are either true or false strictly; all are manifested according to a degree of belonging. The facts always tend to have a part of imprecision, so you have to look at the world based on a gray scale. Fuzziness means multivalence, where everything is a matter of degree, including truth and falsehood in their belonging to a group. This means that, taken to the limit, there are infinite options between the two extremes that hinder the characteristic feature of belonging, that is, the analogic over the binary prevails, the nuances of grays between white and black are infinite.

"The Theory of Fuzzy Subsets constitutes a mathematical theory in the field of multivalent logic" (L. d. Paula and Marins 2018). Its origin is found in the works of Lofti Zadeh in "Fuzzy Sets" (Zadeh 1965). Zadeh defines "fuzzy" multivalent sets, "whose elements belong to them in different degrees to mark the difference between that concept and the then universally accepted binary logic" (L. d. Paula and Marins 2018). In 1968, Lofti Zadeh would create Fuzzy Logic. The same author presents Type-2 fuzzy set (T2FS) (Zadeh 1975) that "is a generalization the ordinary fuzzy set in which the membership value for each member of the set is itself a fuzzy set" (S. Singh and Garg 2017). In 1986, Atanassov introduces the concept "intuitionistic fuzzy set" (IFS) "as a generalization of the notion of fuzzy set" (Atanassov 1986).

In 1991, Zadeh introduced "Soft Computing," a hybrid of methodologies that includes fuzzy logic, neural networks, evolutionary algorithms and probabilistic reasoning. In 1995, Gerstenkorn and Mańko determine that the family of bifuzzy probabilistic sets forms a complete pseudo-Boolean algebra. They describe that "the belonging or non-belonging of an element to a set of some objects, with respect to the payment of Randomness of choosing them" (Gerstenkorn and Mańko 1995). In 2017, Sukhveer Singh & Garg launches the concept of type-2 intuitionistic fuzzy set (T2IFS). In this research, the authors describe a family of distance measures based on Hamming, Euclidean and Hausdorff metrics and presents "a method of group decision making to classify the alternatives" (S. Singh and Garg 2017).

It is perceived the importance of "Fuzzy Logic" with applied scientific research in different areas of knowledge (A. M. Gil-Lafuente et al. 2019).

Therefore, academic research reinforces that fuzzy logic helps the decision maker in environments with a high degree of uncertainty. For this reason, we consider that fuzzy logic can also be useful to help decision makers in the sustainable management of the supply chain.

Algorithms Based on Fuzzy Logic

In this section, we present three algorithms based on fuzzy logic that will be used in our study. First, we explain the Hamming Distance. Second, we present the Adequacy Ratio and third, we detail the OWA Operators.

Hamming Distance

In 1950, Richard Wesley Hamming publishes the "Hamming Distance" (Hamming 1950). In this work, the author shows the utility of a precise technique to calculate the differences between two elements or sets. This algorithm can be defined as follows.

Definition 1. First, we define a notion of distance between two points included in the segment

$$[0,1] : If\ \ [a_{1,}, a_2] \subset [0,1]\ \ and\ \ [b_1, b_2] \subset [0,1],\ \ let\ \mathcal{D}\ \left([a_1, a_2], [b_1, b_2]\right) = \frac{1}{2}(|a_1 - b_1| + |a_2 - b_2|) \tag{1}$$

That defines an object or proposal a_j, $j = 1, 2, ., m$, through certain characteristics or elements $b_i, i = 1, 2, ., n$

The use of $\frac{1}{2}$ before the addition of absolute values is intended only to maintain the distance between 0 and 1. As a result, we observe that:

$$0 \leq \mathcal{D}\left([a_1, a_2], [b_1, b_2]\right) \leq 1 \tag{2}$$

Definition 2. We can define the normalized Hamming distance between two subsets Φ - the same reference fuzzy finite:

If $\underset{\sim}{A}, \underset{\sim}{B} \subset E$ with a card $E = N$ *finite*, we have

$$\delta\left(\underset{\sim}{A}, \underset{\sim}{B}\right) = \frac{1}{n}\sum_{i=1}^{N} \mathcal{D}\left(\mu \underset{\sim}{a}(x), \mu \underset{\sim}{b}(x)\right) \tag{3}$$

where μ is the associated weighting vector (Gil-Aluja 1999).

The Hamming distance has provided very good results when ordering fuzzy sets (Alfaro-García et al. 2019; Blanco-Mesa, Gil-Lafuente, and Merigó 2017; Gil Lafuente & Paula 2010) since we will determine which item is closer to the ideal. "The model, if we give more weight to some characteristics or skills than to others, allows us to consider and pursue the same expression quoted above. For all cases, one should prefer the element that is the smallest distance from what is considered the ideal" (Kaufmann and Gil Aluja 1987). It should be noted that the limitation of the methodology is mainly due to the quality of the information collected.

The Adequacy Ratio

Having different variants to be able to use, we opted for the penalty hypothesis in those elements that their characteristics do not reach the minimum required. This penalty, it should be said will not be total, but will be progressive according to the deficit that is present (Gil-Aluja 1999; Kaufmann and Gil Aluja 1986).

Definition 1. First, we are going to initiate the process from the knowledge of certain fuzzy sub-relations that define an object or proposal $\underset{\sim}{P_j},\ j = 1, 2, ., m$ through specific characteristics or elements $C_i,\ i = 1, 2, ., n$ and μ is the ideal level that is demanded.

The adequacy ratio is designated by $K\left(\underset{\sim}{P_j},\ \underset{\sim}{P_*}\right)$ and is constructed as follows:

$$\text{when } \mu_{\underset{\sim}{P_j}}(C_i) \geq \mu_{\underset{\sim}{P_*}}(C_i)\ do\ K_i\left(\underset{\sim}{P_j} \rightarrow \underset{\sim}{P_*}\right) = 1 \tag{4}$$

$$and\ when\ \mu_{\underset{\sim}{P_j}}(C_i) < \mu_{\underset{\sim}{P_*}}(C_i)\ do\ K_i\left(\underset{\sim}{P_j} \rightarrow \underset{\sim}{P_*}\right) = 1 - \mu_{\underset{\sim}{P_*}}(C_i) + \mu_{\underset{\sim}{P_j}}(\mathrm{C_i}) \tag{5}$$

$$Then,\ K\left(\underset{\sim}{P_j} \rightarrow \underset{\sim}{P_*}\right) = \frac{1}{n}\sum_{i=1}^{n} K_i\left(\underset{\sim}{P_j} \rightarrow \underset{\sim}{\mathrm{P}_*}\right) \tag{6}$$

This algorithm is a useful and effective tool in decision-making processes (Blanco-Mesa, Merigó, and Kacprzyk 2016; L. de Paula and Marins 2018). Its limitation lies in the quality of information received.

The OWA Operators

In 1988, Ronald Yager produced the manuscript "The OWA Operators," which aims to present a family of ordered weighted average operators (OWA) that provide an aggregation that lies between these two extremes (Yager 1988).

Table 1. Specific characteristics.

Characteristics	GC's principles
C_1	"Businesses should support and respect the protection of internationally proclaimed human rights".
C_2	"Make sure that they are not complicit in human rights abuses".
C_3	"Businesses should uphold the freedom of association and the effective recognition of the right to collective bargaining".
C_4	"The elimination of all forms of forced and compulsory labor".
C_5	"The effective abolition of child labor".
C_6	"The elimination of discrimination in respect of employment and occupation".
C_7	"Businesses should support a precautionary approach to environmental challenges".
C_8	"Undertake initiatives to promote greater environmental responsibility".
C_9	"Encourage the development and diffusion of environmentally friendly technologies".
C_{10}	"Businesses should work against corruption in all its forms, including extortion and bribery".

Source: Own elaboration based on United Nations (2008).

Definition 1. An OWA operator of dimension n is an application of $\mathcal{F}:\mathcal{R}^n \to \mathcal{R}$, which has an associated weighting vector (Yager 1988), such as:

$$w_i \in [0,1],\ \ 1 \le i \le n\ \ and\ \ \sum_{i=1}^{n} w_i = w_1 + w_2 + \ldots, + w_n = 1 \tag{7}$$

$$where\ \ \mathcal{F}(x_1, x_2, \ldots, x_n) = \sum_{k=1}^{n} w_k x_{jk} = w_1 x_1 + w_2 x_2 + \ldots, + w_n x_n \tag{8}$$

and x_{jk} *is the* kth largest element of the collection $\{x_1, x_2, \ldots, x_n\}$. OWA operators provide flexibility in the modeling and simulation process, since it is defined by a vector of weights and not by a single parameter. As advantages for its use, OWA helps in the analysis of complex systems and facilitates the decision-makings in scenarios of uncertainty. As a limitation, the result will depend on the quality of information received. This algorithm was used successfully in several investigations (Alfaro-García et al. 2019; Blanco-Mesa, Gil-Lafuente, and Merigó 2017; Merigó and Gil-Lafuente 2011; Vizuete-Luciano et al. 2015) and for these reasons; we chose it for this study.

Application of Models to Evaluate Supply Chain

In this section, we apply the three algorithms to evaluate a supply chain of consumer goods industry. The 10 principles of the Global Compact are the evaluation criteria, and the names of the companies under study are confidential.

First, the firm indicates "a set of values within the areas of Human Rights, Labor Relations, Environment and Fight against Corruption" (United Nations 2008) with the specific characteristics that the suppliers must have, as presented in Table 1.

Table 2. Fuzzy Subset of thresholds.

C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
0.9	0.9	0.8	1	1	0.8	1	1	0.8	1

Table 3. Assessment of five suppliers.

	S_1	S_2	S_3	S_4	S_5
C_1	0.8	0.7	0.7	0.7	0.9
C_2	0.9	0.8	0.5	0.7	0.9
C_3	0.7	0.8	0.7	0.8	0.8
C_4	0.8	0.9	0.9	0.9	0.7
C_5	1	0.5	0.9	0.8	1
C_6	1	0.9	1	0.8	1
C_7	0.9	1	1	1	0.9
C_8	0.7	1	0.9	1	0.7
C_9	0.7	0.9	0.8	0.9	0.8
C_{10}	0.7	0.9	0.7	0.9	1

Table 4. Fuzzy Subset for each supplier.

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
S_1	0.8	0.9	0.7	0.8	1	1	0.9	0.7	0.7	0.7
S_2	0.7	0.8	0.8	0.9	0.5	0.9	1	1	0.9	0.9
S_3	0.7	0.5	0.7	0.9	0.9	1	1	0.9	0.8	0.7
S_4	0.7	0.7	0.8	0.9	0.8	0.8	1	1	0.9	0.9
S_5	0.9	0.9	0.8	0.7	1	1	0.9	0.7	0.8	1

Second, with three experts' support, "the fuzzy subset of thresholds was defined, denoted by $\underset{\sim}{P_*}$ which indicates the degree of significance of each characteristic," as exposed in Table 2.

Third, the experts then assessed each supplier according to the criteria established above, and "they specified their perceptions of the scale [0,1], whereby the closer the estimate is to 1, the better the adaptation to the firm's requirements" (L. de Paula and Marins 2018). Where S_1 it means Supplier 1, S_2 = Supplier 2, S_3 = Supplier 3, S_4 = Supplier 4, and S_5 = Supplier 5. The assessment results as presented in Table 3.

Fourth, this result allows us to obtain a fuzzy subset for each supplier (see Table 4).

Following it will show the results of each supplier based on its own merits with respect to the initial criteria according to a set of thresholds. To achieve this objective, it will calculate the three algorithms as follows.

Applying the Hamming Distance

First, it will calculate the "Hamming Distance". In this case, it assumes that the firm determines a vector of weights, as presented in Table 5, depending on the current priorities at any given time.

Table 5. Vector of determined weights.

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
W =	0.09	0.09	0.07	0.1	0.1	0.05	0.1	0.1	0.05	0.1

Table 6. Results applying the Hamming Distance (HD).

Supplier	Results	Positions
HD S_1	0.0121	4°
HD S_2	0.0107	3°
HD S_3	0.0131	5°
HD S_4	0.0081	2°
HD S_5	0.0080	1°

From (3), we obtain:

$$S_1 = \frac{1}{10}(0.09{*}0.1 + 0.09{*}0 + 0.07{*}0.1 + 0.1{*}0.2 + 0.1{*}0 + 0.05{*}0.2 + 0.1{*}0.1 + 0.1{*}0.3 + 0.05{*}0.1 + 0.1{*}0.3) = 0.0121$$

$$S_2 = \frac{1}{10}(0.09{*}0.2 + 0.09{*}0.1 + 0.07{*}0 + 0.1{*}0.1 + 0.1{*}0.5 + 0.05{*}0.1 + 0.1{*}0 + 0.1{*}0 + 0.05{*}0.1 + 0.1{*}0.1) = 0.0107$$

$$S_3 = \frac{1}{10}(0.09{*}0.2 + 0.09{*}0.4 + 0.07{*}0.1 + 0.1{*}0.1 + 0.1{*}0.1 + 0.05{*}0.2 + 0.1{*}0 + 0.1{*}0.1 + 0.05{*}0 + 0.1{*}0.3 = 0.0131$$

$$S_4 = \frac{1}{10}(0.09{*}0.2 + 0.09{*}0.2 + 0.07{*}0 + 0.1{*}0.1 + 0.1{*}0.2 + 0.05{*}0 + 0.1{*}0 + 0.1{*}0 + 0.05{*}0.1 + 0.1{*}0.1) = 0.0081$$

$$S_5 = \frac{1}{10}(0.09{*}0 + 0.09{*}0 + 0.07{*}0 + 0.1{*}0.3 + 0.1{*}0 + 0.05{*}0.2 + 0.1{*}0.1 + 0.1{*}0.3 + 0.05{*}0 + 0.1{*}0 = 0.0080$$

Finally, the results following were obtained (see Table 6).

The result shows that the supplier (S_5) has the best ranking. This supplier obtained the shortest distance, since conceptually it is closer to the subset of thresholds.

Applying the Adequacy Ratio

Then, we use the method based on the calculation of the adequacy ratios. To do this, the relative distances between the subset of thresholds and each of the five suppliers were found. From (6) it obtains:

Table 7. Results applying the Adequacy Ratio (AR).

Supplier	Results	Positions
AR S_1	0.880	4°
AR S_2	0.900	3°
AR S_3	0.870	5°
AR S_4	0.920	2°
AR S_5	0.930	1°

$$K\left(S_1 \to \underset{\sim}{P_*}\right) = \frac{1}{10}(0.9 + 1 + 0.9 + 0.8 + 1 + 1 + 0.9 + 0.7 + 0.9 + 0.7) = 0.880$$

$$K\left(S_2 \to \underset{\sim}{P_*}\right) = \frac{1}{10}(0.8 + 0.9 + 1 + 0.9 + 0.5 + 1 + 1 + 1 + 1 + 0.9) = 0.900$$

$$K\left(S_3 \to \underset{\sim}{P_*}\right) = \frac{1}{10}(0.8 + 0.6 + 0.9 + 0.9 + 0.9 + 1 + 1 + 0.9 + 1 + 0.7) = 0.870$$

$$K\left(S_4 \to \underset{\sim}{P_*}\right) = \frac{1}{10}(0.8 + 0.8 + 1 + 0.9 + 0.8 + 1 + 1 + 1 + 1 + 0.9) = 0.920$$

$$K\left(S_5 \to \underset{\sim}{P_*}\right) = \frac{1}{10}(1 + 1 + 1 + 0.7 + 1 + 1 + 0.9 + 0.7 + 1 + 1) = 0.930$$

Table 7 presents the results applying the Adequacy Ratio.

In this case, the supplier S_5 presents the best result with the highest adequacy ratio among the subset of thresholds.

Applying the OWA Operators

Finally, we apply the OWA operators using the vector of weights determined (see Table 8).

We are reordering the data (see Table 9).

From (8), we calculate $OWAS_i,\ for\ i = 1,\ 2,\ 3,\ 4\ and\ 5:$

$$OWAS_1 = (0.09*0.8 + 0.09*0.9 + 0.07*0.7 + 0.1*0.8 + 0.1*1 + 0.05*1 + 0.1*0.9 + 0.1*0.7 + 0.05*0.7 + 0.1*0.7) = 0.697$$

$$OWAS_2 = (0.09*0.7 + 0.09*0.8 + 0.07*0.8 + 0.1*0.9 + 0.1*0.5 + 0.05*0.9 + 0.1*1 + 0.1*1 + 0.05*0.9 + 0.1*0.9) = 0.711$$

$$OWAS_3 = (0.09*0.7 + 0.09*0.5 + 0.07*0.7 + 0.1*0.9 + 0.1*0.9 + 0.05*1 + 0.1*1 + 0.1*0.9 + 0.05*0.8 + 0.1*0.7) = 0.687$$

Table 8. Vector of weights determined.

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
W =	0.09	0.09	0.07	0.1	0.1	0.05	0.1	0.1	0.05	0.1

Table 9. Reordering the data.

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
S_1	0.8	0.9	0.7	0.8	1	1	0.9	0.7	0.7	0.7
S_2	0.7	0.8	0.8	0.9	0.5	0.9	1	1	0.9	0.9
S_3	0.7	0.5	0.7	0.9	0.9	1	1	0.9	0.8	0.7
S_4	0.7	0.7	0.8	0.9	0.8	0.8	1	1	0.9	0.9
S_5	0.9	0.9	0.8	0.7	1	1	0.9	0.7	0.8	1

$$OWAS_4 = (0.09*0.7 + 0.09*0.7 + 0.07*0.8 + 0.1*0.9 + 0.1*0.8 + 0.05*0.8 + 0.1*1 + 0.1*1 + 0.05*0.9 + 0.1*0.9) = 0.727$$

$$OWAS_5 = (0.09*0.9 + 0.09*0.9 + 0.07*0.8 + 0.1*0.7 + 0.1*1 + 0.05*1 + 0.1*0.9 + 0.1*0.7 + 0.05*0.8 + 0.1*1) = 0.738$$

Table 10 displays the results applying the OWA Operators.

The OWA Operators indicate that supplier 5 achieved the highest coefficient, followed by the suppliers 4, 2, 1 and 3 respectively.

In summary, Table 11 shows the results of the three algorithms, which allows verifying the same ranking for the five suppliers. In this study, the three algorithms are applied to evaluate the suppliers of a company, and the results were equal, which reinforces the validity of the data and reduces the risks in the decision-making process.

When analyzing results carefully, it is observed that five characteristics had a critical weight in the decision. They are: C_4 (the elimination of all forms of forced and compulsory labor), C_5 (the effective abolition of child labor), C_7 (Businesses should support a precautionary approach to environmental challenges), C_8 (undertake initiatives to promote greater environmental responsibility), and C_{10} (Businesses should work against corruption in all its forms, including extortion and bribery). These characteristics received greater weight from both the experts and the company. The best-evaluated supplier S_5 achieved a high performance in these characteristics.

On the other hand, with the results of the evaluation, the company can execute a supplier development plan based on this sustainability assessment. Then, the company can propose consultancies for each supplier who wants to improve the weakest criteria and to strengthen the strongest ones. In this way, the company generates shared value in its supply chain and contributes positively to sustainable development. These algorithms apply to all types and sizes of companies. The flexibility of these tools allows adaptation to different selection criteria, to several suppliers and the weight of each criterion.

Table 10. Results applying the OWA Operators (OWA).

Supplier	Results	Positions
OWA S_1	0.697	4°
OWA S_2	0.711	3°
OWA S_3	0.687	5°
OWA S_4	0.727	2°
OWA S_5	0.738	1°

Table 11. The results applying the three algorithms.

		Algorithms/Selection criteria		
Positions	Suppliers	Hamming Distance (Shortest distance)	Adequacy Ratio (Highest adequacy ratio)	OWA Operators (Highest coefficient)
4°	S_1	0.0121	0.880	0.697
3°	S_2	0.0107	0.900	0.711
5°	S_3	0.0131	0.870	0.687
2°	S_4	0.0081	0.920	0.727
1°	S_5	0.0080	0.930	0.738

The results indicate a consensus between the experts and the company. Subsequently, these tools can help in making decisions on this topic. The method used has flexibility in the use of algorithms as the number of criteria and the weight given to each characteristic that can be adjusted.

A limitation of the study would be the quality of the information received by the specialists. However, when the three results do not coincide in the same result, the uncertainty becomes so great that there is no convergence toward a single supplier. In this case, the decision-maker should review the weights and how was the process of collecting the information.

Fuzzy Logic models show utility for analyzing complex systems, and mainly with issues that generate impacts on society, such as sustainable development in the supply chain. For these reasons, the results allow a deep reflection and its application in the academic and professional fields.

Conclusions

This study on sustainable supply chain management showed the importance of suppliers for sustainable development. It indicated shared value as a business strategy to reduce risks, increase legitimacy, efficiency, and profits. From a conceptual study, it was possible to evaluate the sustainability of five suppliers that belong to the supply chain of the consumer goods industry through the application of three algorithms of fuzzy logic.

Through this research, we propose tools to help supply chain management generate more sustainable products and supply networks, using a science-based methodology with the measured approach. With better supply chain visibility, it is easier for companies to discover the hidden impacts insight and reduce risks. Improved supply chain management will help improve the sustainability price tag, which is essential to enable consumer goods to continue to grow in a resource-constrained world.

The result allows for the establishment of criteria for selecting suppliers, including sustainability in supplier evaluation processes, reducing risks in the supply chain, identifying points for improvement, generating greater transparency for stakeholders, and contributing to sustainable management. Also, it uses the Global Compact Principles as evaluation criteria for the supply chain. Likewise, the results demonstrate the usefulness of the algorithms used in decision-making for the sustainable development of companies.

The study of sustainability supported by the application of fuzzy logic provides a management model that can help decision-makers. Thus, we consider that the research carried out is an innovative and useful tool for scientific knowledge to advance in the study of sustainability based on the Theory of Uncertainty.

As contributions, the document presented a bibliometric study on the issue that indicates a gap in the literature on the correlation between fuzzy logic and sustainability. The applied study allows for reducing the gap in the advancement of the knowledge frontier. It also shows tools for decision-making that take into account sustainability criteria in the supply chain. This document also supports future studies on the supply chain, shared value, fuzzy logic, and sustainability.

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