A methodology to select suppliers to increase sustainability within supply chains

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Abstract

Sustainability practice within supply chains remains in an early development phase. Enterprises still need tools that support the integration of sustainability strategy into their activity, and to align their sustainability strategy with the supplier selection process. This paper proposes a methodology using a multi-criteria technique to support supplier selection decisions by taking two groups of inputs that integrate sustainability performance: supply chain performance and supplier assessment criteria. With the proposed methodology, organisations will have a tool to select suppliers based on their development towards sustainability and on their alignment with the supply chain strategy towards sustainability. The methodology is applied to an agri-food supply chain to assess sustainability in the supplier selection process.

Keywords: supplier selection, sustainability, supply chain, performance, agri-food

1 Introduction

Managing sustainability in the supply chain (sustainable supply chain management, SSCM) can be defined as "the management of material, information and capital flows, as well as cooperation among companies along the supply chain, while taking goals from all three dimensions of sustainable development, i.e., economic, environmental and social, into account, which are derived from customer and stakeholder requirements" (Seuring and Müller 2008). From this definition, it can be inferred that if supply chains are to manage sustainability, the management supply chain has to incorporate all three dimensions, as well as customer and stakeholder needs.

The practice of supply chain sustainability remains in an early development phase. Organisations present some limitations when incorporating sustainability strategies and practices into their management, even when it is known that their operation relies on their responsibility towards stakeholders and partners in the supply chain (Dyllick and Hockerts 2002; Qorri et al. 2018). Therefore, supply chains still need tools to be developed that help to manage this complexity. It is also necessary to consider that sustainability should emerge from the supply chain's strategy. This requires that the sustainability guidance starts to formulate a robust strategy in which all the enterprises belonging to the supply chain pursue mutual objectives towards sustainability. In this vein, performance management systems (PMSs) are tools that sustain the design and implementation of organisation's strategy, as well as the establishment of mechanisms for performance monitoring.

In the academic and business literature, several PMSs have been designed to manage inter-organisational contexts. The balanced scorecard (BSC), developed by Kaplan and Norton (1992), is one of the most outstanding PMSs for organisations. The BSC was developed to manage a single enterprise, but was later extended to the management of supply chains (e.g. Brewer and Speh 2000; Bititci et al. 2005; Folan and Browne 2005; Alfaro et al. 2007). The single enterprise BSC is composed of different performance elements: perspectives, objectives, key performance indicators (KPIs), targets and action plans. A BSC comprises four perspectives: financial, customer, process, and innovation and learning. These four perspectives are defined for the enterprise's evolution in four key areas in order to gain a broader view of the enterprise's performance status. Therefore, the objectives to be fulfilled in the enterprise are defined within these four perspectives. The evolution of each objective is monitored by defining the KPIs. A target is defined for each KPI so that managers can analyse if the target is met during a pre-defined period for every KPI. Finally, action plans are defined and implemented to support objectives being met.

In an inter-organisational context, the structure of PMSs incorporates the definition of the supply chain's performance elements. In supply chains, the PMS definition is more complex, as the performance elements of both supply chains and individual enterprises should be coherent and aligned to fulfil the objectives defined for supply chains (Alfaro et al. 2007). This requirement demands a higher level of cooperation/collaboration among enterprises to define and process the performance information in the supply chain (Alfaro et al. 2010; Maestrini et al. 2017). Moreover, the structures of inter-organisational PMSs should introduce a logical path to monitor performance from a strategic to an operative (process) level (Alfaro et al. 2007). Despite these developments, the structure of the PMSs defined for supply chains still have to be adapted to manage the supply chain sustainability aligned to decision-making in the supply chain process (Nawaz and Koç 2018; Qorri et al. 2018).

One of the practices to remain competitive that has been most agreed on is to set up collaboration with suppliers (Verdecho et al. 2012; Jimenez-Jimenez et al. 2019). Enterprises need to link the inter-enterprise flows that develop within the supply chain effectively. The supplier selection process is a key process to increase profits, cut time-to-market, enhance innovation capability, etc. (Petersen et al. 2005). It has to be stated that the supplier selection problem has a multi-attribute nature that has been analysed in the literature mainly via two topics: the definition of supplier selection criteria and the usage of multi-criteria models to assess suppliers. If supply chains pursue the fulfilment of sustainability objectives, the criteria used to select suppliers should incorporate sustainability criteria to create a robust system that obtains synergy.

At this point, the enterprises that need to select suppliers and that wish to focus their efforts on increasing supply chain sustainability should incorporate two groups of inputs: supply chain performance and supplier assessment criteria. The first group, supply chain performance, refers to the overall objectives that the supply chain wishes to meet, including sustainability objectives. These objectives are better structured when using a solid PMS. Enterprises will select the suppliers that best match these objectives. The second group, supplier assessment criteria, comprises the criteria that organisations consider relevant for assessing suppliers. These criteria should include sustainability attributes to evaluate the status of suppliers in developing and implementing sustainable practices.

The aim of this paper is to develop a methodology that supports supplier selection decisions by using two groups of inputs that incorporate sustainability: supply chain performance and supplier assessment criteria. With this methodology, enterprises may select suppliers based on their development towards sustainability, because supplier performance criteria will not only include their sustainability practices, but their alignment with the supply chain sustainability strategy.

This work is structured as follows. Firstly, a literature review is presented that comes in three parts: sustainable supplier selection modelling approaches, sustainable supplier selection criteria and supply chain performance measurement systems. Subsequently, the methodology to select suppliers for managing sustainable supply chains is described, after which a case study is presented in an agri-food supply chain. Finally, the conclusions are presented.

2 Literature review

2.1 Sustainable supplier selection modelling approaches

The relevance of supplier selection/assessment has been recognised in the academic literature, where specific literature reviews around supplier assessment/selection models have been developed (Weber et al. 1991; Degraeve et al. 2000; De Boer et al. 2001; Ho et al. 2010; Glock et al. 2017). The literature presents different modelling approaches to address the supplier selection problem: data envelopment analysis (DEA), linear programming, multi-objective programming, fuzzy set theory, analytic hierarchy process (AHP), TOPSIS, analytic network process (ANP), etc., and their hybrid approaches. In the supplier selection problems, the evaluation of potential suppliers may involve either quantitative or qualitative criteria. The AHP method (Saaty 1980) is a multi-criteria decision analysis (MCDA) method that is useful for assessing suppliers as it incorporates both types of criteria.

Numerous applications use the AHP method for supplier selection. Ghodsypour and O'Brien (1998) develop an AHP and linear programming proposal to select suppliers and to assign optimum order quantities. Masella and Rangone (2000) develop different vendor assessment systems by focusing on the time and scope of the co-operative partnership. Akarte et al. (2001) define a multi-criteria model to assess suppliers according to four types of attribute: product development, manufacturing, quality, and cost and delivery. Huan et al. (2004) develop an AHP model for implementing a supply chain operations reference (SCOR) model to assess global supplier performance. Chan (2003) develops a supplier selection model by combining fuzzy and AHP.

In the last few years, interest in developing models that deal with sustainable supplier selection has increased (Zimmer et al. 2016). Four literature reviews (Genovese et al. 2013; Igarashi et al. 2013; Nielsen et al. 2014; Govindan et al. 2015) have addressed environmental supplier selection and one literature review (Zimmer et al. 2016) deals with sustainable supplier selection, including the social dimension. Zimmer et al. (2016) propose a classification of modelling approaches for sustainable supplier selection purposes. They consider four basic types of approach, which are used as a single model or combined: qualitative (Delphi, Ishikawa Diagram and QFD), mathematical programming (linear programming, MILP, goal programming and nonlinear programming), mathematical analytical (AHP, ANP, DEA, TOPSIS, PROMETHEE, ELECTRE, VIKOR, DEMATEL and others), and artificial intelligence (CBR, fuzzy logic, grey systems, rough set, neural networks, particle swarm, genetic algorithm and differential evolution). According to Zimmer et al. (2016), the most widespread approaches are fuzzy logic (31.1%), AHP (18.8%), ANP (11.4%), DEA (8%) and TOPSIS (7.4%). It is worth noting that fuzzy logic is frequently combined with mathematical analytical methods, so it is not an exclusive category. Mathematical analytical approaches (52.9%) are more widely used than mathematical programming ones (3.7%).

The literature presents many models for sustainable supplier selection using mathematical analytical approaches. Noci (1997) develops an AHP model for green supplier selection. Farzad et al. (2008) propose an AHP approach to supplier evaluation and selection in a steel manufacturing company. Hutchins and Sutherland (2008) propose a model to assess the social sustainability of companies, considering the impact of their suppliers using the weighted value of individual indicators. Hsu and Hu (2009) apply hazardous substance management to supplier selection using ANP. Dou and Sarkis (2010) develop a model to evaluate and select various offshoring alternatives by simultaneously considering facility location factors, supplier selection metrics and sustainability factors. Shaik and Abdul-Kader (2011) propose a model for green supplier selection using MAUT. Agarwal and Vijayvargy (2012) develop a model for green supplier assessment in environmental responsive supply chains using ANP. Uysal (2012) presents an integrated model for the sustainable performance measurement of companies using DEMATEL. Azadnia et al. (2013) present an integrated approach to sustainable supplier selection employing fuzzy logic and fuzzy AHP. Falatoonitoosi et al. (2013) present a green supplier evaluation model using DEMATEL. Hsu et al. (2013) utilise DEMATEL to develop a carbon management model for supplier selection purposes. Nie (2013) develops a model for selecting green suppliers based on AHP for the biotechnology industry. Xu et al. (2013) present a model for corporate social responsibility supplier selection using AHP. Zhe et al. (2013) offer a supplier selection model with environmental factors using DEA. Dobos and Vörösmarty (2014) develop a model for green selection and evaluation using DEA. Virender and Jayant (2014) present a green supplier selection model using ANP for an agriculture-machinery industry. Theiβen and Spinler (2014) put forward an ANP model for collaborative CO_2 reduction in manufacturer-supplier partnerships. Shi et al. (2015) present a DEA model to select suppliers for green supply chains. Freeman and Chen (2015) present a green supplier selection model that uses AHP-entropy-TOPSIS methods. Luthra et al. (2017) develop an AHP and VIKOR model for selecting suppliers by increasing sustainability in supply chains. Awasthi et al. (2018) present a model for multi-tier sustainable global supplier selection using fuzzy AHP-VIKOR. Azimifard et al. (2018) develop a model for selecting sustainable supplier countries for Iran's steel industry using AHP and TOPSIS. Mohammed et al. (2019) put forward an integrated fuzzy AHP-fuzzy TOPSIS model to assess and rank suppliers. Xu et al. (2019) propose a sustainable supplier selection model using AHP Sort II in an interval type-2 fuzzy environment. Pishchulov et al. (2019) develop a sustainable supplier selection model by revisiting the voting AHP method.

As previously reviewed, AHP is one of the most widespread approaches used for supplier selection; in the present work, the AHP method is a suitable method as it supports the structuring and linking of different levels and types of element (BSC elements for the supply chain and supplier selection criteria) in order to select suppliers to increase the sustainability of the supply chain.

2.2 Sustainable supplier selection criteria

In the literature, the frameworks and models structure the criteria for sustainable supplier selection into different dimensions and levels. Organisations use various dimensions to structure criteria to select suppliers and to apply different numbers of criteria depending on their own needs. Literature reviews collect criteria structured by dimensions, but decision-makers adapt them to their case. The nature and number of criteria used have to be relevant to the studied case. Bai and Sarkis (2010) present a framework with three dimensions: business and economic, environmental and social. The business and economic dimension comprises classic business supplier selection criteria such as cost, quality, time, flexibility and innovativeness, as well as organisational criteria such as culture, technology and relationships. The environmental dimension includes pollution controls, pollution prevention, the environmental management system, resource use and pollution produced. The social dimension consists of employment practices, health and safety, and the influence of local communities, contractual stakeholders and other stakeholders. However, the example the authors present offers only three criteria within each dimension considered in the model. At this point, it is worth noting that the inclusion of many criteria in models increases their complexity, and it is recommended that decision-makers prioritise the criteria to be applied, and that these are sufficiently representative of the situation. Depending on the method, it can encounter certain difficulties, such as the human capability to process information. This is why, when using AHP or ANP, comparing between seven +/- two elements at a time is recommended, as proposed by Saaty and Ozdemir (2003), referring to Miller (1956).

Ageron et al. (2012) develop an empirical study and include the following as criteria: price, quality, reliability (dependability), service rate, delivery performance, flexibility, size of suppliers' firm, supplier certifications, associated services, length of relationships, location, environmental aspects, economic dependency, application of information technology/information systems, and social responsibility. In the results obtained in their study, classic criteria like quality, price, reliability, service rate, delivery and flexibility feature in the top ranking, while environmental issues are in the middle-low ranking and social responsibility is in the low ranking. These results indicate that some traditional criteria are highly valued and that concerns about environmental issues are higher than those about social issues. Govindan et al. (2013) structure the criteria into three dimensions: economic, green and social. The economic dimension considers costs, delivery reliability, quality and technology capability. The green dimension consists of pollution production, resource use, eco-design and the environmental management system. The social dimension integrates employment practices, health and safety, the influence of local communities and the influence of contractual stakeholders. Zimmer et al. (2016) structure the criteria into three dimensions in their literature review: economic, environmental and social issues. The economic dimension comprises management and organisation, financial performance, capabilities and external perception. The environmental dimension includes environmental practices and environmental performance. The social dimension includes internal social practices, social performance and external social practices. Awasthi et al. (2018) augment the criteria with another category (global risks), as their model aims for sustainable global supplier selection. It also considers the quality of relationships as an independent criterion. The authors consider five dimensions: economics, quality of relationships, and environmental, social and global risks. In the economic dimension, they consider cost, quality, flexibility, speed, dependability and innovativeness as criteria. The quality of relationships criteria are trust, effectiveness of communication and EDI. Environmental criteria are materials, energy, water, biodiversity, emissions, effluents and waste, and the supplier environmental selection procedure. Social criteria are labour practices and decent work, human rights, society, product responsibility and the supplier social selection procedure. Finally, global risks include currency risks, disruption risks through political instability, disruption risks through terrorism, and cultural comparability.

As previously stated, different structures can be used to classify the dimensions and criteria for supplier selection. Some works use the triple bottom line structure (Bai and Sarkis 2010; Govindan et al. 2013; Zimmer et al. 2016,) but others use a different structure (Ageron et al.

2012; Awasthi et al. 2018). The structure used should help to accomplish the objective of the model. In our work, we propose four dimensions (business, structure, interaction and sustainability) (see section 3), as the structure of an organisation and soft aspects (interaction criteria) are highly important in partnerships. This is line with Zaklad et al. (2004), who suggest that 50 per cent of inter-organisational performance is due to people factors, while process and technology factors represent 30 per cent and 20 per cent respectively.

2.3 Supply chain performance measurement systems

The literature includes different PMSs developed for supply chain management based on the BSC. Brewer and Speh (2000) propose extending the BSC internal perspective to include the objectives of information flows and partnership management. Bullinger et al. (2002) develop an integrated measurement methodology for supply network logistics that integrates the SCOR model into an adapted BSC. Bititci et al. (2005) create a structured and solid model for measuring and managing performance in extended enterprises. This approach comprises a sequence of scorecards by building a complex structure that includes both intrinsic and extrinsic inter-enterprise coordinating measures at different levels. Folan and Browne (2005) develop an extended enterprise BSC based on the repetitiveness of a structure of four perspectives (internal, suppliers, customers and extended companies) applied to each node of an extended company. Alfaro et al. (2007) design a PMS for enterprise networks using the BSC structure. Bhagwat and Sharma (2007) present a BSC for supply chains that structures the supply chain framework developed by Gunasekaran et al. (2001) in a BSC. Thakkar et al. (2009) integrate the BSC and the SCOR for SMEs into a PMS.

The development of the BSC to include environmental and social sustainability comprises different dimensions (Figge et al. 2002; Reefke and Trocchi 2013; Tseng et al. 2015; Ferreira et al. 2016; Motevali-Haghighi et al. 2016; Valenzuela and Maturana 2016; Popovic et al. 2017; Qorri et al. 2018). The objectives pursued within the environmental dimension can be grouped into objectives associated with circular economy practices, i.e. the 4Rs (recycle, reuse, reduce and recover), objectives to prevent/manage pollution, and objectives to improve management of the environmental system. Common objectives related to the 4Rs are to reduce waste, reduce water consumption, reduce need for materials, increase recycling, increase reuse, reduce energy consumption, increase renewable energy use, etc. Objectives to prevent pollution involve reducing emissions, reducing environmental accidents and reducing the use of chemicals. Objectives to improve management of the environmental system include implementing environmental certification systems and selecting suppliers with environmental certification systems. The social dimension, according to Popovic et al. (2017), should improve the objectives in four categories: labour practices and decent work, human rights, society, and product responsibility. Labour practices and decent work comprises employment benefits and characteristics, employment practices and relations, health and safety (H&S) practices and incidents, training, diversity and equal opportunities, employee welfare, and innovation and competitiveness. Human rights involves human rights implementation and integration, and basic human rights practice. Society includes community funding and support, community involvement, corruption in business, fair business operations and stakeholder participation. Product responsibility comprises consumer health and safety, product management and product satisfaction.

The BSC may or may not include additional perspectives to manage environmental and social sustainability (Figge et al. 2002). In our model, we propose to use the four classic perspectives of the BSC and two separate perspectives (environmental and social) for the sustainability objectives in order to both maintain the classic BSC structure and include sustainability, but also to cluster the objectives in a suitable manner for applying AHP. The specific BSC structure and strategic objectives used in a supply chain will depend on the supply chain's own strategy. The strategic objectives used for one supply chain may not be the most suitable for another.

2.4 Conclusion

Companies are concerned about the importance of partners' sustainable duty in their own evolution, and the sustainability of any organisation is impossible without incorporating SSCM practices (Ageron et al. 2012; Govindan et al. 2013). However, the literature lacks a methodology that selects suppliers and integrates sustainability performance into both supply chain performance and supplier assessment criteria. Hence, the main aim of the present work is to develop a multi-criteria methodology to help suppliers to bridge this gap. With this methodology, enterprises will have a tool for supplier assessment, while increasing the supply chain's sustainability by improving competitiveness.

3 The methodology to select suppliers to increase sustainability within supply chains

The methodology comprises six phases (Fig. 1). In phase 1, the BSC for supply chain sustainability measurements should be developed. If the supply chain has already developed a BSC, adapting green and social issues into it is the sole requirement. If the supply chain has no defined BSC, it is necessary to produce the whole BSC. The performance elements of the sustainability BSC are structured into six perspectives: the four classic Kaplan and Norton (1992) perspectives (financial, customer, process, and innovation and learning) and the two sustainability perspectives (social and environmental). The literature contains different structures to introduce sustainability strategic elements into a BSC (Figge et al. 2002). In our model, we wish to strategically manage environmental and social issues separately so that the analyses in the AHP model can be provided from the cluster structure. The environmental perspective may include objectives related to circular economy practices associated with the 4Rs, objectives to prevent/manage pollution, and objectives to improve management of the environmental system. Following Popovic et al. (2017), the social perspective may include objectives in four categories: labour practices and decent work, human rights, society, and product responsibility. The specific objectives that are considered in the sustainability perspectives (BSC environmental and social perspectives) will depend on the supply chain's strategy, which also applies to the other perspectives of a BSC. Each supply chain has its own strategy (top level) that needs to be operationalised using measurable objectives. The supply chain's environmental and social strategy will then be translated into specific measurable and significant objectives in the corresponding BSC perspectives.

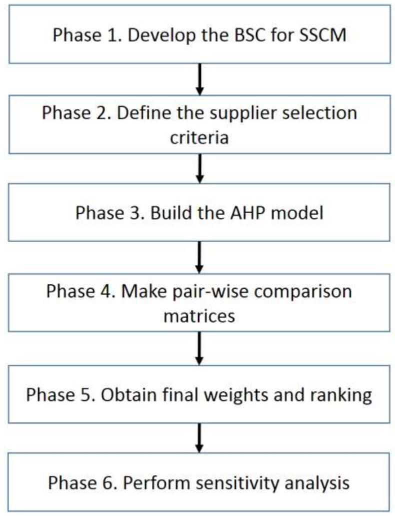


Fig. 1. Methodology

In phase 2, the supplier selection criteria are defined in four dimensions: business, structure, interaction and sustainability. Verdecho et al. (2012) present a conceptual collaboration framework to manage inter-enterprise collaborative relationships. This framework is structured into four dimensions: strategy, culture, organisational structure, and business process and information technology. Our sustainable supplier selection framework is structured into four dimensions: business, structure, interaction and sustainability. The framework of Verdecho et al. (2012) is the basis for adapting the dimensions used to select suppliers and to include sustainability criteria in the selection process. For this purpose, five adaptations are made. Firstly, we consider the definition of the BSC for the whole supply chain: the strategy dimension is mainly introduced and managed in the definition of the BSC elements (e.g. joint vision), but also in elements of the structure dimension (e.g. management support). Secondly, the business process and information technology dimension is integrated into a wider dimension called structure, which also comprises the robustness of the supplier's economic profile, internal methodologies/procedures and other structural criteria. Thirdly, the culture dimension is called interaction to design the intangible (soft factors) of the relationship. Fourthly, the business dimension comprises traditional criteria during the supplier selection process such as price, quality, delivery time, etc. Finally, the sustainability dimension is included to consider all the criteria related to environmental and social issues. The works of Bai and Sarkis (2010) and Zimmer et al. (2016) present interesting classifications of criteria for reference purposes. The specific needs, strategies and priorities of each supply chain should lead the decision on criteria selection to achieve alignment with the BSC.

In phase 3, the AHP method is used to structure the multi-criteria model. The AHP method defines the problem using a hierarchy. As Saaty (1987) suggests, "a general rule is that the hierarchy should be complex enough to capture the situation, but small and nimble enough to be sensitive to changes". The hierarchy is composed of levels linked by relationships. At the top of the hierarchy, the main objective to be fulfilled by the model is defined. The second level comprises the criteria that influence the ultimate objective being met. Afterward, several levels may be defined to structure the subcriteria and attributes. At the lowest level, different alternatives are modelled.

Our model defines four levels (see Fig. 2): the overall objective (increase sustainability in the supply chain); the supply chain's BSC (performance elements, PE), including sustainability assessment; supplier criteria (SC); and suppliers (alternatives).

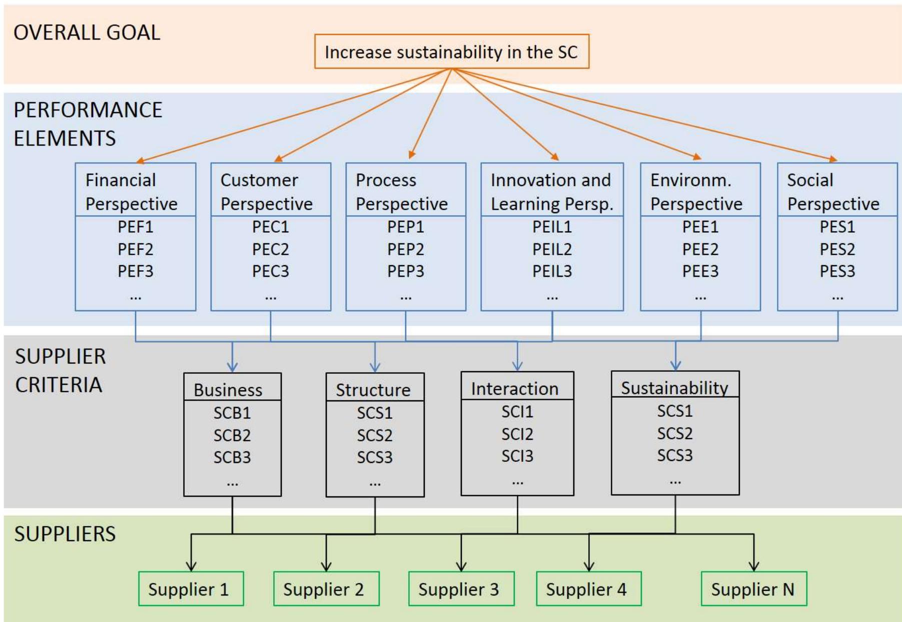


Fig. 2. The AHP multi-criteria model to select suppliers for sustainable supply chains

In phase 4, pair-wise comparison matrices are developed using the basic scale of Saaty (1980). This implies that each element at an upper level is compared with elements in the level immediately below (Saaty 2008). Then all the local priorities are computed at each level. In each pair-wise comparison matrix, it is important to check the consistency of judgements. Consistency is measured by the consistency index. Once obtained, the consistency ratio (CR) is calculated. For each matrix, CR ≤ 0.10 assures the consistency of judgements and the model's final results are acceptable. If CR > 0.10, then judgements have to be reviewed.

In the next phase, phase 5, the overall priorities are computed so that the final ranking of alternatives is obtained. Following Saaty (2008), the priorities obtained from the comparisons are used to weight the priorities on the level immediately below. This step is repeated for each element. Then the weighted values of each element on the level below have to be added and the overall (or global) priority obtained. Continue this process of weighting and adding until the final priorities of the alternatives at the bottom level are obtained.

Finally in the last phase, phase 6, a sensitivity analysis is performed to verify if the changes in the pair-wise comparison matrices actually affect the final ranking. What this phase does is check if the final ranking is consistent enough.

4 Case study

The proposal was applied to select suppliers for a supply chain from the agri-food sector using a sustainability perspective. The supply chain supplies fruits and finished products to the market and takes care of the importance of sustainability issues for its customers. Several sustainability initiatives are introduced into different processes, of which supplier selection is one. A committee of four decision-makers who occupied management positions (purchasing and operations) in two companies, a fruit producer and a processor, participated in the development of the case study.

Phase 1 of the proposal comprises defining the performance elements, objectives and KPIs for the six perspectives—the four BSC perspectives (financial, customer, process, and innovation and learning) and the two sustainability perspectives (environmental and social perspectives)—as the economic sustainability dimension is already introduced into the financial perspective of the BSC. Table 1 shows these elements for the six perspectives.

Table 1. Objectives and KPIs of an agri-food supply chain

Perspectives	**Objectives**	**KPIs**
Financial	FO1. Cut production costs	KPI1 = % variation in production cost
	FO2. Increase profitability	KPI2 = % ROI variation
		KPI3 = % ROA variation
	FO3. Reduce delivery cost	KPI4 = % variation in delivery cost
Customer	CO1. Increase customer satisfaction	KPI5 = % customer satisfied/total customers
		KPI6 = % variation in customer complaints
		KPI7 = % number of backorders to the total number of orders
	CO2. Increase market share	KPI8 = % market share
Process	PO1. Increase shelf life	KPI9 = % variation in shelf life
		KPI10 = % accomplishment of relative humidity and temperature to comply with standard regulations
	PO2. Increase taste properties	KPI11 = % variation in brix values
	PO3. Increase product safety	KPI12 = % making laboratory checks and monitoring processes according to certification schemes
		KPI13 = % of materials with a quality certification of origin
Innovation and Learning	IO1. Increase innovation capability	KPI14 = % of personnel suggestions implemented
	IO2. Increase compromise	KPI15 = Number of policies and

	of personnel	incentives developed
Environmental	EO1. Reduce environmental impacts	KPI16 = % variation in water use KPI17= % variation in energy use KPI18= % variation in recycling and reuse
	EO2. Increase pollution prevention	KPI19 = Pesticide control (quantity and frequency of pesticide use according to regulations). Implementation of action plans (good practices) to reduce their use KPI20 = Fertiliser control (quantity and frequency of fertilisers use according to regulations). Implementation of action plans (good practices) to reduce their use KPI21 = Environmental certification (maintain own certification and agree with suppliers their commitment to obtain environmental certificates such as GlobalG.A.P., LEAF Marque, etc.)
Social	SO1. Improve employment practices	KPI22 = Training planned per critical resource
	SO2. Increase health & safety (H&S) culture	KPI23 = Number of incidents and accidents KPI24 = Implemented H&S programmes

Phase 2 comprises defining supplier criteria into four groups: business, structure, interaction and sustainability. Table 2 shows the subcriteria for each group. Circular economy practices include criteria associated with the 4Rs. Pollution practices include criteria to prevent/manage pollution, as well as criteria related to the environmental system management as agreed by the decision-makers.

Table 2. Supplier criteria

Criteria	**Subcriteria**
Business	B1. Quality
	B2. Price
	B3. Delivery time
	B4. Flexibility

Structure	S1. Financial profile
	S2. Quality methodologies
	S3. Process alignment
Interaction	I1. Coordination
	I2. Long-term partnership
Sustainability	SU1. Circular economy practices
	SU2. Pollution practices
	SU3. Employment practices
	SU4. Health and safety practices

The AHP model is built in phase 3. Fig. 3 shows the AHP model defined in the Superdecisions™ software. The model has four levels and twelve clusters. At the top level, the main goal of this model is defined: to increase sustainability in the supply chain. This goal consists of a node in the top cluster called *1 Goal*. The second level comprises six clusters of the objectives defined in Table 1, respectively corresponding to the six perspectives: *2 Financial Perspective*, *3 Customer Perspective*, *4 Process Perspective*, *5 Innovation and Learning Perspective*, *6 Environmental Perspective* and *7 Social Perspective*. The third level consists of the four criteria clusters defined in Table 3: *8 Business*, *9 Structure*, *10 Interaction* and *11 Sustainability*. Finally, a cluster with the alternatives (called *12 Alternatives*) forms the fourth level.

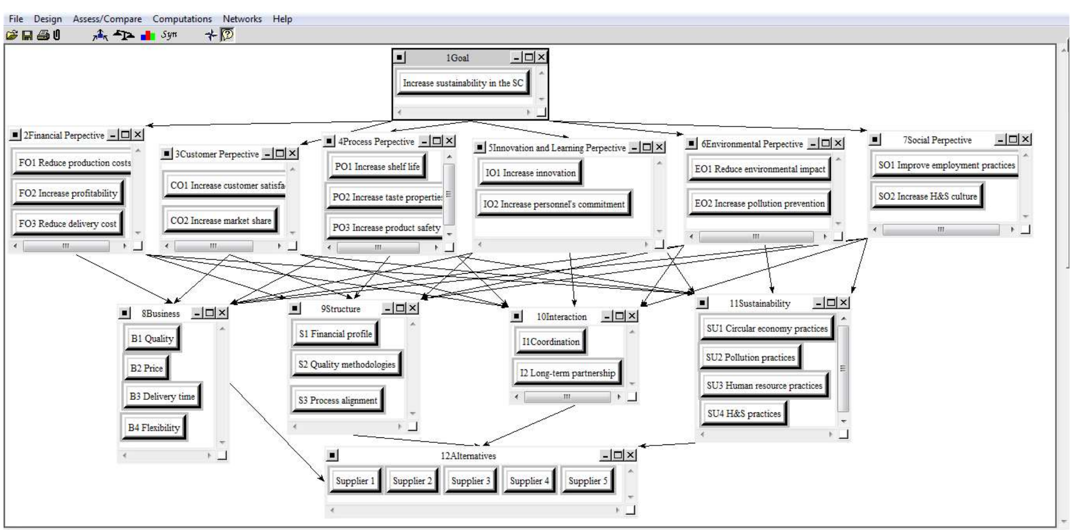


Fig. 3. AHP model in Superdecisions™

In phase 4, the decision-makers who formed the committee completed the pair-wise comparison matrices. Decision-makers met during several sessions to agree on judgements by consensus. To complete the matrices, the Saaty (1980) scale was used. First, the pair-wise comparison matrices of the different clusters of objectives in relation to the goal were completed and local priorities were obtained. Table 3 shows the pair-wise comparison matrix of the financial objectives in the *2 Financial Perspective* cluster in relation to the goal. This table also shows the priorities and how the consistency ratio is below 0.1.

Table 3. Pair-wise comparison matrix of the financial objectives in relation to the goal

	FO1	FO2	FO3	Priorities
FO1	1	1/5	3	0.17818
FO2	5	1	9	0.75140
FO3	1/3	1/9	1	0.07042
			CR	*0.0279*

Next, the pair-wise comparison matrices of the criteria within each criteria cluster in relation to the objectives within each objective cluster were completed and local priorities were obtained. Table 4 shows the pair-wise comparison matrix of the business criteria within the *8 Business* cluster in relation to the FO2 objective to increase profitability. This table also shows the priorities and the consistency ratio.

Table 4. Pair-wise comparison matrix of the business criteria in relation to objective FO2

	B1	B2	B3	B4	Priorities
B1	1	1/3	7	3	0.26587
B2	3	1	7	7	0.58417
B3	1/7	1/7	1	1/3	0.04904
B4	1/3	1/7	3	1	0.10093
			CR		*0.06083*

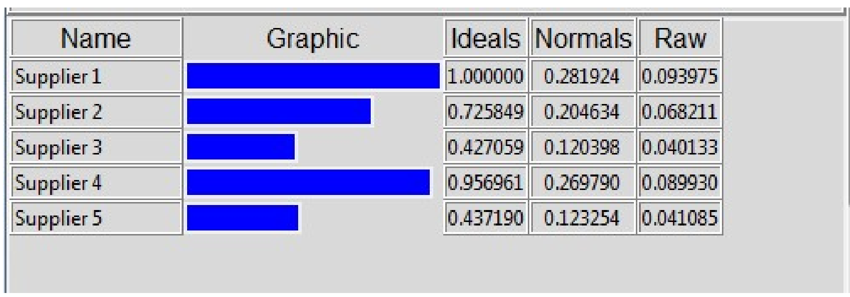
In the next step, the alternatives were compared in relation to each criterion. Table 5 shows the pair-wise comparison matrix for the five suppliers in relation to the SU1 Circular economy practices criterion. This table shows the following priorities: 0.60032 (supplier 1), 0.03553 (supplier 2), 0.08584 (supplier 3), 0.15877 (supplier 4) and 0.11954 (supplier 5).

Table 5. Pair-wise comparison matrix of suppliers in relation to the SU1 criterion

	Supplier 1	Supplier 2	Supplier 3	Supplier 4	Supplier 5	Priorities
Supplier 1	1	9	7	5	7	0.60032
Supplier 2	1/9	1	1/3	1/5	1/5	0.03553
Supplier 3	1/7	3	1	1/3	1	0.08584
Supplier 4	1/5	5	3	1	1	0.15877
Supplier 5	1/7	5	1	1	1	0.11954
					CR	*0.05575*

After obtaining all the pair-wise comparison matrices, the unweighted supermatrix was built (Superdecisions 2018). The supermatrix is an n x n matrix, where n is each element of the model. The priorities that derive from the pair-wise comparisons are included in the unweighted supermatrix. Table 6 shows the unweighted supermatrix. As an example, the priorities of the business criteria in relation to the FO2 objective (obtained in Table 4) are introduced into Table 6 and depicted in italics.

In phase 5, the final priorities were obtained. Table 7 shows the final priorities for all the elements: objectives, criteria and alternatives. For the alternatives (suppliers), Fig. 4 shows the normalised value of the final priorities. The final priorities can be read in the Normals column: 0.281924 (supplier 1), 0.204634 (supplier 2), 0.120398 (supplier 3), 0.269790 (supplier 4) and 0.123254 (supplier 5). After considering the results, supplier 1 took the highest priority and should be selected. In the final ranking, supplier 4 came second, supplier 2 third, supplier 5 fourth and supplier 5 last.



Name	Graphic	Ideals	Normals	Raw
Supplier 1		1.000000	0.281924	0.093975
Supplier 2		0.725849	0.204634	0.068211
Supplier 3		0.427059	0.120398	0.040133
Supplier 4		0.956961	0.269790	0.089930
Supplier 5		0.437190	0.123254	0.041085

Fig. 4. The final priorities for suppliers in Superdecisions™

Regarding objectives, Table 8 shows the normalised priorities, ordered from the highest to the lowest value. As observed in the normalised and accumulated columns, the three most important objectives of the BSC for supply chain sustainability are: FO2 (increase profitability), CO1 (increase customer satisfaction) and IO1 (increase innovation). They are assigned around 53.68 per cent of priority (accumulated value). In addition, there are other important objectives, such as PO3 (increase product safety), FO1 (reduce production costs), SO2 (increase H&S culture) and CO2 (increase market share). The top three objectives and these four represent around 80 per cent of priority. Thus, they will be the most relevant to monitor in the supply chain.

Table 8. Priorities for the BSC objectives

BSC Objectives	**Normalised and ordered**	**Norm. Accumulated**
FO2 Increase profitability	0.297951	0.297951
CO1 Increase customer satisfaction	0.119421	0.417372
IO1 Increase innovation	0.119421	0.536794
PO3 Increase product safety	0.095535	0.632329
FO1 Reduce production costs	0.070653	0.702982
SO2 Increase H&S culture	0.056331	0.759313
CO2 Increase market share	0.039807	0.799120
IO2 Increase personnel’s commitment	0.039807	0.838927

EO1 Reduce environmental impact	0.038013	0.876940
PO1 Increase shelf life	0.031845	0.908785
PO2 Increase taste properties	0.031845	0.940630
FO3 Reduce delivery cost	0.027921	0.968551
SO1 Improve employment practices	0.018777	0.987328
EO2 Increase pollution prevention	0.012672	1.000000

Finally, in phase 6, a sensitivity analysis was performed to verify that the solution is consistent when modifying priorities. Fig. 5 shows the sensitivity analysis (plot mode) of the alternatives when modifying the priorities of objective FO2 (increase profitability). As observed, supplier 1 remains the preferred solution for all the values. When performing the same analysis (in the bar chart mode) for CO1 (increase customer satisfaction) (Fig. 6), the priority of this objective needs to increase to 0.684 to modify the solution (supplier 4 is thus the first option), which is quite a significant change. The solution proved consistent after performing the sensitivity analysis for the model.

Additionally, readers are referred to the following url to access Tables 6 and 7: http://www.cigip.upv.es/docs/2020_CEJOR_Verdecho%20et%20al_Publish.pdf

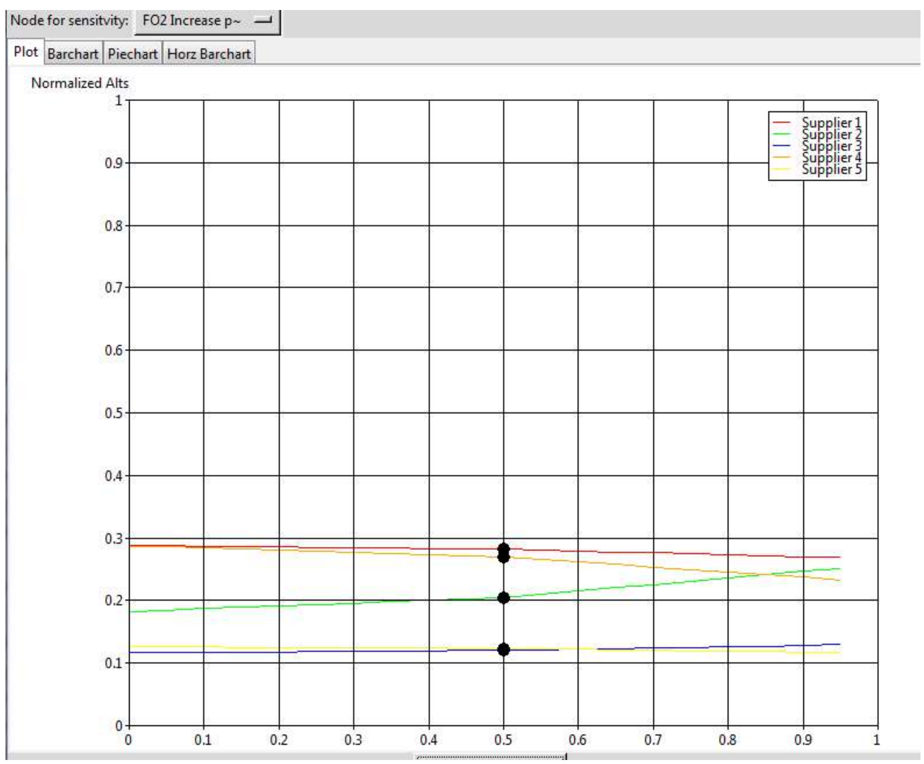


Fig. 5. Sensitivity analysis for alternatives as regards objective FO2 in Superdecisions™

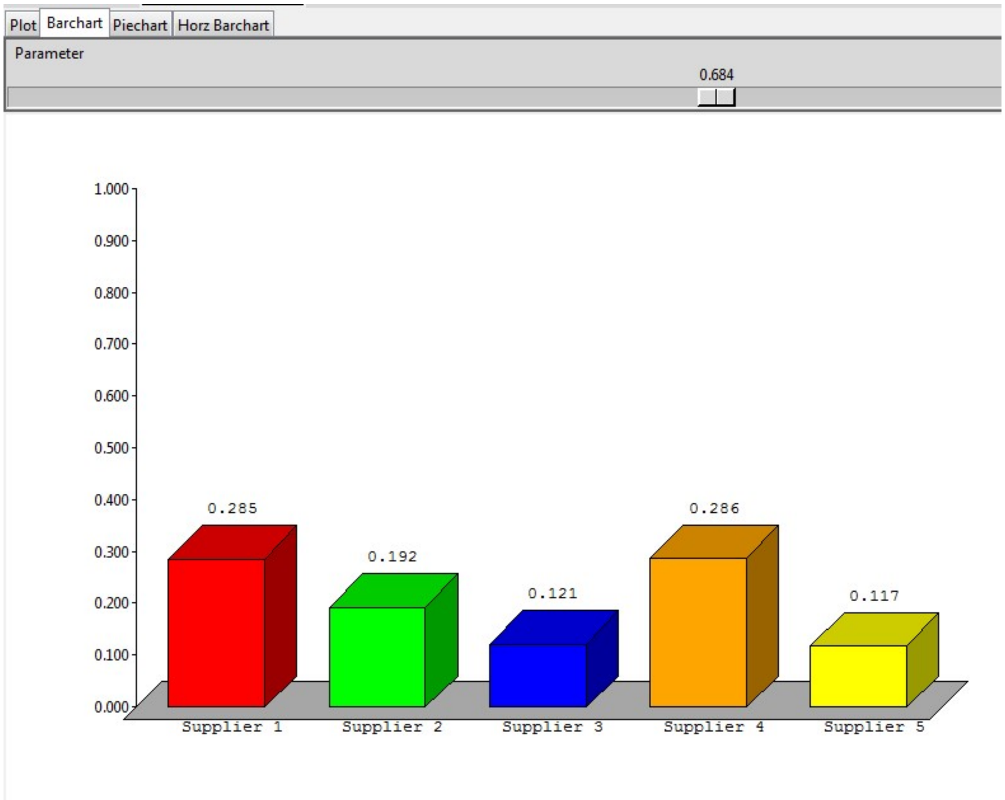


Fig. 6. Sensitivity analysis for alternatives regarding objective CO1 in Superdecisions™

5 Conclusions

The literature offers different tools and models to select suppliers, but lacks a proper model to integrate the supplier selection process with supply chain sustainability management to increase synergies toward sustainability and, at the same time, obtain coherence between the supplier selection process and the supply chain's deployed strategy. This paper develops an MCDA methodology that focuses on bridging this gap by establishing two main groups of criteria to select suppliers: the supply chain's sustainability performance and sustainable supplier selection criteria. Applying this methodology provides many benefits. The first is to support the definition of the supply chain strategy. The second focuses on a strategy for long-term sustainability. The third clarifies and understands the main criteria to select suppliers by considering the supply chain's sustainability. Finally, the last is about using the AHP to structure and compute the decision problem, because it allows decision-makers' judgements to be introduced. The methodology has been applied to an agri-food supply chain, and ranked five suppliers. Future research shall focus on validating this methodology in other applications (other supply chains) and on introducing uncertainty (such as fuzzy sets) into MCDA models to compare the obtained results.

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