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Review

Sustainability metrics for real case applications of the supply chain network design problem: A systematic literature review

Carlos A. Moreno-Camacho [a, b, c], Jairo R. Montoya-Torres [a], Anicia Jaegler [b, c, *], Natacha Gondran [c]

[a] Grupo de investigación en Sistemas Logísticos, Faculty of Engineering, Universidad de La Sabana, km 7 autopista norte de Bogotá, D.C., Chia, Colombia
[b] Kedge Business School, 680 Cours de la Libération, 33405, Talence, France
[c] Mines Saint-Etienne, Univ Lyon, Univ Jean Moulin, Univ Lumière, Univ Jean Monnet, ENTPE, INSA Lyon, ENS Lyon, CNRS, UMR 5600 EVS, Institut Henri Fayol, F – 42023, Saint-Etienne, France

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ABSTRACT

Increasing pressure from governments and stakeholders has motivated the study of sustainability assessment in the supply chain context at operational, tactical, and strategic levels. Several papers have been published during the last two decades, and the number is still rising. Although several authors present complex models that include environmental and social assessment, the applicability and usefulness of these works is often limited by lack of data availability and lack of consensus in what is to be measured on implementations of sustainable practices and strategies. This paper presents a systematic literature review of works addressing the supply chain network design (SCND) problem, in which at least two of the three dimensions of sustainability are assessed. This paper aims to identify indicators that are used when sustainability is evaluated in real applied cases. A total of 113 papers from 2015 to 2018 were selected, including documents studying forward, reverse, and closed loop supply chains (CLSC). Indicators in the economic, environmental, and social dimensions were classified according to an existing framework in the sustainable supply chain literature. The review finds a highlighted emphasis on environmental considerations; social criteria are still hardly studied. The study country origin analysis also shows an increasing concern for sustainable practices in developing economies, mainly in Asia. Finally, this paper presents a brief description of the areas where research opportunities exist, including sectors, measures, and methodologies to assess sustainability in the SCND problem.

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* Corresponding author. Kedge Business School, 680 Cours de la Libération, 33405, Talence, France.

E-mail addresses: carlosmorca@unisabana.edu.co (C.A. Moreno-Camacho), jairo.montoya@unisabana.edu.co (J.R. Montoya-Torres), anicia.jaegler@kedgebs.com (A. Jaegler), natacha.gondran@emse.fr (N. Gondran).

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1. Introduction

Companies all around the world are under continuous pressure from stakeholders and governments to promote a fair and transparent behavior not just in relation to the distribution of money but also in the use of natural resources, impact over the surrounding and global ecosystems, and protection of people and community development (UN General Assembly, 2015). The increasing concern about climate change, poverty, and social development has opened the path for the integration of environmental and social aspects with economic considerations in organizational decision models (Brandenburg et al., 2014). In fact, during the last two decades the integration of the triple-bottom-line (TBL) dimension in classical operations management problems has attracted more and more researchers and practitioners, making sustainability one of the most active topics in the supply chain management research field. This is reflected by the growing number of original papers addressing this issue (Ansari and Kant, 2017; Gupta and Palsule-Desai, 2011; Rajeev et al., 2017; Seuring and Müller, 2008; Touboulic and Walker, 2015) and also the high number of review papers aiming to synthesize the progress in this area (Carter and Washispack, 2018).

Sustainable supply chain management (SSCM) has been defined in the academic literature as “the creation of coordinated supply chains through the voluntary integration of economic, environmental, and social considerations with key inter-organizational business systems designed to efficiently and effectively manage the material, information, and capital flows associated with the procurement, production, and distribution of products or services in order to meet stakeholder requirements and improve the profitability, competitiveness, and resilience of the organization over the short- and long-term” (Ahi and Searcy, 2013, p359). From this definition, at least two aspects stand out and motivate the present review. On the one hand is the measurable character of sustainability in the supply chain context that matches with the words *efficient* and *effective.* Such consideration views that sustainability is not just an external standard to satisfy requirements from stakeholders (effectiveness) but must also consider the accomplishment of internal standards to ensure the profitability and continuity of business (efficiency). Sustainability addresses the balance of economic, environmental, and social objectives. For Taticchi et al. (2013), the notion of balance in performance measurements of sustainability implies the necessity of using different metrics and perspectives that tie together and provide a holistic view of the organization. Hence, the use of metrics constitutes an important element to determine an organization's efficiency and effectiveness through comparing competing alternative solutions (Dekker et al., 2012; Hervani et al., 2005).

On the other hand, the term *sustainability* presupposes a behavior that reaches a steady state within established parameters for the factors evaluated in each dimension of sustainability (i.e., economic, environmental, and social) in a way that can be maintained in the long term (Kannegiesser and Günther, 2014). Therefore, company decisions at the strategic level that have considerable impacts in the long term also have a great impact on sustainable performance, and they limit the field of action in tactical and operational contexts. It is not a coincidence that academics have become increasingly interested in sustainability assessment regarding decisions at the strategic level of the supply chain context (Barbosa-Póvoa et al., 2018). One of the most critical decisions at the strategic level of supply chain management is supply chain network design (SCND). From the upstream level in general terms, SCND encompasses the decisions concerning the selection of suppliers; the definition of the number, location, technology, and capacity of production and storage facilities; the determination of material flow through the facilities; the definition of the transport mode; and the allocation of market demand. These kinds of decisions affect the economic, environmental, and social performances of companies and the whole supply chain. They can add greater complexity in the context of market globalization (Gupta and Palsule-Desai, 2011).

Over the last several years, the number of publications addressing environmental and social assessments of the SCND problem has increased, rapidly. Eskandarpour et al. (2015) present a review of sustainable supply chain design, with special emphasis on optimization models. The authors consider studies from 1990 to 2014 containing mixed-integer mathematical formulations for the forward supply chain design and include the evaluation of at least two of the three dimensions of sustainability (i.e., economic, environmental, or social). The authors review a total of 87 peer-reviewed papers; notably more than 70% of the works were published after 2009. As with several other reviews, the authors point out the higher interest and development of the inclusion of environmental considerations in the SCND problem, in comparison with the minor attention to social aspect concerns (Jaegler and Sarkis, 2014). Specifically, the authors reported that about 96% of reviewed papers include environmental considerations, whereas just about 15% of the papers address social aspects. The authors emphasize that life cycle assessment (LCA) is the dominant approach to incorporate environmental factors, but not all impact categories are considered to the same extent. Furthermore, environmental performance is often limited to the measurement of GHG emissions or energy consumption, which were formerly the most common criteria used to address environmental issues. In the social dimension, the assessment is often limited to the accounting of jobs created.

Despite the relevant progress in the inclusion of metrics to evaluate sustainability in the supply chain field, the assessment of social and environmental dimensions faces serious challenges, namely, (1) the lack of consensus on what should be measured in each dimension (Barbosa-Póvoa et al., 2018) and (2) the scarcity of available data mainly related to the social dimension of sustainability (Finkbeiner et al., 2010). These are the same as the two aforementioned critical drawbacks in the implementation of sustainable practices for real applications of SCND.

According to Stindt et al. (2016), assessing sustainability in the supply chain field requires multidisciplinary teams, because the approach extends beyond economic consideration to include ecological and social factors, which management researchers are often unfamiliar with. In this sense transdisciplinary research is encouraged; however, the integration between SCM models and social and environmental sciences is weak, affecting the quality of the proposed models. The operations research (OR) methods commonly used to address problems in SCND can often be criticized for their shortcomings in fieldwork (Stindt et al., 2016). In some cases, the selection of metrics is too generic. The chosen indicators are too simplistic and do not represent the complexity of the situation. Then, they do not respond to the challenges faced by the specific industry under study in economic, environmental, or social dimensions. This leads to a lack of holistic understanding and shortcomings in the abstraction and its consequent modeling of real-world problems (Stindt, 2017). Hence, the usefulness of these works as support for decision-making in real applications is often compromised.

In this context, this paper seeks to identify and synthesize the inventory of sustainability assessment metrics used in the supply chain field at the strategic level, specifically those studies that address the design of the SCND within a real context, and based on this, to identify promising research gaps in industry-specific research and transdisciplinary research. Particularly, our review is intended to respond the three following questions:

1. Which are the common economic, environmental, and social criteria considered in applied cases of design or redesign of supply chain networks?
2. Which solution methods are employed to deal with the SCND problem?
3. Which real cases are described in the scientific literature?

The remainder of the paper is organized as follows. Section 2 presents the position of the paper within the existing literature. The methodology of the systematic literature review is presented in Section 3. A descriptive analysis of the selected papers is presented in Section 4. In Section 5, a detailed description of the indicators used to measure sustainability in the economic, environmental, and social dimensions is given. Section 6 presents an analysis of the methodologies proposed to solve the problem and their sectoral and geographical contexts. Section 7 presents conclusions based on the research questions and proposes some research avenues.

2. Position in the literature

Since about 2009, sustainability in the supply chain field has been the object of a high number of reviews. To identify potential conflicts between the scope of this work and previous review articles, we began reviewing the review papers identified in Carter and Washispack (2018): 59 systematic literature reviews in the sustainable supply chain management field from 2008 to 2017. The scope of our study is not exactly the same: our focus could highlight other review papers not included in the Carter and Washispack (2018) review.

Based on the focus of the reviews, we distinguish five types of studies:

1. General reviews analyzing and synthesizing the progress of the major trends in supply chain management
2. Theory-building studies analyzing and tracking the concept of sustainability and its evolution in the supply chain field
3. Reviews focusing on solution methodologies, mainly OR methods
4. Reviews dealing with specific functions in supply chain management, such as green procurement, sustainable supplier selection, green manufacturing, and sustainable supply chain design
5. Reviews focusing on a sustainability performance measurement scheme and identification of metrics, the latter of which is also the approach of this work

Considering the existence of literature reviews addressing topics in neighboring domains, it is necessary to check whether the scope of this paper has been covered already by previous works. In the intersection between sustainable supply chain management and identification of metrics, works such as Ahi and Searcy (2015a, 2015b), Hassini et al. (2012), Popovic et al. (2018), Tajbakhsh and Hassini (2015), and Taticchi et al. (2013) were identified.

Ahi and Searcy (2015a) identify and analyze metrics published in the literature on green supply chain management and sustainable supply chain management. The authors present more than 2,000 different metrics, showing the lack of agreement about what should be addressed in the sustainable supply chain. Although this work does not include social aspects, the analysis of social metrics in a sustainable supply chain for the same sample of articles is presented later in Ahi and Searcy (2015b). Hassini et al. (2012) carried out a literature review of papers published from 2000 to 2010 with the goal of extracting a common framework for sustainable supply chain performance and metrics. Their paper focuses on tactical and operational aspects, and presents a framework for the construction of composite indicators aligned with the goals of each actor within the supply chain and its application to a case study of a Canadian company in the energy sector.

Taticchi et al. (2013) explore the evolution of performance measurement in the sustainable supply chain management literature. It implies the process of using data for supporting managers in decision-making processes. The authors emphasize the relevance of assessing sustainability in the whole supply chain perspective, even as literature in performance measurement usually addresses the use of measurement frameworks, such as a balance score card, GRI, SCOR, and their integration with sustainability practices, which are focused on individual organizations. Tajbakhsh and Hassini (2015) review the literature on performance measurement of sustainable supply chains with a focus on comprehensive measures that include multiple supply chain partners as well as different sustainability aspects, not just the three dimensions from a TBL approach but three new dimensions originating from the combination of two of the primary dimensions. The authors present a set of proposed indexes to evaluate sustainability for benchmarking and research purposes addressing resources, products, and facilities.

Most of the previous works have focused on operational and tactical decision levels in the supply chain management and their efficiency and effectiveness assessment. Great efforts have been given to production, scheduling, inventory, and reverse logistics, but the literature on strategy has been only partially considered (Taticchi et al., 2013). Besides, SCND plays a subordinate role in the existing research. For instance, Brandenburg et al. (2014) develop a content analysis of 134 papers from 1994 to 2012 aiming to identify aspects and factors considered in the existing quantitative models, what are the limits of these models, and what sustainability aspect has not been evaluated. This review contains 13 papers in the SCND field.

Our review paper is different from previous papers in that it provides an analysis of the existing literature and identifies sustainability metrics used at the strategic level of supply chain management, specifically addressing supply chain design in real applications. As is stated by Taticchi et al. (2013), research is required to develop principles that consider the intricacies of supply chain structures that distinguish them from the management of individual firms. Moreover, we focus on real applications because several authors emphasize the importance of developing metrics that take into consideration the context (e.g., the specific country and industry characteristics) (Ahi and Searcy, 2015a; Taticchi et al., 2013), because to be valid they need the kind of public acceptance that can be achieved only through well-structured participatory decision processes.

3. Research methodology

In this section, the application of the research methodology is described. For our research, the methodology proposed by Denyer and Tranfield (2009) is applied. The authors define a systematic literature review as a structured methodology including five steps: location of studies, selection and evaluation of contributions, analysis and synthesis of data, and reporting of the evidence. A systematic literature review enables eliminating bias and errors in the process through a clear definition of excluding/including criteria selection. The description of the five steps considered in the methodology is introduced in the following sections.

3.1. Question formulation

The first step aims to define one or more research questions guiding the study. In this sense, Denyer and Tranfield (2009) propose to use the acronym CIMO (context, intervention, mechanism, outcomes) to define precisely the scope of the review. Hence, the main topic of our work is to identify the real application of SCND problems in several sectors (C), under a context of sustainable development (I), which are the leading sustainability indicators and tools chosen by companies or researchers to measure sustainability (M), and meet the economic, environmental, and social demands (O).

3.2. Locating studies

To locate the related publications addressing sustainable supply chain design a total of 21 keywords were proposed: 5 keywords in the context of the classical supply chain design (SCND) problem at the strategic decision level and the remaining related to sustainability topics, extracted from the core subjects of social responsibility established by the ISO 26000 Guidance. The list of keywords is shown in Table 1.

To execute the search on the databases, a set of 14 keyword equations were constructed by combining the listed keywords using simple operators and Boolean logic. The keyword equations were designed combining at least one keyword from terms related to SCD and at least one from the terms related to sustainability to avoid too generic and irrelevant results out of the scope of the research. The applied keyword equations are shown in Table 2.

3.3. Study selection and evaluation

The search was conducted using the databases Scopus and ISI Web of Science because those are some of the major databases providing access to several high-quality peer-reviewed journals and have widespread access to academic institutions. A total of 1,976 papers were yielded applying the keyword equations focusing on the title, abstract, and author keyword domains.

In a first stage, abstracts from the total number of papers were read to ensure pertinence of the study. In this stage, to obtain and include relevant documents to focus on, a list of inclusion and exclusion criteria was established: (1) search for papers, published in a peer-reviewed scientific journal in English, (2) papers from 2015 to 2018, (3) no reviews were included, (4) papers not related to the strategic decision-making level were excluded in accordance with the framework classification proposed by Manzini et al. (2011) (see Fig. 1), (5) papers dealing just with routing or allocation over already defined networks were excluded from the study, and (6) selected papers must contain an assessment of at least two out of three sustainable dimensions under study (i.e., economic, environmental, or social). Indeed, many papers mention some terms related to sustainability issues in their abstracts but do not present indicators to measure it. Finally, (7) only results from the application on a real case study were included in this review. Optimization models and non-optimization studies are included for forward, reverse, or a closed loop supply chain. By applying the described delimitations, a total of 115 papers were selected.

3.4. Analysis, synthesis, and reporting of results

In these steps, a total of 115 papers were thoroughly read and classified attending to the following categories according to their content. First, we used some descriptive category analysis related to the (1) year, (2) journal of publication, and (3) country of association of the authors. Additionally, papers were classified according to (4) the dimensions of sustainability addressed and indicators used to evaluate them. To this end, several existing frameworks classify the indicators within subcategories for each of the dimensions of sustainability assessed; examples of this are the frameworks proposed by the Global Reporting Initiative (GRI), the United Nations Commission on Sustainable Development (CSD), and the Institution of Chemical Engineers (IChemE) (Singh and Trivedi, 2016).

In this research, the framework proposed by Chardine-Baumann and Botta-Genoulaz (2014) is used to classify the indicators for sustainability assessment. These authors propose an exhaustive model composed of 15 sustainable fields, 5 fields for each dimension (i.e., economic, environmental, or social), and each field attends to one of the main challenges for companies to evaluate sustainable performance. Fig. 2 shows the list of fields by sustainability dimension.

Within the analysis, the indicators were classified into the listed categories; each indicator is assigned to exactly one category.

Table 1
List of keywords.

Related to SCD	Related to sustainability
Supply chain—network design, configuration, planning, optimization, facilities location, supplier selection	Social performance, environmental performance, social responsibility, sustainable development, compliance, ethics, human rights, social health, fair labor practices, employment, community development, reuse, recycling, social investment, community development, eco-design

Table 2
Keyword equations.

#	Keyword Equation
1	(Supply chain AND Network design AND Sustainab*)
2	(Supply AND chain AND network AND configuration AND Sustainab*)
3	(Supply AND chain AND network AND planning)
4	(facilit* AND location AND planning AND supply AND (chain OR network))
5	(Supply AND chain AND network AND social AND performance)
6	(Supply AND chain AND network AND environment* AND performance)
7	((Supply AND chain OR logistics AND network) AND (social AND responsibility))
8	((Supply AND chain) AND (ethics OR Human rights)))
9	((Supply AND chain AND network) AND (Employment OR (fair AND labor)))
10	(Supply AND chain AND design AND reuse AND recycling)
11	(Supply AND chain AND network AND logistics AND optimization)
12	((Supply AND chain AND network AND logistics) AND ((social AND investment) OR (community AND development))))
13	(Supply AND chain AND network AND design AND sustainable AND development)
14	(Supply AND chain AND network AND eco AND design)

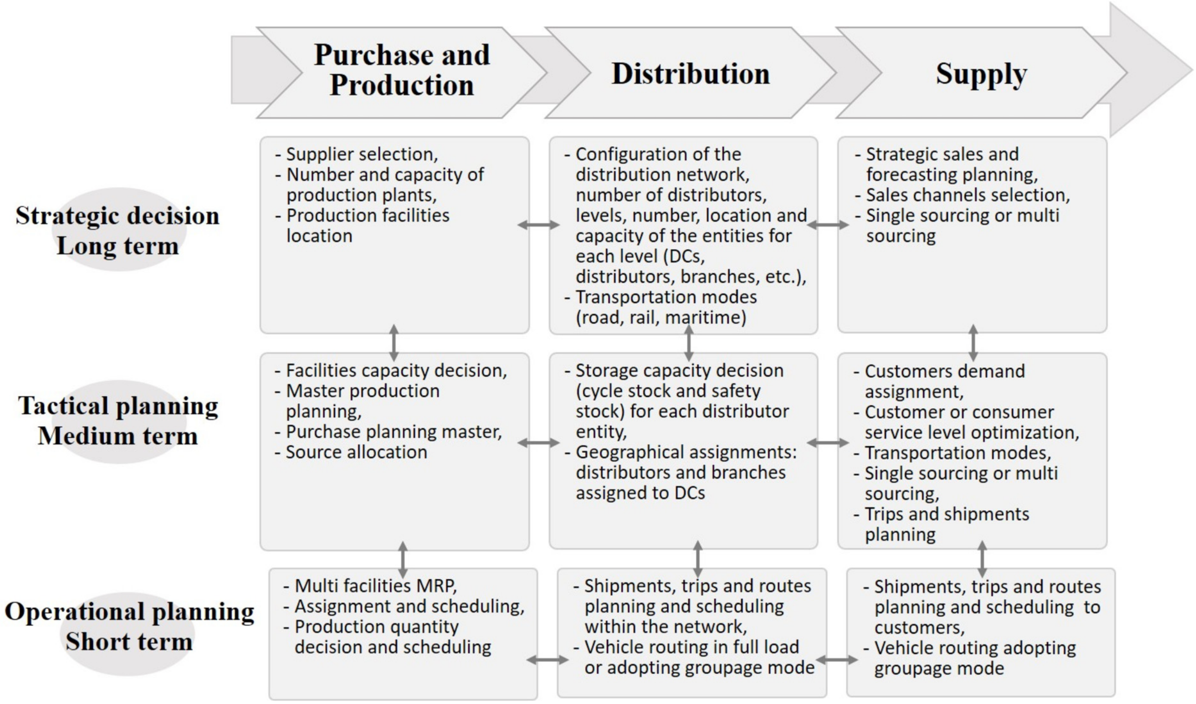

Fig. 1. Issues and decisions in distribution network planning optimization (Manzini et al., 2011).

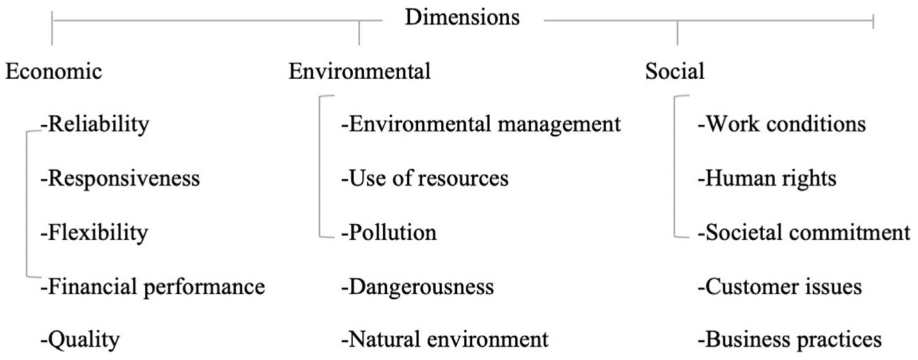

Fig. 2. A classification scheme for sustainability indicators (from Chardine-Baumann and Botta-Genoulaz, 2014).

Furthermore, the papers were classified according to their (5) modeling approaches and (6) solution techniques. The former attends to the features of the problem regarding the number of objectives and nature of data, specifically uncertain or deterministic data. The latter aims to identify the most-common tool to solve the stated problem. Along with the identification of sustainability measures, the solution technique is one of the essential elements in the classification to demonstrate the applicability of different techniques as a supporting decision tool in real cases.

The last part of the methodology proposed by Denyer and Tranfield (2009) consists of reporting the findings of the review. The following sections report the description, analysis of results, and propose various research perspectives.

4. Descriptive analysis

4.1. Distribution across time and main journals

From the review carried out by Eskandarpour et al. (2015), it is possible to appreciate a rising interest in the sustainable SCND problem since 2009; about 80% of the papers under revision by the authors were published from this year and later. This growing trend is continuing and is also evident in the case studies published from 2015 to 2018, as shown in Fig. 3.

As far as the journal of publication is concerned, the papers are distributed among a total of 52 journals, 33 of which having just one publication. A summary of the number of papers by journal is presented in Fig. 4. Nineteen journals contain nearly the 70% of the reviewed papers; the remaining are found in 33 journals, each with just one publication.

4.2. Study of the three dimensions of sustainability

Dimensions of sustainability have been included progressively into supply chain management and the SCND problem. Green supply chain design (GSCD), including economic and environmental criteria, has been more widely studied. There has been less inclusion of social criteria, probably due to two main factors: (1) there is not a collective agreement about the indicators to use and (2) several social indicators are qualitative and others are quantitative by nature, so a standard unit to express consensual social factors does not exist.

Fig. 5 presents the distribution of the reviewed papers concerning the three dimensions of sustainability. It is observed that the economic objective is always present in the whole set of studies. Out of the 115 papers 111 include environmental criteria, and 47 out of the 115 papers address the problem considering two of the three dimensions of sustainability. This first result is consistent with the results of previous reviews, such as Eskandarpour et al. (2015) and Seuring and Müller (2008). Meanwhile, the number of papers considering social criteria seems high; this result affects a large number of papers addressing the problem of partner selection in which the use of qualitative criteria is more extended and so there is the addition of social criteria. Finally, there is just one paper in the intersection between the social and environmental dimensions outside the economic scope. Govindan et al. (2016a,b,c) present a supplier selection problem regarding corporate social responsibility (CSR) criteria as is defined by ISO 26000, so the environment dimension is evaluated as a core subject for social responsibility.

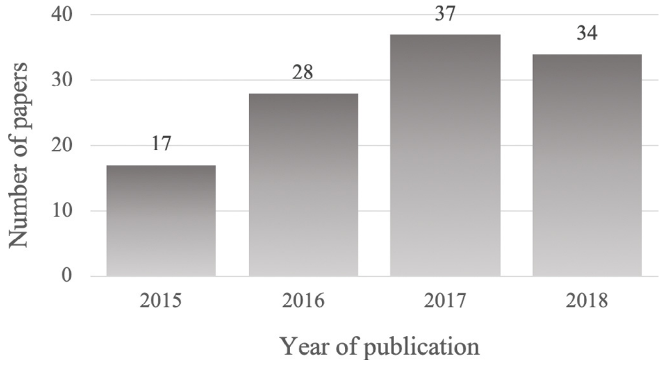

Fig. 3. Number of selected publications per year across the period under study.

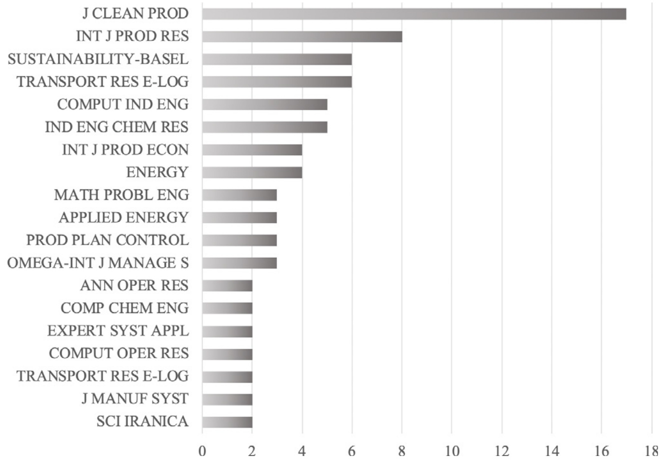

Fig. 4. Number of selected papers by journal
Note: The figure includes only journals with two or more articles published.

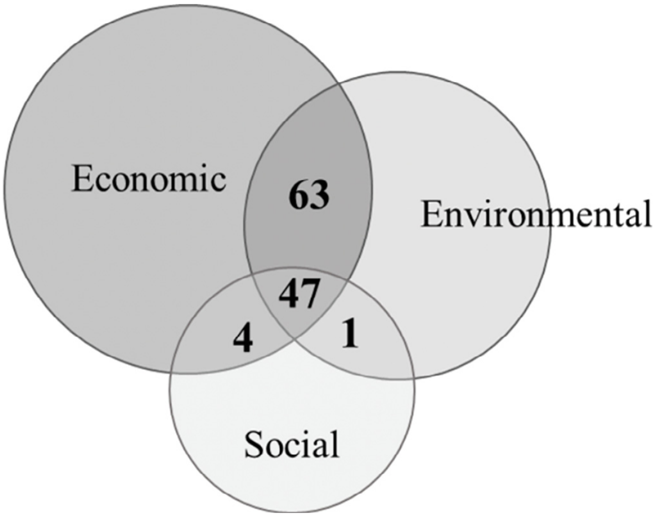

Fig. 5. The focus on the reviewed papers in relation to the three dimensions of sustainability.

5. Indicator characterization

Findings regarding the criteria to assess sustainability in the supply chain context are presented in this section. In the first three subsections, criteria to assess sustainability in the supply chain design context are described. Section 5.4 presents a summary of the findings of used criteria in the problem of partner selection.

5.1. Economic indicators

Although the cost dimension is found in several fields (see Fig. 2), the *financial performance* field still remains more assessed. This subsection presents a characterization of the cost drivers included in the SCND problem. Due to its nature, and the related decisions of the problem, transportation costs and establishment costs of facilities are the most common cost drivers, appearing in 70 and 60 papers, respectively. Other logistics activity costs included in the economic function are production in 47 papers, purchasing addressed by 42 papers, and holding, covered in 30 papers. In a second level with lesser frequency, fixed and variable operation costs at facilities are included in 13 and 16 studies, respectively.

Carbon emission cost appears in 13 studies. Taxation over carbon emissions is one of the worldwide initiatives aimed at reducing GHG emissions in both developed and developing countries (Xu et al., 2017b). The most common carbon policies include carbon caps, carbon emission taxes, and carbon cap and trades (Jin et al., 2014). The carbon cap policy is not directly affected by the cost because it determines a threshold over the number of allowable emissions to a company. Meanwhile, carbon tax emissions and carbon cap and trades enact a relation of substitution between economic and environmental resources. These approaches raise the concepts of weak and strong sustainability.

On the one hand, Feitó-Cespón et al. (2017) present concise and clear definitions for both concepts and argue that a sustainable supply chain is closely related to strong sustainability, establishing a balance among economic, environmental, and social performance, and it is not convenient to assume that natural resources can be substituted by economic goods, because the supply chain often deals with non-renewable resources. Furthermore, weak sustainability approaches present a main drawback and results in complexity when defining the value of environmental goods, because it might depend on the region, economic conditions, natural capital availability, and time, among other criteria (Pearce et al., 2006).

On the other hand, from the 13 papers covering carbon cost, only Rezaee et al. (2017) state an existing relation not necessarily linear but positive between the green design of the chain and carbon price and budget availability. This conclusion could open new ways in the design of effective policies for reducing emissions and consumption of natural resources. Despite the differences in approaches, there is a significant revealed need to model real features for sustainability assessment in supply chains.

Three main objectives appear to be related to the economic dimension: minimization of total cost (MC) is used in 55 papers; maximization of profit (MP), the difference between the incomes from sell activities and the total cost including fixed and operational appear in 16 papers; and finally maximization of net present value (NPV), the value of a specific stream of future cash flows in terms of monetary units of today, is covered in 9 papers. The last category is common when the problem considers an evaluation over multiple time periods. Meanwhile, both MC and MP are independent of the characteristics of the problem under study and are used in multiple and single-period evaluations. This condition is not a minor detail, because sustainability is not seen as a stationary assessment at one point of the time but as a kept state over time.

5.2. Environmental indicators

Global concern over the environment and responsible consumption of natural resources and demand for taking care of environment have prompted companies to involve environmental factors into their decision-making tools, even more when in some cases environmental performance has economic impacts under the scenario of green consumer behavior (Miranda-Ackerman et al., 2017; Tang et al., 2016).

Even though the LCA-based methodologies present a complete approach to evaluating environmental impacts through the whole activities of the supply chain, there are cases in which due to some methodological, technical, or informative barriers an LCA analysis is not possible. To deal with those barriers, a partial assessment of its environmental impacts is considered by companies (Eskandarpour et al., 2015). From the review, just 19 papers use an LCA-based approach to evaluate environmental impacts; meanwhile, the remaining works opt for a partial assessment of environmental factors.

An analysis of the assessment of environmental performance within the five fields listed in the used framework is presented in the following. The *environmental management* field evaluates the impacts derived from the environmental certification owned by the company in compliance with the environmental regulation within a specific sector, as well as the number of resources invested in economic protection. The last concept is easily convertible into a cost, as was explained in the previous section. Meanwhile, the others correspond to a qualitative measure, hardly ever included in an SCND problem, but broadly evaluated within the partner selection problem, as shown in Section 5.4.

One of the most significant impacts caused by company operations comes from the use of raw or recycled material, water, and energy from the surrounding area; those factors are grouped in the *use of resources* field. It is possible to observe a relationship between the sector and concern about specific resources.

Water consumption is included in 8 out of the 77 papers. Anvari and Turkay (2017), Awad-Nunez et al. (2015), Clavijo Buritica and Escobar (2017), and Varsei et al. (2017) deal with the availability of water issue at the candidate location. Anvari and Turkay (2017) also evaluate water consumption in the preoperational stage of facilities (i.e., during the facility construction process). Meanwhile, the amount of water used in the production process is considered in Fahimnia and Jabbarzadeh (2016), Feitó-Cespón et al. (2017), and Jafari et al. (2017) and in relation with technology selection in Miranda-Ackerman et al. (2017).

Use of energy is mentioned in 10 works. For example, Accorsi et al. (2016) restrict the total amount of energy used in transport and production to be not greater than the energy produced by renewable sources, such as solar fields or wind farms, in an agri-food supply chain. Energy consumption during the production process is considered in Azadeh et al. (2017), at warehouse location (Colicchia et al., 2016), technology-dependent (Miranda-Ackerman et al., 2017), and wasted energy while vehicles wait for receiving service in collection centers (Zhalechian et al., 2016). Waste material use is considered in Feitó-Cespón et al. (2017). This criterion is less used even in the closed loop supply chain, in which harnessing of this kind of residues is the mainstay of development.

The *pollution* field has been covered broadly, especially the air pollution subfield. Within the supply chain context there are many sources of pollutant emissions at each tier; however, according to the review, (1) evaluation of environmental impact due to transportation activities and (2) operating facilities in the supply chain are the more frequent scope used in real cases to integrate the environmental dimension assessment into the SCND problem, pollution caused by raw materials or finished goods, and environmental impact of suppliers into the network. These are less frequently studied, not including the studies exclusively dedicated to supplier selection. The number of studies addressing environmental impacts from these sources is shown in Fig. 6.

The transport sector includes the movement of people and goods and produces about 20% of global energy–related CO_2 emissions, approximately 80% of which originate from road transportation (Sims et al., 2014). Emissions in the transportation sector are the result of the combustion of petroleum-based fuels in internal combustion engines. Although other compounds, such as methane (CH_4) and nitrous oxides (NO_x), are discharged during the combustion process, its quantity is relatively small in comparison to the primary component carbon dioxide CO_2. Emission of methane

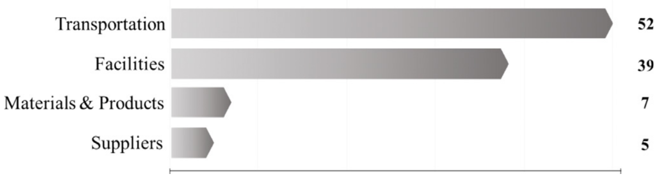

Fig. 6. Scope for partial environmental impact assessment.

and nitrous oxides are rarely measured. Govindan et al. (2015) include measurement of CO_2, chlorofluorocarbons, and NO_x. However, measures to evaluate environmental impact are principally dedicated to reducing emissions of the last compound (i.e., CO_2) during the transport of goods through the whole supply chain, being the environmental impact caused by transportation generally expressed as a function of the distance and the emission caused by fuel consumption.

More-sophisticated methodologies to calculate CO_2 emissions are unconventional in the papers dealing with the SCND problem. Rajkumar and Satheesh Kumar (2015) calculate CO_2 emissions as a function of the capacity in weight used of the truck transporting the product between the different locations. Additionally, Chen et al. (2017a) include factors affecting vehicle emissions depending on vehicle type and shape, road conditions, and regional climate. A sensibility analysis let them conclude that the importance of road conditions over environmental impact might result in a critical point for establishing sustainable supply chains in some developing countries that suffer from a lack of appropriate highways for both freight and passenger transportation.

In the SCND problem, reduction of CO_2 emissions attends to one or more of the following strategies, mainly by (1) reducing travel demand (i.e., reducing the number of miles or kilometers expected to deliver a product), which is a generalized approach of the papers under review because shorter routes usually imply lesser costs. A second strategy consists of (2) fuel switching, which involves the use of alternatives modes of transportation with alternative sources of locomotion, including biofuels, electricity, or other fossil fuels with lower factors of CO_2 emissions; examples are describe in Costa et al. (2018), Feitó-Cespón et al. (2017), and Osmani and Zhang (2017). A third strategy consists of (3) improvement of operating practices; for example, Zhalechian et al. (2016) consider the environmental impact caused by trucks and their waiting time for service at remanufacturing center facilities or route scheduling during improved conditions of traffic or weather to increase fuel efficiency, but these concepts are not studied in the scope of the SCND problem, because those activities do not belong to the strategic level of decision-making addressed in these types of problems.

Operation of industrial facilities is the second most-common factor used to measure environmental impact in supply chain design. In accordance with Sims et al. (2014), facilities operation also contributes to about 28% of global energy–related GHG emissions and is therefore a significant factor. At industrial facilities, GHG direct emissions come mainly from production processes involving combustion of fossil fuel for power or heat, and GHG indirect emissions are a result of energy consumption of power industrial buildings and equipment. Emissions from industrial facilities put several polluting compounds into the air. According to Fischedick et al. (2014), more than 80% of total emissions correspond to CO_2, about 8% to methane, and other compounds, including hydrofluorocarbons, perfluorocarbons, nitrous oxide, and sulphur hexafluoride, constitute the remaining approximate 10%. Indicators of environmental impact on the SCND problem focus on quantifying the amount of CO_2 emitted and quantifying other GHG emissions. Methodologies converting several pollution sources to equivalent CO_2 units (CO_2 eq.) are setting a standard unit of measure.

From the review, measurement of direct emissions coming from the manufacturing process is the most common factor to quantify the environmental impact of industrial facilities. Some authors also consider emissions from other buildings, such as warehouses, recollection centers, dismantling centers, and so on (Aalirezaei and Shokouhyar, 2017; Brandenburg, 2015; Ghaderi et al., 2018; Govindan et al., 2015; Govindan et al., 2016), and measurement of both direct and indirect emissions is less extended and addressed by Accorsi et al. (2016) and Azadeh et al. (2017). Furthermore, as its own feature of the SCND problem, some works consider not just emissions at the operational phase but also the emission caused during the construction process or preoperational phase. The environmental impact caused by the facilities construction is studied in Anvari and Turkay (2017) and Arampantzi and Minis (2017).

Reduction alternatives of emissions from industrial facilities have been included in the SCND problem mainly in relation to (1) the technology selection decision (Zahiri et al., 2017; Zhou et al., 2017). It is assumed the newer the technology, the more efficient the use of energy, and the lower emissions is a trade-off between environmental and economic objectives, because the newer the technology, the higher the cost (Chen et al., 2017b).

A second evaluated condition is associated with (2) the use of different alternative fuels at processing. Osmani and Zhang (2017) include in the environmental objective the expected reduction in GHG emissions due to substitution of conventional electricity with bioelectricity, mixed alcohols instead of heating oil, and bioethanol instead gasoline in the design of a second-generation bioethanol supply chain. Last, (3) recycling is the one of the major pillars for CLSC, but, as was mentioned previously, no impact from the use of recycled material instead raw material is evaluated, and this effect is considered in Feitó-Cespón et al. (2017), who evaluate the positive effect of not disposing recovering material at landfills.

Pollutant emissions related to materials are studied in Zhou et al. (2017). In this work, a computer manufacturing company has the possibility of choosing among different modules to assemble a piece of equipment. The purchase decision is characterized not only by the difference in the cost of the different modules but also by the amount of emissions derived from the product during the assembly stage and during its useful life.

Additionally, in the *pollution* field, water pollution and land pollution are scarcely studied in real applications of the SCND problem. Anvari and Turkay (2017) consider this factor in relation to the waste generated during construction of the facilities. They consider it a sensitive waste factor to the location due to a location with a higher population and that higher aquifers level are more sensitive to waste. Chávez et al. (2018) evaluate the positive effect of using agricultural waste from coffee crops to produce biofuel, avoiding dumping these wastes into the water sources. Additionally, other types of pollution, such as noise, smell, visual, vibration, and radiation, do not take part in the environmental impact assessment of the design of supply chains.

No papers were found attending to consideration of the *dangerousness* field. Meanwhile, in the last field of *natural environment,* just two papers include considerations of promotion and protection of biodiversity. Accorsi et al. (2016) consider the use of land in a rural region, including a reforestation activity. The authors calculate the number of hectares of land devoted to planting trees in such a way that ensures a zero-carbon emissions operation in a food supply chain. Emissions associated with cultivation and logistics activities must be equated to emissions captured by the forest. Izadikhah and Saen (2016) consider a biodiversity factor, calculated like the loss of species, caused by installing a new facility in the candidate zone.

It does not mean pollution is the most important factor to measure environmental impact in the supply chain network, but it does imply that pollution database and assessment methodologies have received greater attention (Table 3).

5.3. Social indicators

In the subfield *work conditions,* employment is the most frequent social indicator used in the real cases. The total number of jobs created is considered by most authors, with small adjustments. Regarding the number of created jobs Miret et al. (2016) evaluate the social benefit through the calculation of the total number of jobs. These authors use an approach to estimate not only the direct jobs created in the transformation echelon but also the indirect and induced jobs created through the whole set of activities in the life cycle. Anvari and Turkay (2017), Arampantzi and Minis (2017), Ghaderi et al. (2018), Varsei and Polyakovskiy (2017), Zahiri et al. (2017), Zhalechian et al. (2016), and Zhu et al. (2017) consider creating jobs with a priority for the region with the highest unemployment rate. The number of fixed jobs (minimum number of workers needed to open a facility) and the number of operating jobs (which are related to the capacity of the facility) are differentiated. Mota et al. (2018) also consider the number of jobs created due to the mode of transport selected. Classification of types of jobs according to yearly incomes and the dependence of the regional economy on a particular sector is considered in Cambero and Sowlati (2016) against the job opportunities created. These authors also distinguish the preoperational job opportunities (which are active during the construction period of the facilities) and operational jobs (which are active from the start of operations at facilities), the same condition considered as well in Osmani and Zhang (2017), Roni et al. (2017), and Mousavi Ahranjani et al. (2018).

Categories in the same subdimension as health and safety are incorporated in Ghaderi et al. (2018), who use the total number of lost days per year caused by injuries to establish an indicator for employee health, and the number of occurred injuries during a period time is related to the technology selected at a particular facility. Aalirezaei and Shokouhyar (2017) introduce a parameter quantifying the damage caused to workers at the collection center due to being exposed to a hazardous substance in a reverse supply chain of waste from electrical and electronic equipment (WEEE). Other aspects related to working conditions, such as employee satisfaction and stability, are addressed in Arampantzi and Minis (2017). These authors present an index to reduce the idle time of employees and to minimize dismissals, respectively. Finally, human resource development is addressed by Govindan et al. (2016b) in an indicator facility location that offers dependent grouping training for local people to develop skills, health and safety measures, and equality associated with developing careers, into the application no formula is shown instead a values from 0 to 1 for the indicator are given.

In the subfield *societal commitment,* the main factor is associated with wealth creation and the advancement of society through the increase of its gross domestic product (GDP), in the same way that regions with high unemployment rates are preferred when creating jobs and regions with lower regional development rates are a priority for the location of new facilities. This condition is considered in Anvari and Turkay (2017), Arampantzi and Minis (2017), Babazadeh et al. (2017), Ghaderi et al. (2018), Mota et al. (2015a), Varsei and Polyakovskiy (2017), Zahiri et al. (2017), and Zhalechian et al. (2016). According to Anvari and Turkay (2017), it promotes a fair distribution of development through the region and, along with the creation of jobs in the regions with the highest unemployment rate, helps to reduce immigration and its potential effects. However, locations in less-developed areas considerably affect environmental and economic objectives due to the increase in the distance between production and consumer sites. The preference for selecting local suppliers is another condition promoting societal community development and is included in Arampantzi and Minis (2017).

Other conditions affecting community development, such as the security level at the location site, medical facility access, and educational level, are introduced in Anvari and Turkay (2017). Security at the location is not just crucial for the operations of the company but also offers a secure habitat for employees, and access to medical services and education offers workers and their families favorable conditions for settling in the area, providing the company with the opportunity to find skilled workers and deal with the problem of staff turnover.

The field *customer issues* groups together all the actions carried out by the company and the effects they have on the consumer. Demand satisfaction is used as a social sustainability metric because the privation of some products could have impacts on the consumer. This feature is evaluated in Anvari and Turkay (2017), Ashfari et al. (2014), and Feitó-Cespón et al. (2017). Zhang et al. (2016) use a similar approach in a reverse supply chain for recovering waste cooking oil in China, as the authors argue, and satisfying the demand helps with the illegal edible oil in this country, which represents a tremendous social benefit.

Products might also affect the health of the customer, so companies that are responsible for offering safety products, health care, and security of customers have been studied by Ghaderi et al. (2018) and Zhu and Hu (2017). These authors consider the average number of hazardous products based on the selection of production technology. Table 4 presents the classification as described previously.

5.4. Partner selection

Selection of partners at different tiers of the supply chain constitutes a strategical decision; this problem has been widely addressed by researchers for a long time (Ho et al., 2010). In contrast to the SCND problem, in which factors are usually declared as quantitative expressions, partner selection problems assessing dimensions of sustainability include an extended use of qualitative factors, too. Hence, a more comprehensive set of criteria is evaluated. This subsection presents separately a summary of the indicators applied to the sustainable partner selection problem.

Sustainable partner selection consists of choosing from a set of available partners at different tiers of the supply chain, the best of which according to a set of criteria including economic, environmental, and social performance (Shahryari Nia et al., 2016). From the reviewed papers, 30 papers are classified in this category. Although, most of them deal with the supplier selection decision, some works deal with other arrangements, such as the selection of third-party logistics service providers (Jung, 2017), selection of an established center distribution (Neumüller et al., 2015), along with economic, environmental, and social evaluations. Additionally, Wu and Barnes (2016a, 2016c) present a general model for partner selection in the forward supply chain, considering the environmental performance of the partner. Partner selection in a reverse supply chain is addressed in Wu and Barnes (2016b).

Definition of criteria in every dimension of sustainability is one of the major tasks in the assessment of partners. In the reviewed applied cases, this duty is in charge of reviewing either experts in the sector of application or decision-makers from the staff of the

Table 3
Field evaluation of the environmental sustainability dimension.

References	Pollution	Use of resources	Natural environment	LCA methodology
Zahiri et al. (2017)	•			
Zhou et al. (2017)	•	•		Cradle-to-gate approach
Tang et al. (2016)	•			
Varsei et al. (2017)	•			
Jafari et al. (2017)		•		
Quddus et al. (2017)	•			
Gao & You (2015)	•			
Zhang et al. (2016)	•			
Galvez et al. (2015)	•			
Chen et al. (2017a)	•			
Feitó-Cespón et al. (2017)	•	•		Eco-Indicator 99
Govindan et al. (2016b)		•		
Govindan et al. (2016a)	•	•		
Yılmaz Balaman et al. (2018)	•			
Accorsi et al. (2016)	•	•	•	
Almansoori & Betancourt-Torcat (2016)	•			
Anvari & Turkay (2017)	•	•		
Arampantzi & Minis (2017)	•	•		
Awad-Nunez et al. (2015)		•		
Azadeh et al. (2017)	•	•		Eco Indicator 99
Brandenburg (2015)	•			
Clavijo Buritica & Escobar (2017)		•		
Cambero et al. (2016)	•			
Cambero et al. (2016)	•	•		LCA-based approach
Chen et al., 2017b	•			
Colicchia et al. (2016)	•	•		
Costa et al. (2018)	•			LCA-based approach
Domínguez-García et al. (2017)	•			
Duarte et al. (2016)	•	•		LCA-based approach
Fahimnia & Jabbarzadeh (2016)	•	•		IMPACT 2002+
Fazli-Khalaf et al. (2017)	•	•		ReCipe
Gargalo et al. (2017)	•	•		ReCipE
Ghaderi et al. (2018)	•	•		ReCipE
Govindan et al. (2016a)		•		
Govindan et al. (2015)	•			
Izadikhah & Saen (2016)		•	•	
Miranda-Ackerman et al. (2017)	•	•		LCA-based approach
Miret et al. (2016)	•	•		Ecocost method
Mohd Idris et al. (2018)	•			
Mota et al. (2015a,b)	•	•		ReCiPe
Mota et al. (2018)	•	•		ReCiPe
Murillo-Alvarado et al. (2015)	•	•		Eco-indicator 99
Osmani & Zhang (2017)	•			
Rajkumar & Satheesh Kumar (2015)	•			
Rezaee et al. (2017)	•			
Roni et al. (2017)	•			
Saif & Elhedhli (2016)	•			
Aalirezaei & Shokouhyar (2017)	•			
Tosarkani & Amin (2018)	•	•		
Urata et al. (2017)	•			LCA-based approach
Varsei et al. (2017)	•	•		
Xu et al. (2017a)	•			
Zhalechian et al. (2016)	•	•		
Zhang et al. (2017)	•			
Zhu et al. (2017)	•			LCA-based approach
Zohal & Soleimani (2016)	•			
Rabbani et al. (2018)	•			
Ebrahimi (2018)	•			
Chávez et al. (2018)	•			
Nodooshan et al. (2018)	•			LCA-based approach
Kesharwani et al. (2018)	•			
Fattahi & Govindan (2018)	•			
Mousavi Ahranjani et al. (2018)	•			
Ghelichi et al. (2018)	•			
Jiang et al. (2018)	•			
Fang et al. (2018)	•			
Palacio et al. (2015)	•			
Kuo et al. (2018)	•			LCA-based approach
Fahimnia et al. (2018)	•			
Khorasani & Almasifard (2018)	•			LCA-based approach
Zeballos et al. (2018)	•			
Chen et al. (2018a,b)	•			
Ahn & Han (2018)	•			
Asadi et al. (2018)	•			
Babazadeh (2018)	•			Eco-indicator 99
Yáñez et al. (2018)	•			

Table 4
Field evaluation of the social sustainability dimension.

Reference	Work conditions	Societal commitment	Customer issues	Business practices
Zahiri et al. (2017)	•	•		
Varsei et al. (2017)	•	•		
Jafari et al. (2017)	•			
Zhang et al. (2016)			•	
Feitó-Cespón et al. (2017)			•	
Govindan et al. (2016b)	•	•		•
Ashfari et al. (2014)			•	
Anvari & Turkay (2017)	•	•	•	
Arampantzi & Minis (2017)	•	•		
Awad-Nunez et al. (2015)		•		
Babazadeh et al. (2017)		•		
Cambero et al. (2016)	•			
Ghaderi et al. (2018)	•	•	•	
Govindan et al. (2016a)	•	•	•	
Miret et al. (2016)	•			
Mota et al. (2015a)	•	•		
Mota et al. (2018)	•	•		
Osmani & Zhang (2017)	•			
Roni et al. (2017)	•			
Aalirezaei & Shokouhyar (2017)	•	•		
Zhalechian et al. (2016)	•	•		
Zhu et al. (2017)	•	•	•	
Rabbani et al. (2018)	•			
Chávez et al. (2018)	•			
Kesharwani et al. (2018)		•		
Fattahi & Govindan (2018)	•	•	•	•
Jiang et al. (2018)	•	•		
Mousavi Ahranjani et al. (2018)	•			

focal company choosing a partner. Usually, these potential partners are subjected to an interview, survey, or Delphi group to know their preferences about the required or desired conditions of a supply chain partner as well as the importance of each selected criteria. Each criterion receives an evaluation with a defined scale and then methodologies such as fuzzy logic, data enveloped analysis (DEA), analytic hierarchy process (AHP), analytic network process (ANP), important performance analysis (IPA), or a Grey relational analysis (GRA), among others, are used to determine the relevance or weight of each of the selected criteria. Finally, available partners are ranked according to their overall performance in the selected criteria to choose the best option among them.

Table 5 presents the number of papers addressing sustainability criteria in the economic, environmental, and social dimensions for each of the fields of assessment proposed in the classification framework selected for this review (Chardine-Baumann and Botta-Genoulaz, 2014).

6. Modeling approaches and sectoral analysis

6.1. Modeling approaches and solution techniques

This section presents a brief description of the modeling approaches and solution techniques used to deal with the SCND problem in the applied cases. The use of mathematical programming–based methodologies is extended. Usually, those models are based on classical models for the SCND and add either new objectives or additional constraints, addressing the performance assessment of the additional environmental and social dimensions. LCA is used in 15 papers to calculate the environmental impacts directly through the whole chain.

6.1.1. Single and multiple objectives

Regarding the establishment of objectives, 16 papers propose single-objective models. Those papers consider the economic and environmental dimensions. Frequently, under this modeling approach, environmental impacts caused through the chain are monetized under any of the carbon-tax schemes presented previously in Section 4.1. Examples of this are shown in Almansoori and Betancourt-Torcat (2016), Quddus et al. (2017), and Zhou et al. (2017). Clavijo Buritica and Escobar (2017) include penalty costs due to a violation of environmental standards in a different tier of the network. Another strategy to consider environmental impacts, using the single-objective approach, is to include constraints establishing a threshold for the total amount of emissions of CO_2, such as shown in Xu et al. (2017a). Accorsi et al. (2016) propose a single-objective model considering a zero carbon ecosystem. In this model, the carbon neutrality scenario constraint ensures that total emissions caused by crops and logistics activities in the food supply chain are offset through the sequestration of CO_2 at the forestation area. A similar approach is considered by the same authors to deal with the impact caused by the energy produced by fossil fuels and the commitment to produce at least the same quantity of energy from renewable sources of energy at solar fields or wind farms.

A more-common approach is to use separate objectives for each one of the dimensions of sustainability; multi-objective models appear in 39 papers. Under this approach, an objective for each dimension of sustainability is proposed separately. Economic objectives consist of a summation of costs from strategic and tactical decisions. Environmental objectives quantify the environmental impact in the network; in some cases, it is expressed as sums of the equivalent CO_2 emissions generated from production and transportation activities. Papers using LCA-based approaches consider the sum of environmental impacts through the entire product life cycle to construct the environmental objective function. Otherwise, for example, social assessments might involve several different factors with multiple measurement units, because objective functions for the social dimension are frequently constructed as a linear weighting of the deviation from an optimal value of each factor assessed, as described in Anvari and Turkay (2017) and Zahiri et al. (2017).

Table 5
Sustainability indicators in the partner (supplier) selection problem.

Dimension	Field	Number of references	References
Economic	Reliability	20	(Azadi et al., 2015; Badri Ahmadi et al., 2017; Chung et al., 2016; Faisal et al., 2017; Fallahpour et al., 2016, 2017; Govindan et al., 2017a; Izadikhah et al., 2017; Jain et al., 2016; Jung, 2017; Kannan, 2018; Kannan et al., 2015; Kumar et al., 2017; Low et al., 2016; Shahryari Nia et al., 2016; Tavana et al., 2017; Tsui et al., 2015; Wang Chen et al., 2016; Wu and Barnes, 2016a, 2016c)
	Responsiveness	14	(Azadnia et al., 2015; Chung et al., 2016; Fallahpour et al., 2016; Ghadimi et al., 2017; Govindan et al., 2017b; Hashemi et al., 2015; Jeong and Ramírez-Gómez, 2018; Kannan, 2018; Low et al., 2016; Lu et al., 2018; Tsui et al., 2015; Wu and Barnes, 2016b, 2016c; Zhou and Xu, 2018)
	Flexibility	11	(Amin-Tahmasbi and Alfi, 2018; Azadi et al., 2015; Faisal et al., 2017; Fallahpour et al., 2017; Govindan et al., 2017a,b; Kannan, 2018; Lin et al., 2015; Neumüller et al., 2016; Wu and Barnes, 2016c; Zhou and Xu, 2018)
	Financial performance	33	(Amin-Tahmasbi and Alfi, 2018; Azadi et al., 2015; Azadnia et al., 2015; Badri Ahmadi et al., 2017; Chen et al., 2018b; Chung et al., 2016; Faisal et al., 2017; Fallahpour et al., 2016, 2017; Govindan et al., 2017a,b; Hashemi et al., 2015; Izadikhah et al., 2017; Jabbarzadeh et al., 2018; Jain et al., 2016; Jeong and Ramírez-Gómez, 2018; Jung, 2017; Kannan, 2018; Kannan et al., 2015; Kumar et al., 2017; Low et al., 2016; Lu et al., 2018; Mahdiloo et al., 2015; Neumüller et al., 2015, 2016; Shahryari Nia et al., 2016; Tavana et al., 2017; Tsui et al., 2015; Wang Chen et al., 2016; Wu and Barnes, 2016a, 2016c; 2016b; Zhou and Xu, 2018)
	Quality	27	(Amin-Tahmasbi and Alfi, 2018; Azadi et al., 2015; Azadnia et al., 2015; Badri Ahmadi et al., 2017; Chen et al., 2018b; Chung et al., 2016; Faisal et al., 2017; Fallahpour et al., 2016, 2017; Ghadimi et al., 2017; Govindan et al., 2017a,b; Hashemi et al., 2015; Jain et al., 2016; Kannan, 2018; Kannan et al., 2015; Kumar et al., 2017; Lin et al., 2015; Low et al., 2016; Lu et al., 2018; Neumüller et al., 2016; Shahryari Nia et al., 2016; Tavana et al., 2017; Tsui et al., 2015; Wang Chen et al., 2016; Wu and Barnes, 2016c, 2016a; Zhou and Xu, 2018)
Environmental	Environmental management	25	(Amin-Tahmasbi and Alfi, 2018; Azadi et al., 2015; Azadnia et al., 2015; Badri Ahmadi et al., 2017; Faisal et al., 2017; Fallahpour et al., 2017; Govindan et al., 2017a,b; Govindan et al., 2016; Hashemi et al., 2015; Izadikhah et al., 2017; Kannan, 2018; Kannan et al., 2015; Lin et al., 2015; Liou et al., 2016; Low et al., 2016; Lu et al., 2018; Mahdiloo et al., 2015; Shahryari Nia et al., 2016; Tavana et al., 2017; Tsui et al., 2015; Wang Chen et al., 2016; Wu and Barnes, 2016c, 2016b)
	Use of resources	24	(Amin-Tahmasbi and Alfi, 2018; Azadi et al., 2015; Faisal et al., 2017; Fallahpour et al., 2016, 2017; Govindan et al., 2017a,b; Govindan et al., 2016; Hashemi et al., 2015; Jabbarzadeh et al., 2018; Jeong and Ramírez-Gómez, 2018; Kannan, 2018; Kannan et al., 2015; Kumar et al., 2017; Liou et al., 2016; Lu et al., 2018; Mahdiloo et al., 2015; Neumüller et al., 2015, 2016; Tavana et al., 2017; Tsui et al., 2015; Wu and Barnes, 2016c, 2016a; Zhou and Xu, 2018)
	Pollution	22	(Amin-Tahmasbi and Alfi, 2018; Azadi et al., 2015; Azadnia et al., 2015; Fallahpour et al., 2016, 2017; Ghadimi et al., 2017; Govindan et al., 2017b; Hashemi et al., 2015; Jabbarzadeh et al., 2018; Jain et al., 2016; Kannan, 2018; Kannan et al., 2015; Kumar et al., 2017; Mahdiloo et al., 2015; Neumüller et al., 2015, 2016; Shahryari Nia et al., 2016; Tavana et al., 2017; Wu and Barnes, 2016a, 2016c; 2016b; Zhou and Xu, 2018)
	Dangerousness	13	(Azadi et al., 2015; Badri Ahmadi et al., 2017; Chung et al., 2016; Ghadimi et al., 2017; Govindan et al., 2017a; Govindan et al., 2016c; Jabbarzadeh et al., 2018; Kannan, 2018; Kannan et al., 2015; Liou et al., 2016; Shahryari Nia et al., 2016; Tsui et al., 2015; Wu and Barnes, 2016a, 2016c)
	Natural environment	2	(Jeong and Ramírez-Gómez, 2018; Neumüller et al., 2015)
Social	Work conditions	21	(Azadi et al., 2015; Azadnia et al., 2015; Badri Ahmadi et al., 2017; Faisal et al., 2017; Fallahpour et al., 2017; Ghadimi et al., 2017; Govindan et al., 2017a; Govindan et al., 2016c; Izadikhah et al., 2017; Jabbarzadeh et al., 2018; Jung, 2017; Kannan, 2018; Kannan et al., 2015; Lin et al., 2015; Low et al., 2016; Lu et al., 2018; Mahdiloo et al., 2015; Neumüller et al., 2015, 2016; Tavana et al., 2017; Wu and Barnes, 2016b; Zhou and Xu, 2018)
	Human rights	10	(Azadi et al., 2015; Fallahpour et al., 2017; Ghadimi et al., 2017; Jabbarzadeh et al., 2018; Jung, 2017; Kannan, 2018; Kannan et al., 2015; Shahryari Nia et al., 2016; Tavana et al., 2017; Wu and Barnes, 2016c)
	Societal commitment	16	(Azadnia et al., 2015; Badri Ahmadi et al., 2017; Faisal et al., 2017; Govindan et al., 2016c; Jabbarzadeh et al., 2018; Jeong and Ramírez-Gómez, 2018; Jung, 2017; Kannan, 2018; Kannan et al., 2015; Kumar et al., 2017; Lin et al., 2015; Lu et al., 2018; Neumüller et al., 2015, 2016; Wu and Barnes, 2016b; Zhou and Xu, 2018)
	Customer issues	7	(Govindan et al., 2016c; Jabbarzadeh et al., 2018; Kannan, 2018; Kannan et al., 2015; Neumüller et al., 2015, 2016; Wu and Barnes, 2016b)
	Business practices	10	(Azadi et al., 2015; Chen et al., 2018b; Faisal et al., 2017; Govindan et al., 2017a; Govindan et al., 2016c; Kannan, 2018; Kannan et al., 2015; Lin et al., 2015; Shahryari Nia et al., 2016; Tavana et al., 2017; Wu and Barnes, 2016c)

6.1.2. *Deterministic and non-deterministic considerations*

Based on the fact that in real scenarios of the supply chain, decisions are rarely made under certainty, and even more, because SCND problems imply long-term decisions, and hence, there are multiple non-deterministic parameters that might change across the time, several works incorporate uncertainty into their modeling approaches. We found demand uncertainty is the most common uncertainty parameter to consider; 13 papers address it. Five works consider uncertainty in supply; this number includes papers considering uncertainty in harvest rate, which is the raw material for the process of biofuel conversion. Uncertain recycled products rate as the number of units recovered from the market in a closed loop supply chain scenario and is addressed by four papers. Finally, there are other non-deterministic parameters included corresponding to production and transportation costs and facilities capacity. Table 6 presents a summary of the main characteristics of the modeling approaches and how the dimension of sustainability is addressed.

6.2. *Origin and sectoral analysis*

In this subsection, papers are classified according to the origin country of the study case when it is possible to identify such information. Classification of studies in each continent was related to the countries joining the Organization for Economic Co-operation and Development (OECD). The OECD gathers 36 economies to promote sound energy policies, economic growth, prosperity, and sustainable development for member and non-member countries.

According to the U.S Mission to the OECD, the 37 countries belonging to the organization account for near to 63% of the world GDP, more than 75% of global trade, are home to about 20% of the population of the world, and represent more than half of global

Table 6
Modeling approach for the SCND problem.

Modeling approach	Reference
Single objective	
Deterministic	*Eco* + *Env*
	(Accorsi et al., 2016; Almansoori and Betancourt-Torcat, 2016; Babazadeh, 2018; Clavijo Buritica and Escobar, 2017; Costa et al., 2018; Duarte et al., 2016; Galvez et al., 2015; Izadikhah and Saen, 2016; Mohd Idris et al., 2018; Varsei et al., 2017; Zhang et al., 2017; Zhou et al., 2017; Zohal and Soleimani, 2016)
	Eco* + *Soc
	Babazadeh et al. (2017)
	Eco* + *Env
Stochastic	(Ahn and Han, 2018; Fahimnia et al., 2018; Ghelichi et al., 2018; Quddus et al., 2017; Rezaee et al., 2017; Saif and Elhedhli, 2016; Xu et al., 2017)
Multiple objectives	
Deterministic	Eco + Env
	(Cambero et al., 2016; Chen et al., 2017a; Chen et al., 2018a; Chen et al., 2017b; Colicchia et al., 2016; Domínguez-García et al., 2017; Fang et al., 2018; Gao and You, 2015; Govindan et al., 2016a; Kuo et al., 2018; Miranda-Ackerman et al., 2017; Murillo-Alvarado et al., 2015; Nodooshan et al., 2018; Palacio et al., 2015; Tang et al., 2016; Urata et al., 2017)
	Eco* + *Env* + *Soc
	(Aalirezaei and Shokouhyar, 2017; Anvari and Turkay, 2017; Arampantzi and Minis, 2017; Awad-Nunez et al., 2015; Cambero and Sowlati, 2016; Chávez et al., 2018; Govindan et al., 2016b; Jafari et al., 2017; Jiang et al., 2018; Kesharwani et al., 2018; Miret et al., 2016; Mota et al., 2015a; Rabbani et al., 2018; Roni et al., 2017; Varsei and Polyakovskiy, 2017; Zhu and Hu, 2017)
Stochastic	***Eco* + *Env***
	(Asadi et al., 2018; Azadeh et al., 2017; Brandenburg, 2015; Ebrahimi, 2018; Fahimnia and Jabbarzadeh, 2016; Fazli-Khalaf et al., 2017; Gargalo et al., 2017; Govindan et al., 2015; Khorasani and Almasifard, 2018; Rahmani Ahranjani et al., 2017; Rajkumar & Satheesh Kumar, 2015; Tosarkani and Amin, 2018; Yılmaz Balaman et al., 2018; Zeballos et al., 2018)
	Eco* + *Soc
	Afshari et al. (2016)
	Eco* + *Env* + *Soc
	(Fattahi and Govindan, 2018; Feitó-Cespón et al., 2017; Ghaderi et al., 2018; Jabbarzadeh et al., 2018; Mota et al., 2018; Mousavi Ahranjani et al., 2018; Osmani and Zhang, 2017; Zahiri et al., 2017; Zhalechian et al., 2016; Zhang et al., 2016)

Eco (Economic criteria), Env (Environmental criteria), Soc (Social criteria)

energy consumption. In 1990, CO_2 emissions from OECD countries represented more than 50% of global emissions, but because of the increasing global concern about environmental protection, these economies have made efforts to control and reduce the number of emissions from their industrial activities; nowadays their emissions represent about 38% of global CO_2 emissions. However, as mentioned by Wiedmann and Lenzen (2018), this number, rather than being a better environmental performance, might represent a burden shift from developed countries to developing ones. It is partially evidenced by the high number of cases addressing sustainable supply chains in developing economies in non-OECD countries, as shown in Fig. 7.

Globalization has brought significant changes in supply chain networks, leading to geographical separation of production and consumption zones (Wiedmann and Lenzen, 2018). A rising offshoring strategy has taken place among manufacturing companies; low labor costs are often the primary reason for companies to relocate operations, and considerations such as lesser environmental taxes and the advantages of economies of scale in high-volume production result in sensible factors for companies consider looking abroad. This phenomenon results in a change of the scale of environmental and social impacts due to the industrialization process.

At first, China was the preferred destination to relocate company operations; movement to other countries in South Asia, Africa, and Latin America are more recent (Jiang and Green, 2017). In Fig. 7, it is possible to identify that about 60% of the total cases addressing sustainability in the SCND problem have their origin in Asia, with Iran, China, and India being the countries with the highest contributions. The rising concern about sustainable development in China and India is influenced by the accelerated growth in production and consumption emissions because of the industrialization process. In 2017, although some of the OECD members countries experienced declines in their total amount of energy-related CO_2 emissions, including the United States, United Kingdom, Japan, and Mexico, Asian economies accounted for two-thirds of global increase in carbon emissions, with China and India the countries with the most considerable growth (IEA, 2017).

The high number of applied cases in Iran has another source, as is pointed out by Babazadeh et al. (2017). Iran has an abundant source of fossil fuels and is one of the biggest exporters of crude oil in the world. However, due to the emissions caused by extraction and processing, some cities deal with serious issues having negative impacts on environmental and socially unsustainable development. Air quality causes skin and respiratory diseases, acid rain, and unacceptable living conditions in these cities. For this reason, state entities have increased budgets for the promotion of alternatives biofuels, which has yielded new research in biomass supply chain design, which apparently has contributed to the aforementioned results.

Surprisingly, from the review, no study cases addressing sustainable supply chain design were found in African countries, although some studies aim to reduce carbon emissions in specific activities of the supply chain, such as Makan and Heyns (2018), and recent research focuses on the identification of drivers and barriers for sustainable supply chain implementation (Agyemang et al., 2018; Niehaus et al., 2018).

Regarding the sector of application, manufacturing of electronic components and production of energy from biomass are the most representative sectors applying sustainability criteria to the SCND and partner selection decisions. Regarding the electronic component market, one of the significant threats affecting sustainability in the chain is the treatment or disposal of electronic components at the end of life. This interest for electrical and electronic equipment and their waste is probably driven by the European directives on WEEE and the restriction of use of certain hazardous substances (RoHS) that were published in 2002. Following this European initiative, governments worldwide, mainly those belonging to the OECD, provide for the creation of schemes that involve safe and responsible collection, recovery, and recycling procedures for all

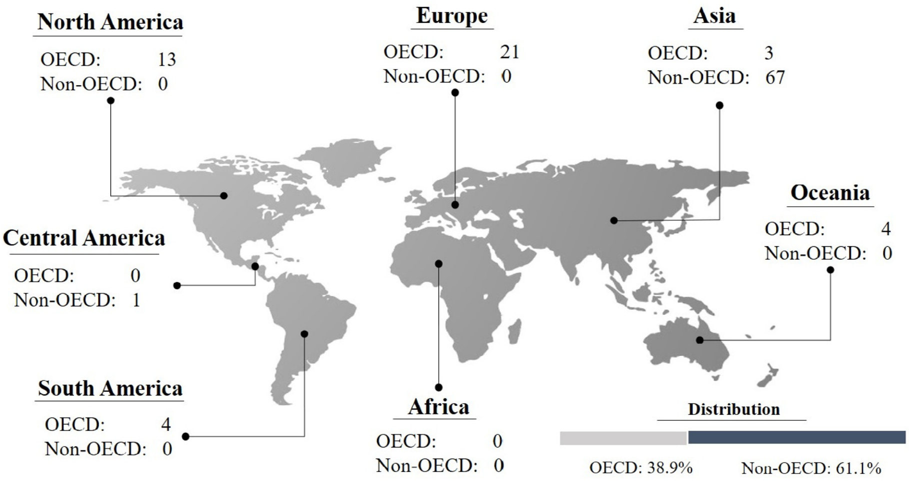

Fig. 7. Continent of origin of the study case.

types of electronic waste. Studies addressing sustainability in this sector often use a closed loop supply chain approach. The total environmental impact from raw materials, assembly, and production process, recovery, and disposal are evaluated, usually through quantification of CO_2-equivalent emissions or directly by the calculation of produced waste (Anvari and Turkay, 2017).

A similar result with Eskandarpour et al. (2015) is the frequency of the biomass-to-bioenergy sector, due to the high environmental impacts of fossil fuels and the extensive research on alternative fuels. Design of the biofuels supply chain for first and second generations, including environmental and social considerations, is one of the leading sectors of real applications. There is an increasing concern in the agricultural sector, including food and beverage and agribusiness. Environmental impacts from harvesting to consumption are analyzed. However, social criteria are hardly evaluated, and this presents an opportunity, because care of crops is a labor-intensive activity with low wages, especially in developing countries. The automotive and fashion sectors are increasing their respect for environment results, as described in Eskandarpour et al. (2015). The textile industry is a high-water-consumption sector (Jafari et al., 2017) and energy-intensive (Fahimnia and Jabbarzadeh, 2016); hence, those criteria are usually evaluated in this context. Moreover, a tremendous environmental impact might be caused by the use of inks. Finally, sectors such as construction, information and communication technology, and e-commerce present a low frequency of applied cases. Table 7 presents a summary of the classification of studies by sector.

Table 7
Number of study cases by sector.

Sector	*Total*	*Sector*	*Total*
Bioenergy	25	Commerce	4
Technology	19	Agrobusiness	3
Food and beverage	13	Pharmaceutical	2
Industrial goods	10	Timber	2
Automotive	9	Mining	3
Fashion	7	Construction	1
Energy	6	Information and communication	1
Chemicals	5	Steel	1
Home and office products	4		

7. Conclusion and opportunities for future research

The design of the whole supply chain network is a critical decision in supply chain management. Decisions regarding the number, location, and capacity of facilities, the selection of suppliers and transportation modes, the allocation of demand, and so on have a strategic impact on economic, as well as in environmental and social, performances. This paper presents a comprehensive review of academic literature following a systematic review approach in order to guarantee explicit and reproducible steps for identifying, evaluating, and interpreting the existing body of research. A particular focus was given to analyzing real-life case studies published in the scientific literature that contain an assessment of at least two dimensions of sustainability. Among the outcomes of this review, it is interesting to highlight that a little more than 40% of the short-listed papers considered all three dimensions—economic, social, and environmental—especially in the partner-selection context, although there is just one published real-life case study that considers social and environmental metrics without evaluating economic issues. Economic and environmental criteria have received more attention by academics than social criteria. However, in the incremental inclusion of criteria, the social dimension is becoming a relevant study topic.

The conclusions of the review and the opportunities for future research in the framework of the research questions guiding this study can be summarized as follows.*Which are the common economic, environmental, and social criteria considered in applied cases of design or redesign of supply chain networks?*

Economical dimensions are still mainly represented by criteria in the financial performance field. Minimization of total operational costs, including fixed and variable costs, is the most common criteria to assess economical sustainability. Although some authors highlight the dynamical approach of sustainability and the need of inversion in the long term to reach a steady state in sustainable development, the NPV objective has been used to a lesser extent (Barbosa-Póvoa et al., 2018; Kannegiesser et al., 2015). Opportunities exist to propose solution methodologies evaluating sustainability in the long term and its impacts on monetary flow. Emissions taxes seem to gain acceptance in SCND modeling. The idea behind this cost is to encourage companies to adapt cleaner technologies to avoid taxes by overproduction of GHG emissions; however, because most of the approaches evaluated the performance during a single period, the dynamic perspective of this adoption could be misconstrued.

Regarding the environmental dimension, air pollution is still the most assessed criteria for sustainability, but direct emissions coming from operation of facilities and transportation are the most common factors to evaluate. Pollution from other sources, such as water or land, has been scarcely studied. Future research could include the impact on land-use change, because location of industrial facilities affects the resources in the zone. Water consumption and energy consumption are addressed by few works. Just a few authors justify the use of this metric in relation to the specific context, namely, the use of water consumption in the textile industry (Jafari et al., 2017) and the use of energy consumption criteria for the fiber production industry (Fahimnia and Jabbarzadeh, 2016).

Forthcoming works addressing sustainability assessment in decision-making at the strategic level of supply chain management could include a description of the real challenges in the sector to establish context-based criteria. It could be required that the construction of interdisciplinary teams validate the assessed metrics. Moreover, this could lead to a broader vision of sustainability in the supply chain through the use of evaluation techniques or methods specific to environmental sciences (Blass and Corbett, 2018).

Social considerations remain the least studied, and this conclusion agrees with several previous reviews. Metrics in this dimension are often reduced to the evaluation of isolated factors, not specific methodologies as applied to this objective, despite the qualitative specificity of these aspects. Meanwhile, LCA methodologies are employed by about 15% of the reviewed papers to measure environmental impacts; there is no register of the use of the extended methodology S-LCA (social life cycle assessment) to consider the evaluation of social impacts on the SCND problem.

The number of created jobs is the main metric in the reviewed works. However, the impact on society of these employees is not evaluated. Future studies might consider the impact of employment in the improvement of social conditions through some indicators such as the Human Development Index (HDI) or the Gini coefficient. A methodology to obtain a sectorial evaluation of the HDI is presented in Forcael et al. (2016) and could present a way to include such considerations into the SCND.

Issues addressing health and safety for workers and customers are becoming more frequently discussed. Workers are affected by failures in the production process, and customers are affected by defective products; process failures and defective products often relation to the technology selection. In the societal commitment field, some works consider the GDP of the region to decide whether to install a facility at that location. However, as was explained previously, the impact on the future GDP of the region is often not assessed. It is challenging to incorporate a dynamic perspective of sustainability in future research and evaluate its effects in the long term, not just to evaluate sustainable criteria at one point in the time.

It is worthy to note that to highlight the common factors in each of the dimensions does not imply establishing the accuracy of these factors to assess sustainability in supply chains. Rather, it shows the availability of data, familiarity of this criterion with researchers in the supply chain field, the present progress in this field of the research, and constitutes a starting point to identify gaps in the evaluation of sustainability.*Which solution methods are employed to deal with the problem?*

Supply chain design is related to optimization techniques. The classical OR models have incorporated elements (i.e., objective function, constraints, parameters, and variables) to extend the evaluation from the classical economic perspective to environmental and social dimensions. The multi-objective approach is the common paradigm to deal with sustainability and the balance of its conflicting goals. Uncertainty modeling has received less attention, even when strategical decisions dealing with decisions affect the long term and these parameters are very likely to change.

Regarding the sustainable supplier selection problem, most of the studies use multi-criteria decision-making models. DEA, AHP, and ANP techniques are the most common techniques to evaluate the importance of the attributes in each dimension of sustainability to select the most suitable supplier. Multi-criteria decision-making methodologies enable establishing a great number of attributes and rank them based on the industry-specific context.

After considering the results of this review, several lines for future research appear to be of interest. The first opportunity can be to extend the analysis of the SCDN problem using modeling approaches for efficient decision-making. Indeed, because the configuration of the supply network is a long-term decision, the problem has traditionally been solved using modeling approaches from the OR and management sciences, using single-objective and multi-objective optimization, as well as some multi-criteria decision-aid techniques. These solution approaches very often require simplifying the problem to a cost-related function. However, when comparing diverse objectives with different dimensional units (e.g., cost, carbon emissions, number of jobs), the multi-objective problem becomes very complicated to assess using indicators for the three dimensions of sustainability together. An interesting line for future research is to couple optimization modeling with formal social and environmental assessment tools and methods traditionally employed in the environmental economics field. It will imply perhaps the use of hybridized techniques including multi-criteria methods with optimization techniques.*Which real cases are described in the scientific literature?*

Finally, regarding the sector of application, several advances have been made in bioenergy and electronic components to assess environmental and social performance at the strategic level of supply chain planning because of the regulatory constraints in this sector. Agricultural applications start to gain an essential place in the literature, showing that there are multiple opportunities for improving this sector. This sector represents a challenge in the selection of sustainability criteria, because different crops require different growing times, different levels of water, different harvesting techniques, and different considerations of distribution also, as in the case of the cold chain. This presents an emphatic call to the identification and evaluation of context-based metrics. Additionally, there are valuable opportunities for further research in the automotive and steel industry and textile sectors due to their characteristics of high-water consumption, high-energy demand, and labor-intensive activities, especially because of the spreading globalization, environmental, and social footprints that mainly affect the population of developing countries.

Another line for future research is related to carrying out cross-country evaluations of real-life case studies in developing and developed economies, in particular regarding the assessment of social and environmental dimensions. As a matter of fact, this paper revealed that 30% of short-listed papers account for works in North America and Europe, and 60% account for works in non-OECD countries in Asia. However, no comparative studies have been carried out. Also, regarding the geographical location of studies, there were a minimal number of study cases in Central and South America, as well as in Africa. There is an opportunity to begin and increase the amount of research about the assessment of sustainability in supply chain design in these regions.

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