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Invited Review

# Opportunities and challenges in sustainable supply chain: An operations research perspective

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ABSTRACT

Sustainable Supply Chain have become a cornerstone to any company that seeks to achieve sustainable goals. A company's image is no longer related to the old paradigm of being sustainable in its own activities, but instead is associated with a strong collaboration between all supply chain stakeholders, towards a sustainable activity. It is then critical to create new methods and tools to account for the three pillars of sustainability: economic, environmental and social, in a multi-stakeholder chain. In this context, operational research (OR) methods play a key role in supporting sustainable supply chain activities. This paper aims to review the trends and directions of OR methods applications towards the achievement of sustainable supply chain. A set of 220 papers has been reviewed to identify the OR methods being employed, the levels of decision considered and how sustainability practices were treated through OR. We found that optimization models applied to strategic level decisions are the most preponderant studies. Moreover, it was verified that sustainability has been mainly tackled by assessing economic and environmental aspects, leaving behind the social aspects. Additionally, OR-based studies do not yet present a clear definition of sustainability, a fact that is proven by the number of environmental and social methodologies explored. Based on the major trends identified in the literature, a research framework is derived, pointing towards a future research agenda in the area.



## 1. Introduction

Supply Chain (SC) has appeared for the first time in the literature more than thirty years ago when Oliver and Webber (1982) proposed the first definition for the management of such systems. Since then, the SC management (SCM) area has grown considerably at both research and industrial levels, and SC are nowadays bedrock systems in any organization. SC, in its classical form – forward supply chain, are viewed as a combination of processes aimed at fulfilling customers' requests, that include all possible network entities such as suppliers, manufacturers, transporters, warehouses, retailers and customers, whose main purpose is the customerś satisfaction at a minimum cost (Simchi-Levi, Kaminsky, & Simchi-Levi, 2007). However, such a purpose has enlarged over time, and SC have been expanding their activities towards the goal of integrating not only economic, but also environmental aspects. Reverse logistics activities have been incorporated within the existing networks, and the collection and treatment of end of life products through recycling, or remanufacturing, repairing, and/or finally disposing of some used parts, have been considered within those networks (Cardoso, Barbosa-Póvoa, & Relvas, 2013; Fleischmann et al., 1997). This led to the dawn of the closed-loop supply chain (CLSC) (Guide & Van Wassenhove, 2002). CLSC are logistic systems whose design, planning and operation aim to maximize value creation over the entire life cycle of a product, pursuing a dynamic recovery of the product value from different types and volumes of returns. Savaskan and Van Wassenhove (2006) highlighted the benefits of an integrated CLSC, and such systems have been explored in several published works, namely by Cardoso et al. (2013); Salema, Barbosa-Póvoa, and Novais (2010); and Zeballos, Méndez, Barbosa-Póvoa, and Novais (2014). Some reviews have appeared in the area where supply chain with reverse flows were analyzed in detail (see, Sasikumar & Govindan, 2008a, 2008b, 2009).

Recently, this trend has been widening to include not only the economic and environmental concerns, as the ones present in the CLSC, but also social concerns, following the requisites defined by the World Commission on Environment and Development for Sustainable Development (WCED, 1987), where sustainability was defined as the "use of resources to meet needs of the present without comprising the ability of future generations to meet their own needs". This has resulted in the appearance of the Sustainable Supply Chain (SSC) area, which is nowadays recognized as a challenging area by both academics and industrialists

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(Barbosa-Póvoa, 2009; Barbosa-Póvoa, 2014; Brandenburg et al., 2014; Seuring & Müller, 2008).

Sustainable Supply Chain (SSC) can be described as complex network systems that involve diverse entities that manage the products from suppliers to customers and their associated returns, accounting for social, environmental and economic impacts (Barbosa-Póvoa, 2014). The treatment of such systems has recently gained a noticeable importance, as companies face the challenge of dealing with sustainable issues caused by growing society's awareness towards environmental and social problems. The United Nations Global Corporate Sustainability report identified an intense shift in corporate attitudes towards sustainability (United Nations, 2013). Even facing one of the worst economic downturns in nearly a century, commitments to sustainability supply chain principles are now at a historic high. But while companies are making progress in terms of setting expectations for supply chain sustainability, most fail to implement tangible measures to drive adherence to such actions. This is justified by several reasons. The first one is related to the understanding of the true meaning of SSC within the organizations and how this should be managed amongst the different entities involved. Additionally, as interest in responsible SCM grows, increasing numbers of initiatives have sprouted up in every sector promoting various methods and standards, leaving companies with the discouraging task of identifying the best practices to use. Thus, a clear understanding of the meaning of SSC and of what is important at the corporate level is essential. Moreover, the sheer size and complexity of global SC means that companies that begin their journey towards sustainability need tools to support their decision-making process from the strategic to the operational levels, where the presence of uncertainty and risk is a rising reality that must be dealt with.

In this context, the question on how to design, plan and operate SSC in an uncertain environment is a research question yet to be answered. Based on this research challenge, the present paper aims to develop a comprehensive literature review of the papers published on SSC, focusing on the use of Operational Research (OR) methods to support the SSC complex decision process. From this analysis, we aim to understand how SSC have been treated by the OR academic community and based on this identify the still existing research gaps. Grounded on these gaps, a research framework will be derived, pointing towards a future research agenda in the area, that we hope will be used as a roadmap for SSC OR future research.

The remainder of this paper is structured as follows: Section 2 describes the review methodology followed in the present paper and characterizes the analyzed sample; Section 3 states the position of the present paper when compared to the reviews published in the area; in Section 4 the sample characteristics are analyzed and a descriptive analysis is performed; Section 5 presents a detailed insight on how OR has been contributing to the decision process within SSC. Papers addressing strategic, tactical to operational decisions levels are analyzed in detail. Section 6 details how the three pillars of sustainability have been modeled; and Section 7 pinpoints the main industrial sectors where SSC have been addressed. Section 8 develops a critical analysis of the works published and proposes a future research agenda in SSC, identifying the main research lines where the OR community can, in the future, contribute to shape SSC. Lastly, in Section 9, conclusions are presented.

## 2. Research methodology and initial data statistics

The present paper performs a comprehensive literature review on SSC focusing on the usage of OR methods to inform the SSC decision process, spanning from strategic to operational decisions. A systematic research methodology is used (Tranfield, Denyer, & Smart, 2003) to ensure the consistency and quality of the work developed and to provide a suitable examination of the decisions, procedures, and conclusions taken. Additionally, the usage of such methodology allows replicability and provides appropriate means of synthesizing the field of knowledge evolution (Carter & Easton, 2011). The methodology followed is structured along four steps:

***Step 1: Material collection***

In this step, the unit of analysis, as well as the material to be collected, are specified. As for unit of analysis, only papers written in English and published in peer-reviewed journals, with no limit set on the date range, were considered. The papers' selection was made through an exhaustive search using Thomson Reuters Web of Knowledge (TR) and Science Direct (SD) Data Bases. The final updated set of data for the review was compiled in May 2016.

The primary search considered as keywords the words Sustainable Supply Chain. As results, 2634 papers in TR and 32,107 papers in SD were identified. This search was then refined and the first level keywords was combined respectively with the keywords "Operational Research" and "Operations Research". The results lead to 7 papers in TR and 12 papers in SD for the first keyword and 16 papers in TR and 51 papers in SD for the second one. These numbers are not, however, representative of the work developed on SSC using OR methods, and a more all-inclusive search was performed. This combined sustainable supply chain keywords with the topics characterizing operational research methods as defined by the EURO and INFORMS organizations: "simulation"; "optimization"; "queuing theory"; "Markov decision processes"; "economic methods"; "data analysis"; "statistics"; "neural networks"; "expert systems"; "meta-heuristics", and "decision analysis". A total of 3958 papers was identified, distributed through the topics mentioned as follows: simulation, 1333; optimization, 1960; queuing theory, 3; Markov decision processes, 13; economic methods, 10; data analysis, 135; statistics, 223; neural networks, 92; expert systems, 41; meta-heuristics, 44; decision analysis, 104.

In order to understand if the selected papers match the present paper's objective, which aims to understand how researchers studying SSC have been supporting SSC decisions through the use of OR methods, the 3958 papers were subjected to a content analysis. In this process, papers were excluded if they did not match all the criteria below that represent this paper objectives:

1) The paper is written in English and was published in a peer-reviewed journal.
2) The paper applies a formal OR method. Empirical manuscripts not making use of quantitative OR-based methods; explorations of non-managerial topics; or review papers were not considered.
3) The paper addresses "sustainable supply chain" concepts where apart from the economic pillar, the environmental or the social pillars are considered (i.e. papers on closed-loop supply chain (CLSC) or reverse chain that did not explicitly model environmental or social aspects were excluded). This is justified as there is a large body of literature in CLSC and Reverse Chain that does not model explicitly environmental or social aspects.
4) Papers model a supply chain problem. Meaning that papers exploring a single operation were excluded (e.g. production planning or scheduling problems looking just to the shop-floor problem were excluded), as supply chain papers should consider the interaction amongst two or more entities in the chain. This goes in line with the conclusion of Brandenburg, Govindan, Sarkis, and Seuring (2014), which states that most of the SSC papers focused on single operations problems – namely manufacturing problems, questioning the validity of the classification of existing works under the label of sustainable supply chain.

A final sample of 220 papers was obtained. This is considered for the detailed analysis that will be performed within this paper.

The literature review developed was extensive, but not exhaustive. While TR and SD provide a broad coverage of the academic literature, they do not cover all peer-reviewed publications and, consequently, it is possible that relevant papers on SSC using OR methods were not selected.

***Step 2: Descriptive analysis***

In order to understand the position of the present paper in the related literature, its scope is comparable to the ones from the literature reviews published in the area from 2007 onwards, when Srivastava (2007) published his review on Green Supply Chain (Green SC). One year later Seuring and Müller (2008) published a detailed review on SSC, which has been identified as the most cited review paper in Sustainable Supply Chain (731 citations in WoK in October 2017). The results are presented and discussed in Section 3.

Secondly, and to better apprehend the breath of the papers collected in step 1, a 4 W's analysis (When, Who, What, and Where) is applied. These four questions provide a framework for structuring our analyses towards important issues that we aim to address. The following questions are used as motivation:

Q1) When were published the papers that explore OR methods in SSC?
Q2) Who has been exploring OR methods in SSC?
Q3) What OR methods have been explored when addressing SSC?
Q4) Where are located the researchers that have been exploring OR methods in SSC?

To answer to question Q1, papers have been divided by year of publishing. Q2 is addressed by identifying the journals where the different papers have been published. The analysis proceeds and the identification of the OR methods that have been applied when addressing SSC is made, allowing the answer to question Q3. Finally, in order to understand the geographic origin of the SSC research - Q4, the countries of the researcher's institutions are identified. This analysis is presented and discussed in Section 4.

***Step 3: Category selection***

To obtain a deep understanding of how OR methods have been used to support SSC decisions and what have been the main sustainability pillars treated within the SSC decision process, a categorization of the decision levels and sustainability dimensions is considered. At the decision levels, strategic, tactical and operational problems within SSC are analyzed. As sustainability dimensions, the three pillars established by the Triple Bottom Line (TBL: economic; environmental and social) are contemplated (Elkington, 2004). The different OR methods, as classified in step 1 of this methodology, are also analyzed. The treatment or not of uncertainty within the decision problems studied is looked at. The analysis performed is then conducted by answering the following questions:

Q5) What SSC decisions levels (strategic; tactical or operational) have been addressed when applying OR methods to SSC?
Q6) What sustainability pillars (economic; environmental and social) have been explored when using OR methods in SSC?
Q7) What OR methods have been used along the different SSC decision levels?
Q8) What type of problem has been treated at the different SSC decision levels – deterministic or subject to uncertainty?

This analysis is developed throughout Sections 5 and 6 of this paper.

Finally, and to better understand what industrial sectors have been targeting SSC, the following question is also considered:

Q9) Which industrial sectors have been addressed when applying OR methods to SSC?

Industrial sectors as bio-related products and processes; food and beverage; manufacturing; retail; etc., are considered (Section 7).

***Step 4: Material evaluation***

In this step, we carry out the assessment of the sample of papers according to the selected categories and dimensions. To identify groups of published papers that demonstrate similar approaches in terms of decision levels, sustainability pillars and OR methods, an agglomerative hierarchical cluster analysis (HCA) is performed. A conceptual map is developed, which describes in a summarized form why the analysis is performed and helps to categorize, organize, visualize and structure the discussions and main findings of the systematic literature review performed (Section 8). A critical analysis, motivated by the answers to questions 5–9 is performed and, as a result, the main existing research gaps are identified. Based on these gaps a framework is proposed, which contemplates a future research agenda that embraces a holistic view on how OR can contribute in the future, to design, plan and operate SSC (Section 8).

The developed research methodology is summarized in Fig. 1, where the objective of each step; the methods and tools used; as well as the section where the results are analyzed and discussed, along the paper, are presented.

## 3. Related literature reviews published recently (2006 onwards)

In recent years, several reviews have been published on SSC demonstrating the growing interest in the area. A total of 26 relevant review papers were identified and classified based on different criteria: research focus and objectives; research methodology analyzed; whether a systematic review was performed; number of papers reviewed; and the time horizon covered. Additionally, and to understand how SSC have been addressed, other criteria have been contemplated in line with this present paper's objectives: type of supply chain structure considered (forward; reverse and/or both); decision levels explicitly analyzed; and sustainability dimensions studied. Finally, if provided, the main journals publishing SSC works were identified. The result of this classification is shown in Table 1.

From Table 1, we can ascertain that the year with the highest number of published review papers over the last 10 years was 2015 (8 out of 26). This undoubtedly supports the rising interest of the academic community in the SSC topic. Additionally, when performing a review, the selected methodology was most commonly a systematic review (present in 19 out of 26 papers), translating a methodological rigor pursued by the authors. Moreover, in terms of supply chain characteristics, most of the reviews studied the three SC structures: forward, reverse chain and closed-loop supply chain (e.g. forward & reverse, in Table 1) with the forward structure being always present. Regarding the treatment of sustainability, most of the papers have considered the three pillars of sustainability (economic, environmental and social), with some exceptions related to the green supply chain where the main focus is the environmental pillar (9 papers - Ahi & Searcy, 2015a; Fahimnia et al., 2015; Golicic & Smith, 2013; Ilgin & Gupta, 2010; Ilgin, Gupta, & Battaïa, 2015; Min & Kim, 2012; Sarkis, 2012; Sarkis, Zhu, & Lai, 2011; Srivastava, 2007). On the decision-making levels, most of the review papers did not disclose such information, with one exception (Eskandarpour, Dejax, Miemczyk, & Péton, 2015) that looked into the supply chain network design, considering only the strategic decision level.

When considering focus and objectives, as well as research methodologies studied, five groups of reviews can be identified.

**Table 1**
Literature reviews in the last 10 years on SSC (2006 onwards).

| Reference | Research focus and objective | Research methodologies | Systematic literature review | Number of papers | Time horizon | Supply chain structure | Decision level analyzed | Sustainability dimensions | Main journals |
|---|---|---|---|---|---|---|---|---|---|
| Srivastava (2007) | Focus on Green Supply Chain (Green SC). Identifies Green SC major areas; green design and green operation. | General | Yes | 227 | 1990–2006 | Forward & Reverse | n.a. | Economic Environmental | n.a. |
| Carter and Rogers (2008) | Explores the concept of sustainability in SSC. Proposes a framework for SSC Management | Theory Building | No | n.a. | n.a. | n.a. | n.a. | Economic Environmental Social | n.a. |
| Seuring and Müller (2008) | Focus on research in SSC. Proposes a conceptual framework that summarizes the research in SSC. | General | Yes | 191 | 1995–2007 | Forward | n.a. | Economic Environmental Social | JCLP, POM, IJPR |
| Gold et al. (2010) | Quantitative analysis of case-studies in SSCM. | Empirical Case-studies | Yes | 70 | 1994–2007 | n.a. | n.a. | Economic Environmental Social | n.a. |
| Ilgin and Gupta (2010) | Focus on environmentally conscious manufacturing & product recovery. | IE and OR Methods | n.a. | 540 | 1999–2010 | Forward & Reverse | n.a. | Economic Environmental | n.a. |
| Carter and Easton (2011) | Identifies major gaps and trends in SSCM research. | Empirical | No | 80 | 1991–2010 | n.a. | n.a. | Economic Environmental Social | n.a. |
| Sarkis et al. (2011) | Establishes major lines of research in Green SC | Organizational Theories | No | + −150 | 1995–2010 | Forward & Reverse | n.a. | Economic Environmental | n.a. |
| Sarkis (2012) | Through the use of a framework analysis the literature Green SC. | Empirical | Yes | + −100 | 2000–2010 | Forward & Reverse | n.a. | Economic Environmental | n.a. |
| Min and Kim (2012) | Identifies major research issues and research lines in Green SC. | General | Yes | 519 | 1995–2010 | Forward & Reverse | n.a. | Economic Environmental | JCLP, IJPR, IJPE,EJOR |
| Ashby et al. (2012) | Focus on SC looking into explicitly to environmental and social sustainability dimensions. | General | Yes | 134 | 1983–2011 | Forward & Reverse | n.a. | Economic Environmental Social | BSE, GMI,JBL,SCM-IJ |
| Dekker et al. (2012) | Focus on the use of Operational research methods in green logistics. | OR Methods | Yes | 60 | n.a. | Forward & Reverse | n.a. | Economic Environmental Social | IJPR, IJPE, EJOR |
| Hassini et al. (2012) | Focus on SSC metrics. Proposes a framework for sustainable SC metrics. | Metrics | Yes | 87 | 2000–2010 | Forward & Reverse | n.a. | Economic Environmental Social | IJPR, IJPE, EJOR |
| Tang and Zhou (2012) | Develops a framework to classify literature that uses OR/MS methods in SC for sustainable operations. | OR and MS Methods | No | 56 | n.a. | Forward & Reverse | n.a. | Economic Environmental Social | n.a. |
| Seuring (2013) | Analyses quantitative models for forward sustainable supply chain. | OR Methods | Yes | 36 | 1994–2010 | Forward | n.a. | Economic Environmental Social | JCLP, EJOR, IJPE, IJPR |
| Golicic and Smith (2013) | Analyses through a meta-analysis Green SC environmental practices | Empirical | No | 77 | 2000–2011 | Forward & Reverse | n.a. | Economic Environmental | n.a. |
| Alexander et al. (2014) | Analyses decision-making theory in SSC exploring the use of decision theory concepts and how these can help SSC theory Building. | Decision Theory & Theory Building | Yes | 160 | 1980–2013 | n.a. | n.a. | Economic Environmental Social | IJPE, IJPR, JCOP,EJOR SCM-IJ,JBE, PPC |
| Brandenburg et al. (2014) | Focus on the use of model-based methods in Forward SSC. | OR Methods | Yes | 134 | 1994–2012 | Forward | n.a. | Economic Environmental Social | JCLP, IJPR, IJPE, EJOR, DSS,OR |
| Brandenburg and Rebs (2015) | Focus on the use of model-based Forward SSC. | Model-Based SC | Yes | 185 | 1994–2014 | Forward | n.a. | Economic Environmental Social | JCLP, IJPE EJOR, IJPR |

(*continued on next page*)

Table 1 (*continued*)

| Reference | Research focus and objective | Research methodologies | Systematic literature review | Number of papers | Time horizon | Supply chain structure | Decision level analyzed | Sustainability dimensions | Main journals |
|---|---|---|---|---|---|---|---|---|---|
| Fahimnia et al. (2015) | Bibliometric research to identify research opportunities in Green SC | General | Yes | 1066 | 1992–2013 | Forward | n.a. | Economic Environmental | JCP, IJPE, IJPRBSE, SCMIJ |
| Touboulic and Walker (2015) | Analyses the existent theoretical perspectives in SSCM. Proposes an SSCM integrated theoretical map. | Organizational theories in SSCM | Yes | 308 | 1996–2013 | Forward | n.a. | Economic Environmental Social | JCP, SCMIJ, IJPE, BSE, IJPDLM, JBE |
| Ahi and Searcy (2015a) | Studies the metrics in Green SC. Proposes a framework for measuring performance in Green SC. | Metrics | Yes | 445 | 1989–2012 | n.a. | n.a. | Economic Environmental | JCP, IJPE, IJPR, IJPO, SCM-IT |
| Ahi and Searcy (2015b) | Identifies and analyses the published definitions of Green SC and SSC. Proposes a new definition for SSCM | General | Yes | 180 | 2002–2012 | Forward & Reverse | n.a. | Economic Environmental Social | JCP, IJPE, BSE, JOM, Bench.,IJPDLM, SCM-IT |
| Taticchi et al. (2015) | Focus on the generic use of decision-support tools and performance measurement in SSCM. | DSS tools & Performance measurement | Yes | 384 | 2000–2013 | Forward & Reverse | n.a. | Economic Environmental Social | JCP, IJPE, IJPR, SCM-IT,BSE,EJOR |
| Ilgin et al. (2015) | Focus on environmentally conscious manufacturing and product recovery. | OR Methods | n.a. | 190 | 1999–2010 | Forward & Reverse | n.a. | Economic Environmental | n.a. |
| Eskandarpour et al. (2015) | Focus on supply chain network design (SCND) models and methods that account for sustainability issues. | OR Methods | Yes | 87 | 1990–2014 | Forward & Reverse | Strategic level | n.a. | IECR, CCE, IJPE, AIChE, EJOR, JCP |
| Banasik et al. (2016) | Focus on multi-criteria decision making approaches (MCDM) in Green SC | MCDM Methods | Yes | 188 | 2000–2015 | Forward & Reverse | n.a. | Economic Environmental | JCP; IJPE; IJPR; EJOR; ESA; CACE; Sustainability |

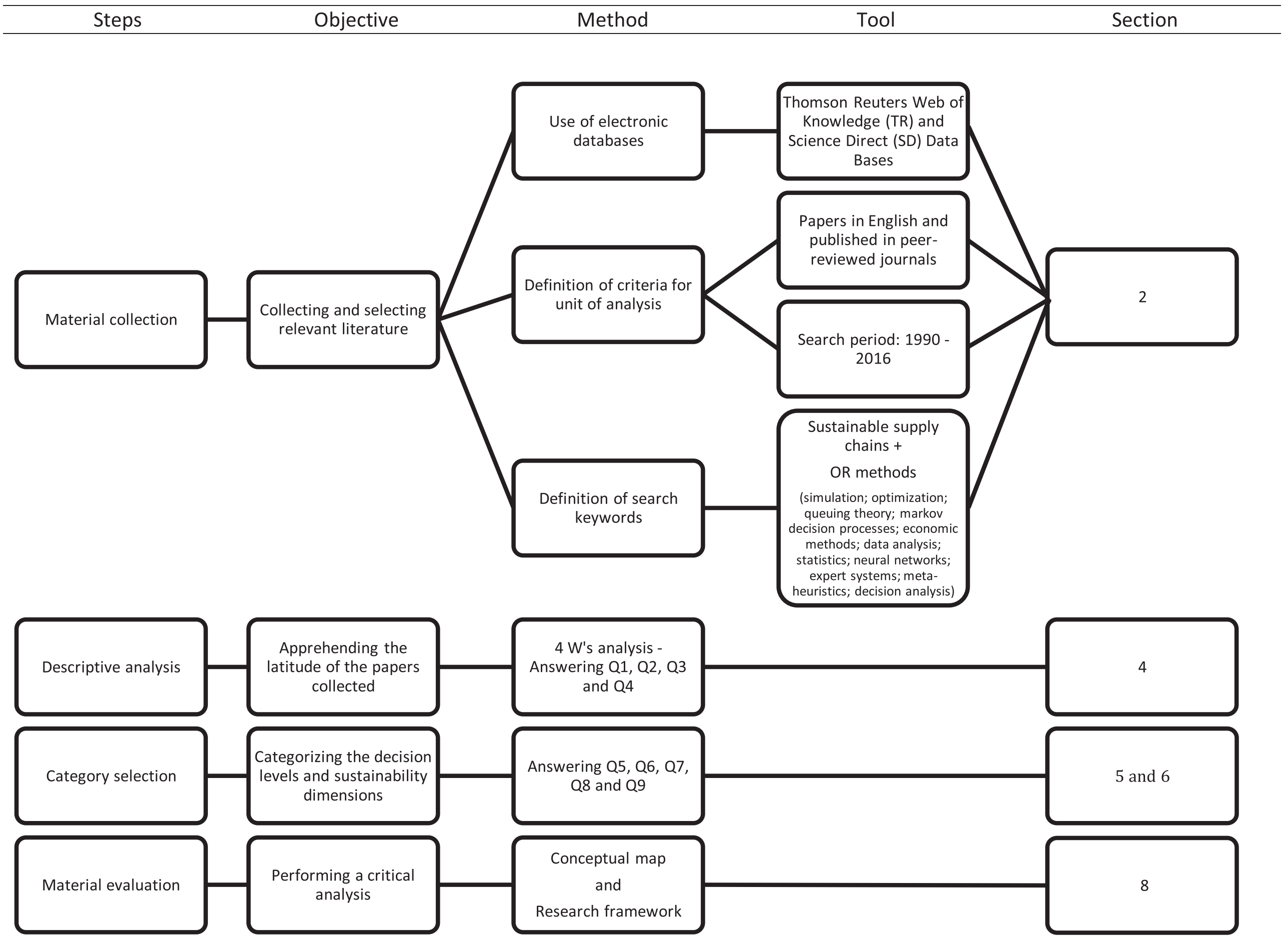


**Fig. 1.** Research methodology, objectives, methods, tools and structure of analysis.

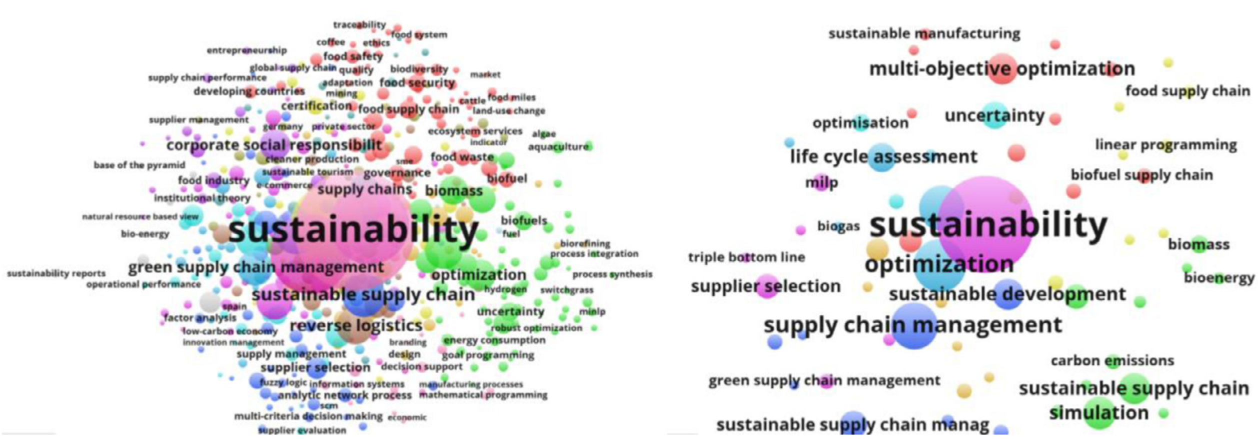


**Fig. 2.** Keywords bibliometric analysis of both initial (left) and final (right) sample.

A first group contemplates papers that explored a general research focus, meaning that the authors followed a holistic approach to analyze the published papers that address SSC (5 papers - Ahi & Searcy, 2015b; Ashby, Leat, & Hudson-Smith, 2012; Fahimnia, Sarkis, & Davarzani, 2015; Min & Kim, 2012; Seuring & Müller, 2008; Srivastava, 2007). The second group of papers uses an empirical approach, which is essentially aligned with papers that explored qualitative methodologies (4 papers - Carter & Easton, 2011; Gold, Seuring, & Beske, 2010; Golicic & Smith, 2013; Sarkis, 2012). A third group looked into organizational theory concepts (5 papers - Alexander, Walker, & Naim, 2014; Carter & Rogers, 2008; Golicic & Smith, 2013; Sarkis et al., 2011; Touboulic & Walker, 2015), where one of them combined decision theory with organizational theory (Alexander et al., 2014). Group four considered papers exploring OR methods (9 papers - Banasik, Bloemhof-Ruwaard, Kanellopoulos, Claassen, & van der Vorst, 2016; Brandenburg & Rebs, 2015; Brandenburg et al., 2014; Dekker, Bloemhof, & Mallidis, 2012; Eskandarpour et al., 2015; Ilgin & Gupta, 2010; Ilgin et al., 2015; Seuring, 2013; Tang & Zhou, 2012). Finally, the fifth group looks into metrics and performance

(3 papers - Ahi & Searcy, 2015b; Hassini, Surti, & Searcy, 2012; Taticchi, Garengo, Nudurupati, Tonelli, & Pasqualino, 2015).

Taking a closer look at group four, the one closest to the objectives of this paper, only four papers identified as their main focus the use of quantitative models in SSC (Brandenburg & Rebs, 2015; Brandenburg et al., 2014; Seuring, 2013; Tang & Zhou, 2012). Tang and Zhou (2012) analyzed 56 papers and within these explored five main dimensions for analysis where OR/MS methodologies could have been used: product design; technology selection in production processes; remanufacturing and cannibalization, competition and incentives for collection and recycling; supply chain design/restructuring; supply chain operations; reverse supply chain. Seuring (2013) studied 36 papers that employed quantitative models when studying forward SSC. The author, based on existing reviews, considered that CLSC and reverse chain were extensively studied and these were not within his focus. Two main dimensions of analysis were considered: sustainability dimensions and modeling approaches. Brandenburg et al. (2014) presented a very comprehensive review on forward SSC, and like in Seuring (2013), CLSC and reverse chain were also not considered by the authors. A sample of 134 papers was analyzed, and in order to do this the authors considered three main dimensions: supply chain dimensions, including four major characteristics: actor research focus, organizational level of analysis, SCOR processes, and applications; sustainability dimension: economic, environmental; social pillars and all three; modeling dimension, exploring models as prescriptive - problem solved oriented; or descriptive - to evaluate or understand the problem. Deterministic or stochastic approaches were added to the model's usage – leading to four combinations; still on the modeling dimension the authors considered the model type (e.g. analytical, simulation…), modeling technique (e.g. multi-objective, MCDM…), solution approach; the research dimension, where the type of data used (empirical, generic example, none), and what the research perspective (extend/validate; none; specific) was analyzed. Finally, Brandenburg and Rebs (2015) identified 185 papers also associated with forward SSC. For dimensions of analysis, as in Brandenburg et al. (2014), these authors considered the supply chain dimensions; sustainability dimensions; modeling dimension, but within this they considered only the model type and purpose and added a new dimension which they called sustainable supply chain dimension, where sustainable supplier management, pressures incentives and sustainability risks were considered.

After a careful analysis of the above four reviews it is our understanding that although detailed evaluations were performed, important dimensions of SSC are still lacking a detailed analysis. So far none of the previously mentioned reviews analyzed the usage of OR methods across the three chain decision levels (strategic; tactical and operational) towards the achievement of sustainability goals. Such analysis will provide researchers and managers with the information on what OR tools have been explored in each decision level, and what type of problems have been studied, leading to the identification of current gaps when trailing the development of effective decision supporting tools. Additionally, it is also important to understand through a sound basis how the three sustainability pillars have been approached in supply chain at each decision level. What methodologies and metrics have been used to assess and model each one of the pillars? Moreover, accounting for the ever-changing context where SSC operate, it is crucial to determine if any uncertainty has been dealt with, complementing Brandenburg et al. (2014) work, which concluded that uncertainty was rarely addressed. It is important to understand what OR methodologies have been used so as to identify the best form of dealing with such a problem. Moreover, this paper also aims to apprehend if risk and resilience aspects have been addressed and how, as such factors require a special attention when dealing with SSC as stated by Brandenburg and Rebs (2015). Finally, and as considered in Brandenburg et al. (2014), Brandenburg and Rebs (2015) and Seuring (2013), this paper will also look into the industrial areas explored.

This paper's analysis will be performed not only on forward SSC, as developed by Brandenburg et al. (2014), Brandenburg and Rebs (2015) and Seuring (2013) but also on CLSC and reverse chain. This is because although we agree with Seuring and Brandenburg and co-authors that CLSC and reverse chain have been comprehensively studied (see, reviews by Govindan, Soleimani, & Kannan, 2015b; Sasikumar & Govindan, 2008a, 2008b, 2009), for ample analysis), we want to understand if apart from the management of reverse flows and reverse operations, environmental and social dimensions have also been addressed explicitly. So, in our review, these structures will be considered if named as "sustainable supply chain".

Another important idea to explore in this paper, is related to the concern expressed by Brandenburg et al. (2014) that questioned the validity of classifying most of the existent works analyzed under the label of "sustainable supply chain", as these concentrated sustainability concerns in a single SC activity, particularly the production function. These authors claimed that the research community should decide and agree on the proper concept for SSC so that a holistic view of such systems can be pursued. This led us to carefully choose our sample, focusing only on the papers that treat "sustainable supply chain". Papers considering a single operation were left out from our study as explained in Section 2. This will help us to conclude if the concern of Brandenburg and co-authors is still valid.

With this proposed detailed analysis, this paper aims to actualize the conclusions and research challenges specified in the above reviews on SSC, and through the study of different dimensions to contribute to the establishment of a research agenda that can help researcher's pursuit the development of OR methods as a mean to support SSC decisions in an uncertain context.

## 4. Sample description and main characteristics

A keywords-based bibliometric analysis on both the initial (3958 papers) and final (220 papers) samples were performed to better understand what keywords are usually used in papers that address SSC through the usage of OR methods (see Fig. 2). The bibliometric analysis performed to the initial sample reveals that, although there is a great concentration of keywords related to sustainability, other keywords with similar concentration are not visible (e.g. life cycle assessment). On the other hand, the analysis of the final sample gives us an idea of the keywords related not only to sustainability but also with OR methods, enabling the validation of the content analysis performed in order to refine the initial sample of 3958 papers into 220 papers. Fig. 2 points out to important keywords that represent dominant research options when using OR methods in SSC, namely optimization, and within this multi-objective optimization; simulation; lifecycle assessment and carbon emissions; and bio-related supply chain. This translates, at an early stage, possible conclusions to be drawn from this paper's analysis.

To further characterize the final sample of papers (220 papers), the first four main questions are answered and the results presented in Figs. 3–7, and Table 2.

Fig. 3 shows that the number of papers that have been exploring OR methods in SSC has been growing over the last five years, reaching its peak in 2015, with 60 papers being published. As our search was conducted in May 2016, it is expected that in 2016 the usage of OR methods dealing with SSC will continue to rise, probably over the number of 60 papers from 2015.

The top 10 journals that have been publishing papers in SSC are shown below in Fig. 4, the Journal of Cleaner Production and the

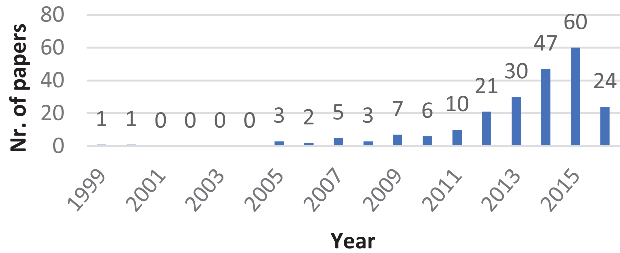


**Fig. 3.** Number of Papers published per year since 1999.

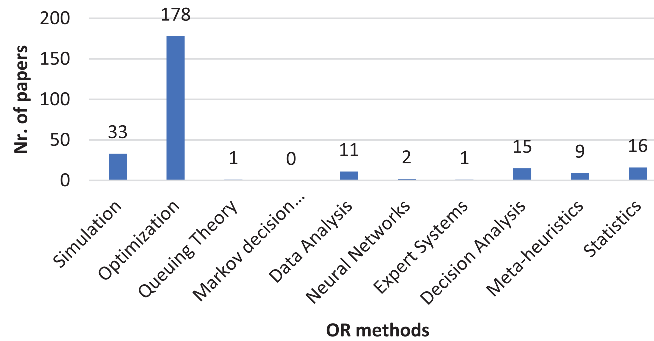


**Fig. 5.** Main OR methods addressing SSC.

**Table 2**
Optimization plus other OR method addressing SSC.

| Other OR methods | Sustainability pillars | | |
|---|---|---|---|
| | Economic | Environmental | Social |
| Simulation | 17 | 15 | 2 |
| Queuing theory | 1 | 0 | 0 |
| Markov decision processes | 0 | 0 | 0 |
| Data analysis | 2 | 1 | 0 |
| Neural networks | 0 | 0 | 0 |
| Expert systems | 0 | 1 | 0 |
| Decision analysis | 7 | 7 | 3 |
| Metaheuristics | 9 | 6 | 1 |
| Statistics | 4 | 4 | 0 |

International Journal of Production Economics being the ones that have been publishing more frequently in the area. It is interesting to observe that four of the top journals (Computers and Chemical Engineering; Industrial and Engineering Chemical Research; ACS Sustainable Chemistry and Engineering; and AIChE Journal) come from the Chemical Engineering area, a fact that is undoubtedly justified as in this area there is a very active community in Process Systems Engineering that explores OR-based methods in the modeling and solution of Operations and Supply Chain related problems, pointing out to a possible treatment of chemical-related applications. Additionally, the area of Energy is also being represented by two journals (Applied Energy and International Journal of Hydrogen Energy), which again shows the interest of this community on SSC and their treatment through OR methods. The European Journal of Operational Research, the flagship journal in OR methods, is also within the top ten journals with 8 papers published.

Regarding OR methods, from Fig. 5 it can be concluded that optimization based methods, where the development of a mathematical programming model is contemplated, are the most used methods (178 papers), followed by Simulation (33 papers). In this analysis, more than 220 papers, the sample size considered, are identified showing the usage of more than one OR method in the same problem (42 papers use more than one OR method).

Taking as an example the papers that explore optimization based methods, the combination of these with other OR methods are shown in Table 2. Simulation is the method more frequently used, jointly with optimization, followed by decision analysis and metaheuristics. In Table 1, it is further identified what different sustainability pillars have been studied when optimization was explored in conjunction with other OR method. The economic pillar is nearly always present, followed by the environmental pillar and few papers address the social pillar (6).

Another important aspect to analyze is related to tendency observed over the years on the usage of the OR methods. This is shown in Fig. 6. Through the analysis of this figure, it can be seen that optimization has grown over the years, reaching its peak of usage in 2015 (more than 90 published papers addressing optimization). Moreover, optimization has been following the growing research interest in SSC.

Although simulation, decision analysis and statistics do not have the representativeness that optimization has in the analyzed sample, these OR methods have always been used over the years, reaching the maximum number of publications in 2015. On the other hand, data analysis, neural networks, expert systems and queuing theory are OR methods that are used less frequently over the years.

Finally, the analyzes of the country of origin of the corresponding authors (see Fig. 7), confirmed a strong focus on USA (60 papers), Italy (21), Germany and China (10 each).

## 5. How have OR methods been used to support sustainable supply chain decisions?

In this section, a detailed analysis of SSC will be presented with the aim of understanding how OR methods have been supporting SSC decisions. This analysis follows the fifth to eighth questions raised in the methodology section (Section 2). A general overview, considering the three levels of decision will first be presented, fol-

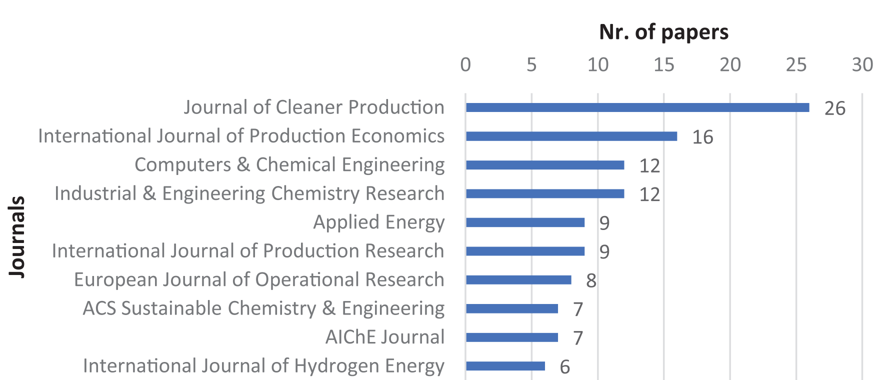


**Fig. 4.** Top 10 journals publishing papers that explore OR methods when dealing with SSC.

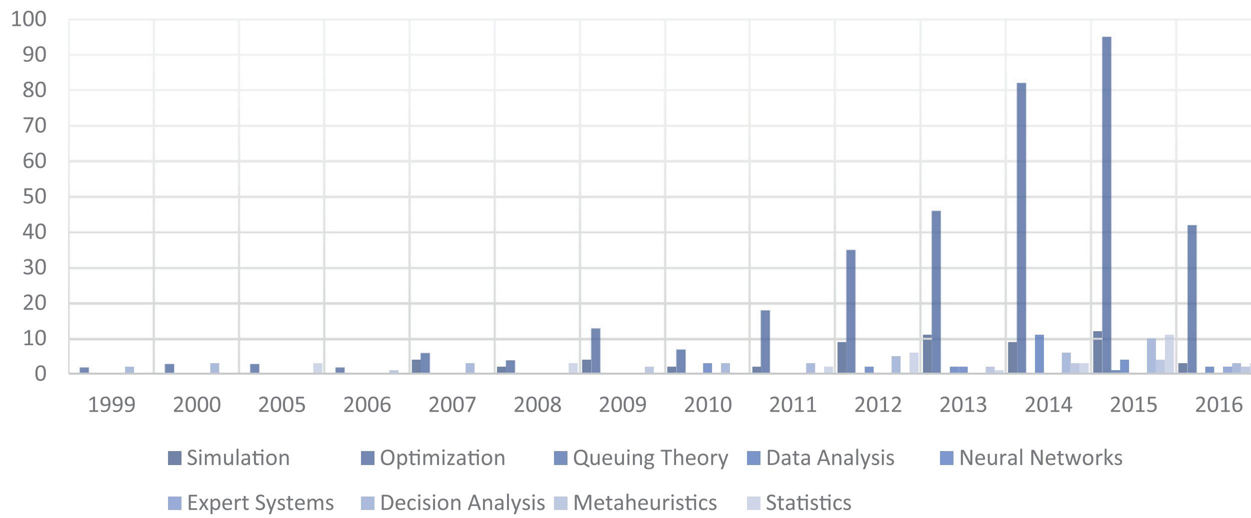


**Fig. 6.** Usage of OR methods along the years.

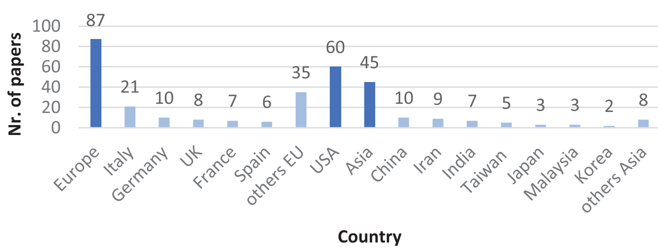


**Fig. 7.** Country of origin of the corresponding authors of the papers analyzed.

lowed by a deeper analysis of the papers covering each decision level.

### 5.1. General overview

This analysis will focus globally on the questions mentioned above, which are related to decision level; sustainability pillars; OR methods used and whether deterministic or stochastic problems have been considered.

The categorization of the sample was an important process that required special attention due to the variety of decisions involved in sustainable supply chain management (SSCM). Some decision rules were used to categorize papers in strategic, tactical or operational category. A paper to be considered strategic should address a long planning cycle for several years out, which may be accomplished at an executive management level. On the other hand, a tactical paper deals with a shorter planning cycle, which is more concerned with inventory, demand and/or supply planning. Furthermore, papers related with operational SSC include demand fulfillment, production, transportation, scheduling and monitoring activities that are current planning tasks measured weekly. The combination of decision levels namely strategic-tactical and tactical-operational are also analyzed as these will allow to understand about the investment that the authors have made on the integration of more than one decision level, leading to more wide-ranging papers.

From Fig. 8 it is possible to verify that authors have been mainly focused on strategic aspects of SSC (207 papers), from where 59 papers explored the integration with tactical aspects. Only six papers exclusively focused tactical aspects (Alharbi, Wang, & Davy, 2015; Amorim, Alem, & Almada-Lobo, 2013; Azadi, Jafarian, Farzipoor Saen, & Mirhedayatian, 2014; Battini, Persona, & Sgarbossa, 2014; Bortolini, Faccio, Ferrari, Gamberi, & Pilati, 2016; Hoen, Tan, Fransoo, & van Houtum, 2014). Furthermore, when looking at operational aspects authors have been essentially addressing them combined with tactical aspects (Chardine-Baumann & Botta-Genoulaz, 2014; Hsueh, 2015; Mansoornejad, Pistikopoulos, & Stuart, 2013; Ramos, Gomes, & Barbosa-Póvoa, 2014), existing only three papers that only explored operational aspects (Bouchery, Ghaffari, Jemai, & Dallery, 2012; Mansouri, Aktas, & Besikci, 2016; Sabio, Kostin, Guillén-Gosálbez, & Jiménez, 2012). The exception to the aforementioned papers is Liotta, Stecca, and Kaihara (2015) and Zhang, Gong, Skwarczek, Yue, and You (2014), which cover the three decision levels, presenting a holistic perspective of SSCM. However, none of these papers cover the three pillars of sustainability simultaneously.


**Fig. 8.** Number of publications covering the different decision levels in SC.

To understand the main relationships between decision levels and sustainability pillars, an HCA analysis is performed. Four clusters were obtained (Table 3), where the strategic decision level *per se* justifies a single cluster followed by the strategic-tactical integration levels showing the authors' main attention to this kind of decisions, as previously mentioned. Such decisions, when dealing with the sustainability pillars, have been focused on the economic sustainability aspect and most papers considered the economic and the environmental aspects together, while the social aspect was mainly analyzed when addressing the previous two pillars combined (42 papers). This shows a tendency to have a more complete

**Table 3**
Cluster analysis of decision level and sustainability pillars.

| | Cluster | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | 4 |
| **Cluster size** | 59 | 145 | 6 | 10 |
| **Decision level** | | | | |
| Strategic | – | 145 | – | – |
| Strategic-Tactical | 59 | – | – | – |
| Tactical | – | – | 6 | – |
| Tactical-Operational | – | – | – | 4 |
| Operational | – | – | – | 3 |
| Strategic-Operational | – | – | – | 1 |
| Strategic-Tactical-Operational | – | – | – | 2 |
| **Sustainability pillars** | | | | |
| Economic | 12 | 17 | 2 | 1 |
| Economic-Environmental | 35 | 81 | 3 | 5 |
| Environmental | – | 15 | – | – |
| Environmental-Social | – | 1 | 1 | 1 |
| Social | – | – | – | – |
| Economic-Social | 1 | – | – | – |
| Economic-Environmental-Social | 11 | 31 | – | 3 |

**Table 4**
Cluster analysis of decision levels and OR methods.

| | Cluster | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | 4 |
| **Cluster size** | 66 | 145 | 6 | 3 |
| **Decision level** | | | | |
| Strategic | – | 145 | – | – |
| Strategic-Tactical | 59 | – | – | – |
| Tactical | – | – | 6 | – |
| Tactical-Operational | 4 | – | – | – |
| Operational | – | – | – | 3 |
| Strategic-Operational | 1 | – | – | – |
| Strategic-Tactical-Operational | 2 | – | – | – |
| **OR methods** | | | | |
| Simulation | 10 | 23 | – | – |
| Optimization | 60 | 110 | 5 | 3 |
| Queuing Theory | 1 | – | – | – |
| Data analysis | – | 9 | 1 | 1 |
| Neural networks | 1 | 1 | – | – |
| Expert systems | – | – | 1 | – |
| Decision analysis | 4 | 10 | – | 1 |
| Metaheuristics | 4 | 5 | – | – |
| Statistics | 2 | 12 | – | 2 |

view on the SSC where the three pillars are considered simultaneously. The other clusters show that the tactical aspects, if not in conjunction with strategic decisions, are seldom studied and operational decisions are almost inexistent when addressing SSC. It is, however, interesting to note that in relative terms the number of papers covering social aspects is much higher than in the previous clusters. Also in these cases, the combination of economic and environmental aspects together is still the main trend. Furthermore, a lack of multi-decision level approaches is missing, as only two papers have addressed the three decision levels, and in none of these papers considered the three pillars of sustainability. These facts point out that further research is required to cover a complete SSC analysis. Additionally, the authors have been naming SSC to SC decisions that consider economic and environmental aspects together, and thus have been "abusively" calling green supply chain as SSC. A holistic view on SSC is still far from reach. Finally, the treatment of SSC addressing tactical and operational problems is still an area to further explore when considering the usage of OR methods.

Another important aspect to grasp is related to the type of OR methods explored to address the different levels of decision. To do so, an HCA analysis was carried out once more, whose results are shown in Table 4. Four clusters are identified. As expected, the larger cluster is the one that deals with strategic decisions, followed by cluster 1 that encompasses all papers that combine decisions considering two to three levels. These clusters show the usage of a wide diversity of OR methods, missing, however, the expert's system and showing a clear focus on the usage of optimization methods. An interesting find is that, when addressing only strategic problems (cluster 2), several other OR methods have been combined with optimization-based methods. Thus, SSC characteristics at the strategic level have been usually represented through a mathematical formulation, but simulation, neural networks, data analysis, decision analysis, metaheuristics and statistics have been applied to deal with the complex input data and resolution of the developed models. In cluster 3 only the tactical papers are included, and here it is possible to verify that optimization is clearly dominating the approach towards these problems. Finally, cluster 4 includes only operational studies, which have been all addressed by optimization combined with another method. Strangely enough, simulation methods have not been explored in these problems, being, however, one of the more adequate methods to treat tactical and operational problems. Additionally, operational activities are run on a daily basis and therefore the amount and volume of available information to be treated cannot be solely addressed by optimization methods. Therefore, the integration of other OR methods becomes critical.

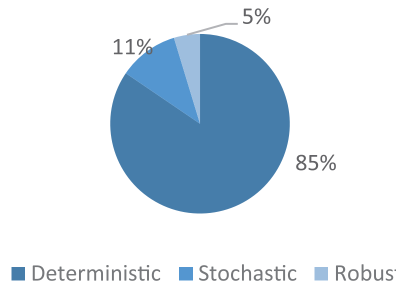


**Fig. 9.** Distribution of papers dealing with deterministic, stochastic and robust approaches.

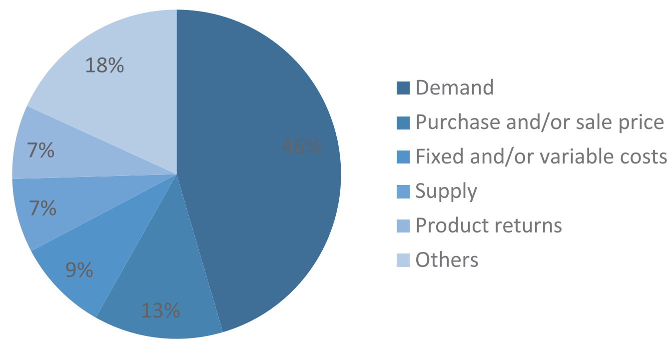


**Fig. 10.** Uncertainty aspects considered in stochastic and robust models.

In conclusion, the study of methods apart from optimization is still open to exploration, and the integration of other methods is also a future challenge that should be trailed, as SSC are complex systems that often deal with conflicting objectives and a large set of diversified data.

Finally, since the supply chain are often subject to diverse types of uncertainty, it is important to understand if this has been a factor of concern by the authors. After analysis, it has been concluded that only 16% of papers have considered uncertainty aspects (Fig. 9), 11% of them through the development of stochastic approaches and 5% considering a robust approach. Furthermore, when considering the type of uncertainties treated (Fig. 10), product demand has been the main focus (46%), followed by purchase and/or sale prices (13%), and fixed and/or variable costs (9%), which

**Table 5**
Aspects considered in the papers focused on network design (number of papers).

| | Facility design | Facilities location | Technologies | Transportation | Suppliers | Inventory | Production allocation |
|---|---|---|---|---|---|---|---|
| **CLSC** | 1 | 14 | 3 | 13 | 2 | 7 | 7 |
| **Forward** | 10 | 56 | 46 | 69 | 16 | 26 | 23 |
| **Reverse** | 2 | 4 | 2 | 3 | 1 | 1 | 1 |

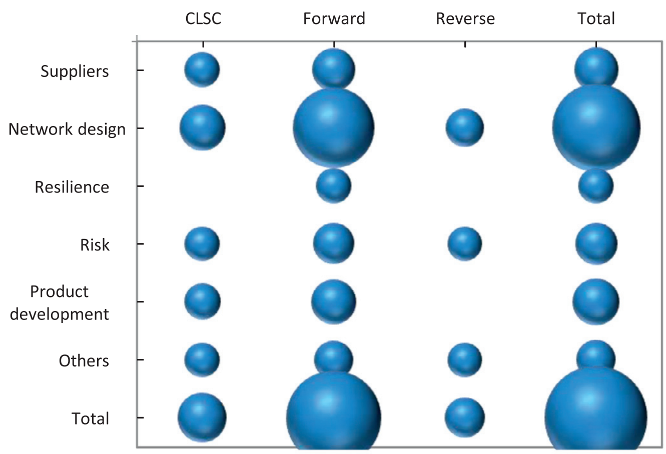


**Fig. 11.** Strategic aspects considered in the different types of SC.

include diverse types of costs as: opening costs; inventory costs; transportation costs; and processing costs. Additionally, the next two aspects, 1) supply and 2) products returns, accounts for 7% each. Finally, other aspects, such as environmental impacts, collection of goods, consumer purchasing behavior and transportation count for 18% of the uncertainties approached by the authors.

In conclusion, uncertainty in SSC is still not thoroughly contemplated, and the development of approaches that consider it is urgent, not only focusing on economic parameters but also considering environmental and social parameters.

### 5.2. Strategic decisions

A deeper analysis was undertaken in order to analyze what has been done within the strategic decision of SSC (see Fig. 11).

A first point to consider is concerning the structure of the SC when addressing explicitly sustainability issues. Through Fig. 11, it is possible to verify that authors have been mostly looking into SSC as forward SC and only a few authors have explored the reverse SC as well as the CLSC. When attaining SSC, CLSC appears to corporations as the basis structure towards the achievement of sustainability, since it allows the integration of waste as raw materials in a circular economy. The lack of research studies covering CLSC within a sustainable supply chain context indicates that a long research path has yet to be covered towards the approximation of research work and real needs for the companies. Is not enough to design, plan and operate reverse flows and reverse operations, this should be done in conjunction with the explicit evaluation of environmental and social impacts (e.g. assessing $CO_2$ minimization, creation of jobs, amongst other sustainability indicators).

Within the papers covering the strategic aspects of SSC, network design arises as the most discussed topic among authors (Fig. 11) for all types of SC structure (forward, reversed and closed-loop). Within network design decisions (Table 5), transportation aspects appear as the most analyzed problems followed by facilities' location and technologies decisions. In the transportation studies, some decisions are related to the transportation network definition, while some are related to the selection of transportation modes. Aspects such as inventory positioning, facility design (in here the design within the facility is considered) as well as production allocation to different facilities and supplier's integration are only considered in a few papers.

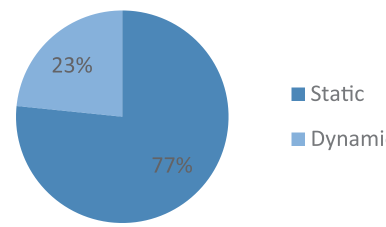


**Fig. 12.** Distribution of the papers addressing static and dynamic problems within the network design.

Still on the network design problem, from Fig. 12, it can be stated that most papers (77%) deal with static models, meaning that the network, when defined, stays the same during the analyzed time horizon. It is also worth mentioning that no paper covering dynamic systems in reverse SC has been found. Thus, an opportunity of research for considering dynamic networks within the network design problems is established.

Other aspects within the strategic level have been addressed, namely: suppliers' selection/integration, resilience within the network design problem, risk, product development and others (Fig. 11 and Table 6).

- **Suppliers' selection:** Some authors have been analyzing the suppliers' selection on the forward SC (e.g. Altmann, 2015; Aqlan & Lam, 2016; Ashayeri, Ma, & Sotirov, 2014; Varsei & Polyakovskiy, 2016; amongst others, see Table 4), two papers cover the supplier's integration in CLSC (Devika, Jafarian, & Nourbakhsh, 2014; Eskandarpour, Zegordi, & Nikbakhsh, 2013) and one paper considers the reverse SC together with the suppliers selection (Govindan, Jafarian, & Nourbakhsh, 2015). This leads to an unexplored area where sustainability improvements can be reached if CLSC and reverse SC researchers start exploring further the collaboration with the suppliers. Moreover, although more papers have addressed supplier selection within a forward SC, these are still few. Thus, as stated by Brandenburg and Rebs (2015), suppliers' selection towards sustainability goals is an area that still needs further research within a SSC context.
- **Resilience:** Works exploring SSC resilience is practically inexistent. There are only two papers (Henriques et al., 2015; Mari, Lee, & Memon, 2014) that cover this topic. The two papers address a network design problem where resilience is related to the network restructuring when facing a disruptive event. It is also interesting to verify that these two issues have only been included in studies that are focused on forward SC. Thus, exploring resilience of SC together with sustainability aspects especially in the reverse SC and CLSC seems to be a future line of research to explore. Henriques et al. (2015) cover a specific aspect of water treatment and energy, while Mari et al. (2014) is the only paper that presents a solution for network design covering resilience and sustainability at a strategic level.

**Table 6**
Decisions levels: main aspects addressed by the different papers.

| Decision level | SC type | Suppliers | Network design | Resilience | Risk | Product development | Others |
|---|---|---|---|---|---|---|---|
| **Strategic** | Forward | [35]; [85]; [92]; [103]; [106]; [108]; [120]; [122]; [156]; [181]; [187]; [191]; [195]; [197] | [1]; [3]; [7]; [8]; [10]; [11]; [13]; [16]; [17]; [18]; [20]; [21]; [28]; [29]; [31]; [32]; [34]; [37]; [38]; [40]; [41]; [42]; [43]; [45]; [46]; [47]; [48]; [49]; [50]; [52]; [54]; [57]; [58]; [59]; [66]; [67]; [68]; [69]; [70]; [71]; [74]; [73]; [75]; [78]; [80]; [82]; [84]; [86]; [88]; [89]; [90]; [93]; [95]; [97]; [100]; [101]; [104]; [105]; [110]; [111]; [112]; [113]; [114]; [116]; [117]; [118]; [119]; [123]; [124]; [126]; [129]; [130]; [131]; [132]; [133]; [136]; [137]; [139]; [140]; [141]; [142]; [143]; [145]; [147]; [149]; [151]; [153]; [154]; [155]; [157]; [158]; [159]; [161]; [166]; [167]; [171]; [174]; [175]; [176]; [177]; [178]; [179]; [180]; [182]; [185]; [189]; [190]; [192]; [196]; [198]; [200]; [202]; [204]; [205]; [207]; [208]; [209]; [210]; [211]; [212]; [214]; [213]; [215]; [216]; [217]; [218]; [219] | [89]; [138] | [8]; [10]; [17]; [49]; [52]; [69]; [115]; [138]; [150]; [170]; [172]; [218] | [3]; [7]; [9]; [10]; [12]; [15]; [18]; [22]; [27]; [28]; [30]; [33]; [46]; [62]; [76]; [81]; [99]; [102]; [137]; [183]; [184]; [214] | [56]; [65]; [77]; [96]; [152]; [186]; [201]; [206] |
| | Reverse | | [44]; [63]; [79]; [83]; [128]; [165]; [188]; [194] | | [87] | | |
| | CLSC | [4]; [146] | [26]; [39]; [51]; [53]; [55]; [60]; [61]; [64]; [72]; [107]; [109]; [121]; [125]; [148]; [160]; [162]; [163]; [168]; [164]; [193]; [199]; [203] | | [94] | [23]; [26]; [98]; [127] | [144] |
| **Tactical** | Forward | [14]; [36]; [91]; [187] | [2]; [8]; [16]; [18]; [19]; [24]; [28]; [29]; [34]; [37]; [38]; [40]; [41]; [43]; [49]; [50]; [59]; [66]; [68]; [70]; [95]; [100]; [101]; [126]; [129]; [131]; [132]; [134]; [139]; [147]; [149]; [153]; [158]; [159]; [166]; [174]; [179]; [182]; [190]; [198]; [202]; [209]; [211]; [214]; [218] | [89] | [6]; [8]; [49]; [115]; [218] | [9]; [12]; [18]; [22]; [28]; [81]; [99]; [184]; [214] | |
| | Reverse | | [128] | | | | [169] |
| | CLSC | [4] | [60]; [64]; [107]; [148]; [160]; [162]; [164]; [203]; [220] | | [94] | | |
| **Operational** | Forward | [36]; [91] | [25]; [88]; [131]; [134]; [166]; [173] | | | | [135] |
| | Reverse | | | | | | [169] |
| | CLSC | | | | | | |

- **Risk:** Regarding risk assessment, it is important to understand how risk aspects have been modeled and evaluated when applying OR methods. Some authors have been dealing with risk in a very simplistic way. Mari et al. (2014), for example, presented a model where resilience is related to location-specific risks. These authors have allocated a probability of occurrence of disruption events according to associated locations. Risk is considered as a parameter, which is included in disruption cost estimation. Reich-Weiser and Dornfeld (2009) also consider risk as a parameter in the model. In this case, the risk assessment of water scarcity in different regions is considered through risk cost mitigation. Nagurney, Nagurney, and Li (2015) incorporated risk in the objective function, attaining to its minimization. This work is focused on perishable health goods, which in contact with people might be harmful. The risk is modeled as a function of the flow between entities multiplied by a risk parameter, which estimates the harm probability. The risk parameters are dependent on population density in the areas of the transportation, travel time, transportation route, distance, etc. Zhou, Cheng, and Hua (2000) include risk as a constraint in the optimization model. They model supply chain planning where they assume a minimization of risk associated with a guarantee of stock correspondent to three days of production. Few authors have attempted to model risk, where risk metrics are incorporated. Amorim et al. (2013) consider a risk-averse production planning model incorporating financial risk measures. They measure a risk-neutral attitude through the upper partial mean and the conditional value-at-risk (Cvar). This model has been developed to analyze the financial risk within a supply chain of perishable food, which considers the spoilage ad the revenue loss due to risk in demand, decay rates and consumer behavior. Another work, which models risk in a more complete form, is the work of Giarola, Bezzo, and Shah (2013). This model aims to mitigate the risk for decision makers through the application of risk metrics, namely expected downside risk (eDR) and value at risk (var). They apply a multi-objective risk constraint formulation applied to bioethanol supply chain' design and planning. The risk has been considered only at the economic level. Other approaches to model risk have also been applied. Kim, Lee, and Moon (2011) have developed a relative risk index that could be applied to classify the risk of implementing supply chain entities in different locations. An optimization model was developed. Ruiz-Femenia, Guillén-Gosálbez, Jiménez, and Caballero (2013) were the only authors that assessed risk related to environmental aspects of the supply chain. These authors have determined the worst case scenario, obtaining the maximum global warming potential (GWP) attained over all scenarios under uncertainty. This scenario was then used as a metric to establish the environmental impact risk that was modeled in the environmental objective function.
Regarding the sectors addressed in the risk targeted work, it is possible to verify that most papers cover risks associated with the energy sector and at a strategic level, namely when defining a SSC structure. Some are specific to hydrogen-based energy SC (Dayhim, Jafari, & Mazurek, 2014; De-León Almaraz, Azzaro-Pantel, Montastruc, & Domenech, 2014; Kim et al., 2011), others with biofuels (Babazadeh, Razmi, Saman, & Rabbani, 2016; Giarola et al., 2013) and finally one article covers renewable energies in general (Lee, Chen, & Chen, 2015). The remaining papers cover different risk aspects related to specific sectors, namely the perishable food (Amorim et al., 2013), water (Reich-Weiser & Dornfeld, 2009), medical aspects (Nagurney et al., 2015), chemicals production (Ruiz-Femenia et al., 2013; Zhou et al., 2000) and waste management (Yu, Solvang, Yuan, & Yang, 2014). Only two papers are not industry related and assess generic economical risks in

SSCM (Ashayeri et al., 2014; Mari et al., 2014). It is also important to mention that none of the papers cover risks in CLSC.

- **Product Development:** 25 papers cover product development in their analysis (see Fig. 12). None of them relates product development with a reverse SC. This indicates that authors have not been focused on the design for logistics when thinking about the recovery of the products. The lack of analysis regarding these two topics together indicates that the life cycle approach required to achieve SSC has not been fully addressed, when it comes to the return of the products.

### *5.3. Tactical decisions*

When analyzing the papers that cover tactical aspects it is concluded that most of them also cover strategic decisions and four of them cover operational decisions. Only five papers cover exclusively tactical aspects. Alharbi et al. (2015) present a tactical model for the schedule of containers with time windows. Amorim et al. (2013) and Bortolini et al. (2016), have focused their studies in the planning and distribution of perishable goods. Battini et al. (2014) have studied inventory policies at the tactical level and Azadi et al. (2014) focused on the efficiency aspects of supplier's integration in the supply chain. The aforementioned areas are still requiring a deeper analysis and other tactical decisions in SSC would benefit from research specifically applied to this decision level. On the OR methods all five papers have employed optimization, where three of them exclusively consider optimization methods and Bortolini et al. (2016) have combined optimization with experts system methods for economic and environmental considerations. Azadi et al. (2014) combine optimization with data analysis. None of the papers cover the three pillars of sustainability, being Azadi et al. (2014) the only paper covering tactical aspects and assessing the social pillar.

Regarding the treatment of uncertainty within tactical decisions, only Amorim et al. (2013) presented a stochastic model. The remaining models are deterministic.

### *5.4. Operational decisions*

Only 10 papers were identified that deal with operational decisions, where out of those three are exclusively focused on the operational level (see Fig. 8 and Table 6).

Bouchery et al. (2012); Chardine-Baumann and Botta-Genoulaz (2014) and Ramos et al. (2014) are the only three papers that cover the three pillars of sustainability considering operational decisions. Chardine-Baumann and Botta-Genoulaz (2014) proposed a framework to assess sustainability in SSC and therefore they have included the TBL approach. Bouchery et al. (2012) include the TBL decisions in the SC inventory management and Ramos et al. (2014) incorporates the three dimensions of sustainability into a reverse chain.

The other papers considering operational decisions focus on different issues, like Corporate social responsibility practices in the daily companies' management (Hsueh, 2015); collaboration towards an integrated distribution between companies (Liotta, Kaihara, & Stecca, 2016); specific KPI to assess forest-based biorefineries (Mansoornejad et al., 2013); scheduling of equipment and human resources considering energy consumption issues (Mansouri et al., 2016); cost assessment on $CO_2$ emissions (Harris, Naim, Palmer, Potter, & Mumford, 2011) or minimization of the life cycle environmental impact of hydrogen infrastructures (Sabio et al., 2012). The operational decisions towards a SSC leave a huge research path for future development in the mentioned areas and in many other operational decisions, which have not been considered yet (e.g. employee's safety and wellbeing, environmental legislation in the workday, among others).

Consideration of uncertainty has been revealed to be inexistent at this decision level. No papers have been found covering uncertainty and operational decisions. This also opens a major research avenue, which is completely unexplored at the moment.

All operational decision papers have applied optimization models, which in some cases are combined with simulation (Harris et al., 2011; Liotta et al., 2016), data analysis (Sabio et al., 2012), decision analysis (Bouchery et al., 2012) and statistics (Sabio et al., 2012).

It is important to highlight that the few publications on operational aspects are due to the fact that only papers involving at least two SC entities were considered for analysis, as mentioned in Section 2. This means that several papers focused on sustainable operations management of a single facility have been excluded from this literature review since they did not have the holistic view of a SC. In the literature, there are several authors working on sustainability practices at the operations management level (e.g. green lean practices; green EOQ models, etc. (see Absi, Dauzère-Pérès, Kedad-Sidhoum, Penz, and Rapine (2013, 2016) and Retel Helmrich, Jans, van den Heuvel, & Wagelmans, 2015). Therefore, it is recommended integrating these papers on sustainable operations management in the holistic view of the supply chain in order to achieve the sustainability across operations among entities.

In summary, the strategic decision level has been the most analyzed level of decision, and network design is the focus of the majority of the authors when tackling strategic decisions. Optimization appears to be the most applied OR method.

Table 6 indicates the papers that have been analyzed using the previously identified categories within the SSC decision levels (please refer to Table A1 in Appendix A for the papers reference number). Table 6 includes a category titled "others", which comprises all papers that do not fit completely in the remaining categories: "suppliers", "network design", "resilience", "risk", and "product development". As an example, Garrone, Melacini, and Perego (2014) present a model that designs and implements a strategy to reduce food insecurity and limit food waste. In the same way, Gopal and Thakkar (2015) shows a framework to identify relationships among the SSC practices, inhibitors, enablers and SC performance. Additionally, Hussain, Awasthi, and Tiwari (2016) evaluate alternatives for sustainable supply chain management through a framework.

## 6. How have the three pillars of sustainability been modeled in sustainable supply chain?

In the different papers analyzed, sustainability has been addressed in dissimilar ways. It is then critical to understand how sustainability has been addressed in the OR studies. To do so, indicators are considered, related to the different sustainability pillars.

### *6.2. Economic pillar*

Fig. 13 shows the distribution of the economic indicators used in the papers to assess the economic pillar. It is possible to verify that cost has been the main economic objective function (59% of the papers), while profit has been considered in 25% of the papers while the Net Present Value (NPV) is considered in only 9% of the studies. In the previous section, (see Fig. 11) it was possible to verify that the network design problem has been the most addressed topic at the strategic level and, within this, transportation and location aspects as the top two aspects studied. When the SC network is fixed and only transportation decisions are undertaken, cost appears as a good economic indicator, however, when addressing location problems NPV appears as the most suitable economic indicator since it can better translate investments and other types

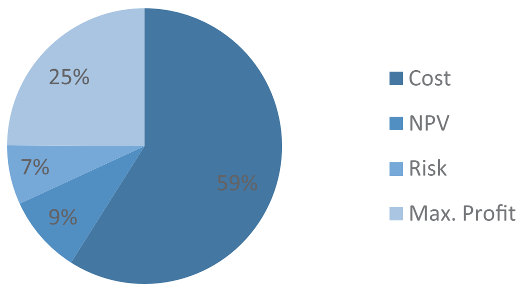


**Fig. 13.** Economic pillar assessment.

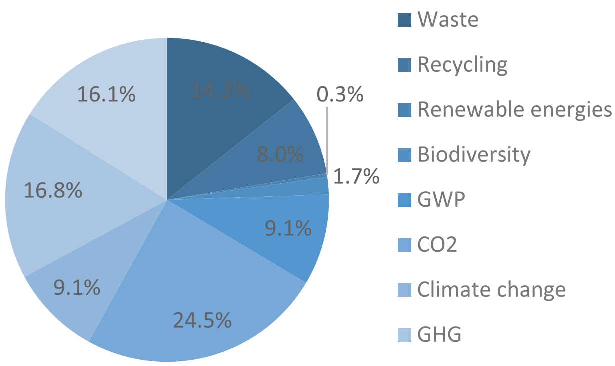


**Fig. 14.** Environmental pillar assessment.

of costs associated with revenues. Additionally, investment decisions involve risks that should be accounted for. However, this is not generally the case, and only 7% of the papers deal with risk modeling, where an economic risk is considered associated with economic parameters. Furthermore, despite the main finding that the economic pillar focus essentially on financial metrics it is important to state that also some works address non-financial aspects (7%), such as service level, product or process quality, which however are then transformed into financial measures, mainly cost (e.g. Chardine-Baumann and Botta-Genoulaz (2014); Hussain et al. (2016); Jakhar (2015); Kuo, Wang, & Tien (2010)). Concluding, the distribution of the indicators in the economic pillar, presented in Fig. 13, shows an uneven distribution. The percentage of papers applying NPV as objective function should rise, especially when considering network design decisions. Researchers should then invest more in selecting the most suitable economic indicator for their analysis.

### *6.3. Environmental pillar*

In terms of environmental assessment, the disparity of indicators applied is considerable, see Fig. 14. Most papers only cover aspects related to carbon dioxide ($CO_2$) emissions, namely: directly assessing the carbon footprint; measuring Green House Gases (GHG); assessing $CO_2$ emissions through the environmental impact category “Global Warming Potential”; and assessing $CO_2$ through the environmental impact category “Climate Change” (CC). All these indicators, which correspond to 59,5% of the papers treating environmental aspects, are evaluating the same impact, which is global warming, the only difference being the way it is measured: direct assessment of $CO_2$ emissions, through flows of life cycle inventory (Fig. 14- $CO_2$); or through a cause-effect relation, by calculating the values of characterized impact categories (Fig. 14- GHG, GWP and CC). These results highlight that the environmental studies developed have been exploring a narrow perspective, where only the carbon footprint has been measured, leaving behind other important environmental impact categories in the assessment.

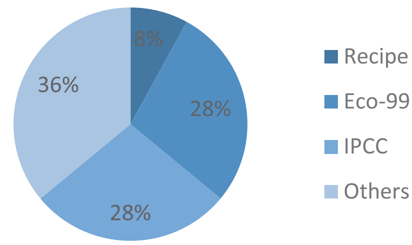


**Fig. 15.** Life cycle assessment methodologies applied to assess the environmental pillar.

Additionally, 14,3% of environmental aspects have been measured in terms of waste reduction, 8,0% alongside the percentage of recycling. Once more, the same aspect is measured in different ways, both aiming to reduce the process' waste. It is also important to mention that waste is not an environmental impact category but a flow. These authors do try to measure the environmental impact indirectly, through flows quantification, avoiding the application of environmental impacts assessment methods. But waste flows do not represent the elements and compounds existing in the waste stream and therefore the information that can be extracted through this assessment is partial.

Also, still considering a mono impact category, 1,7% of the papers focus on biodiversity, and 0,3% address the renewable energies consumption as an indicator of environmental benefit.

All aforementioned works are solely focused on a single environmental impact perspective, which may lead to misleading results. Thus, the application of a wider perspective is required.

Finally, the use of Life Cycle Assessment (LCA) approach, is only verified in 16,1% of the papers. In such studies different entities of the supply chain are considered where multiple environmental impact categories are employed. Within LCA several methods covering different impact categories can be applied, as shown in Fig. 15, where it is possible to verify that EcoIndicator-99 and IPCC (method to assess in LCA the $CO_2$ emissions) are the most common LCA methods applied (each present in 28% of the papers). EcoIndicator-99 reports several environmental impacts through a multi-echelon perspective, and has been used in the works presented by Chibeles-Martins, Pinto-Varela, Barbosa-Póvoa, and Novais (2016), Sabio et al. (2012), Sahebi, Nickel, and Ashayeri (2014) and Santibañez-Aguilar et al. (2014). Such works appear as pioneers in the assessment of a multi-stage supply chain using a multi-impact categories' assessment. IPCC, on the other hand, is a single-issue method, which means that a single impact category is measured through a multi-echelon perspective. The works that explore such method (e.g. Su, Chen, and Yang (2016); Taskhiri, Garbs, and Geldermann (2016); Virtanen et al. (2011)), although including a multi-echelon perspective, miss the use of a broader environmental impact assessment method, as IPCC only measures climate change through $CO_2$ emissions.

Lastly, the use of the ReCiPe method is presented in 8% of the papers. Such method has originated from the further development of the EcoIndicator-99 and its recent transformation along with the CML method. Therefore, ReCiPe appears nowadays as the most appropriate method to be applied. But only two papers have been identified using this more comprehensive method: Mota, Gomes, Carvalho, and Barbosa-Póvoa (2015b); and Oberhofer and Dieplinger (2014)). LCA being a more complete methodology to assess environmental impacts it should be further applied when studying the environmental pillar within SC, where the extended characteristics of LCA should be explored.

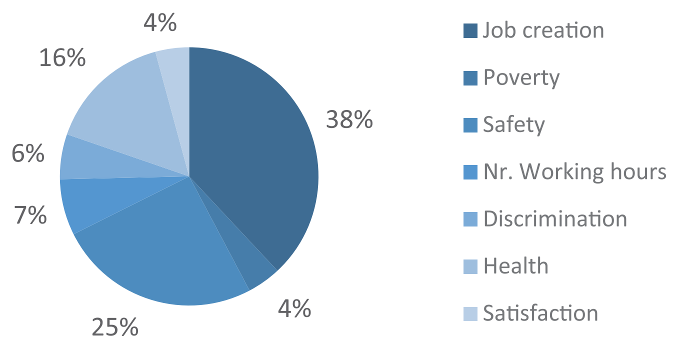


**Fig. 16.** Social pillar assessment.

### 6.4. Social pillar

Regarding the social pillar, it is possible to verify from Fig. 16 that job creation has been the most used indicator (38%). Then Safety comes up with 25%, health 16%, number of working hours 7%, discrimination 6% and finally 4% are related to satisfaction and poverty aspects.

These indicators cover different social aspects, which are all required in a holistic analysis of social assessment. The main problem in the social assessment is that only single issues have been applied and so there is no integrated approach. Moreover, the diversity of indicators employed show that authors are still looking for a clear definition of social sustainability. Social LCA has not yet been applied, this being a good approach towards a life cycle assessment perspective and is therefore recommended to be explored in the future.

Looking in more detail at the papers covering optimization and social aspects, it is interesting to analyze how authors have been modeling these aspects. Job creation has been the most applied social criteria, which has been mainly modeled as a mono-criteria objective function (e.g. Martínez-Guido, González-Campos, Ponce-Ortega, Nápoles-Rivera, & El-Halwagi, 2016; Miret et al., 2016; Mota, Carvalho, Gomes, & Barbosa-Póvoa, 2015; amongst others, see Table 9). Some authors have explored other mono-criteria objective function, namely, Bouchery et al. (2012) and Kim et al. (2011), that applied safety as an objective function, maximizing its value. Bouchery et al. (2012) have applied injury rate as a social objective function and Kim et al. (2011) applied a safety index to account for safety. Ramos et al. (2014) applied the maximization of working hours as an objective function and finally, Santibañez-Aguilar, Ponce-Ortega, González-Campos, Serna-González, and El-Halwagi (2013) considered health as an objective function.

There are several authors who combine multiple social dimensions in their objective functions, which might be incorporated in one single indicator or in multiple. For instance, Boukherroub, Ruiz, Guinet, and Fondrevelle (2015) consider employee well-being, modeled as the proximity of employees to production sites, minimizing the total traveled distance multiplied by the total flow of employees. These authors also include a second social objective function as employment stability, where layoffs are minimized. Mota et al. (2015) include a single indicator, which promoted the social benefit. The maximization of the social benefit promotes the job creation in areas with higher poverty rates so that their economy might be improved. Hsueh (2015) assesses corporate social responsibility through the maximization of collaboration in SC towards a profit maximization. Employee injuries are used as the formulation applied by Chen and Andresen (2014) to measure health and safety issues, and therefore the social impact assessment. Dayhim et al. (2014) applied a monetization method to transform social aspects into costs, therefore making the objective function the minimization of those costs. Devika et al. (2014) applied traditional job creation as an objective function and also explored another objective function related to the worker's safety. Kravanja and Čuček (2013) propose a sustainability index, which covers the three pillars of sustainability as objective function. The social aspects considered in that index are job creation, working hours, satisfaction and health. Pishvaee, Razmi, and Torabi (2014) applied an objective function, which includes job creation plus the value for local communities minus the consumer risk, minus the damage to health. This is a multi-criteria objective function. Another work where a social multicriteria objective function has been presented is Ziolkowska (2014). Here the objective function considers job creation and welfare, health and safety and support to local communities.

Some authors have considered social aspects as constraints in their modeling approach, imposing a minimum number of jobs created (Chardine-Baumann & Botta-Genoulaz, 2014; Gonela, Zhang, & Osmani, 2015; Hall, Matos, & Silvestre, 2012), minimum health and safety required (Chardine-Baumann & Botta-Genoulaz, 2014; Hall et al., 2012) and level of satisfaction (Zhou et al., 2000).

There is a single paper exploring simulation methods and social aspects. Sarkis and Dhavale (2015) explore the simulation of social responsibility in supplier's selection.

Additionally, within the academic community, social aspects still require a clear definition of the areas to assess followed by a clear definition of social quantitative indicators that can be included in optimization models. This fact opens up a future research path, where a step backward should be taken in order to define social aspects in a clear and quantitative way. Decision-analysis seems an interesting methodology to address this bottleneck.

### 6.5. OR methods and the sustainability pillars

By crossing the sustainability pillars measure with the type of OR research methods used by the researchers within SSC, we obtain Fig. 17. As previously discussed, optimization has been the most applied OR method when addressing SSC, and consequently, the different measures identified to characterize the sustainability pillars have been considered as an objective function in the optimization models proposed by the different authors. On the one hand, cost has been the most widely applied sustainability metric in all OR methods. This appears as the easiest metric to assess and, in many cases, maybe the most adequate one. However, researchers need to pay attention to whether investments are involved, since in those cases more suitable metrics should be applied. On the other hand, some sustainability measurements have only been applied in very few methods. For instance, renewable energies consumption has been considered as an environmental objective in optimization models; Biodiversity impact has only been considered in optimization and statistic research, and NPV has only been applied as an economic indicator in optimization, simulation and statistics.

Globally a wide diversity of economic, environmental and social measures has been used, demonstrating a lack of consensus among authors. Therefore, new concerns need to be considered. Namely, the adequacy of the economic indicators to the problem at hand should be carefully analyzed. Additionally, a detailed assessment of the environmental, but above all the social aspects is still missing. The latter appears as the most difficult objectives to quantify (e.g. discrimination, satisfaction) and a greater effort needs to be made regarding this issue. These aspects bring to the table the need of combining optimization methods with other OR methods, like decision analysis, data analysis, and statistics that support the establishment of the right trade-offs among the sustainability measures used.

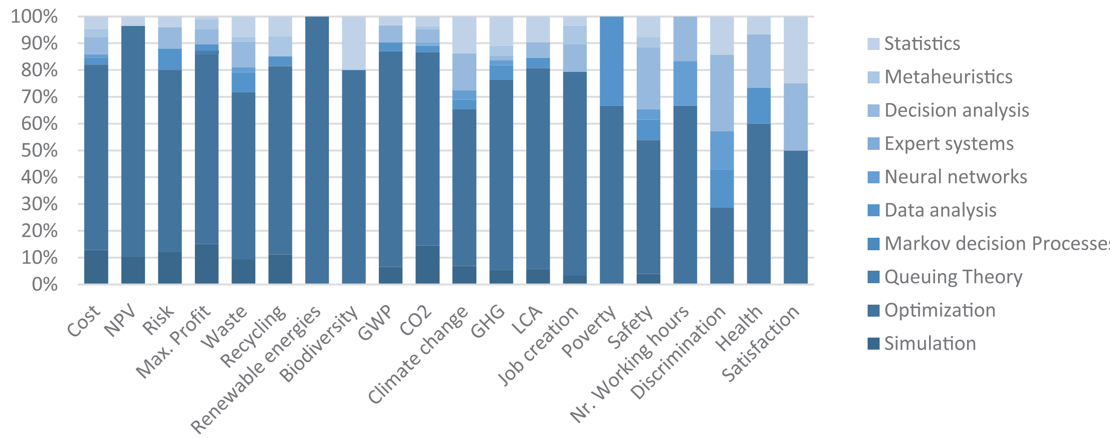


**Fig. 17.** OR methods applied in the three pillars of sustainability.

**Table 7**
Sustainability aspects assessed in each decisions level - Economic pillar.

| Decision level | Economic | | | |
|---|---|---|---|---|
| | Cost | NPV | Risk | Max. Profit |
| **Strategic** | [1]; [3]; [5]; [7]; [8]; [9]; [11]; [12]; [13]; [15]; [16]; [17]; [20]; [22]; [23]; [26]; [28]; [29]; [30]; [31]; [32]; [33]; [34]; [37]; [38]; [39]; [41]; [42]; [43]; [45]; [46]; [48]; [49]; [51]; [52]; [55]; [57]; [58]; [59]; [60]; [61]; [62]; [63]; [64]; [66]; [67]; [68]; [70]; [72]; [74]; [75]; [76]; [77]; [78]; [79]; [80]; [81]; [83]; [84]; [85]; [87]; [90]; [92]; [93]; [94]; [95]; [97]; [98]; [99]; [100]; [101]; [103]; [105]; [106]; [107]; [108]; [111]; [112]; [114]; [115]; [119]; [120]; [121]; [122]; [124]; [125]; [126]; [127]; [130]; [132]; [133]; [136]; [138]; [139]; [140]; [141]; [142]; [143]; [144]; [145]; [146]; [148]; [149]; [150]; [152]; [153]; [155]; [157]; [161]; [162]; [163]; [164]; [165]; [170]; [174]; [178]; [180]; [181]; [182]; [183]; [184]; [185]; [186]; [187]; [188]; [189]; [190]; [191]; [192]; [193]; [194]; [196]; [197]; [198]; [199]; [200]; [202]; [203]; [205]; [206]; [209]; [210]; [211]; [212]; [213]; [214]; [215]; [216]; [217]; [219] | [10]; [17]; [20]; [21]; [28]; [44]; [45]; [47]; [58]; [68]; [70]; [71]; [81]; [82]; [114]; [117]; [118]; [119]; [123]; [141]; [147]; [167]; [172]; [175]; [208] | [8]; [17]; [49]; [52]; [55]; [69]; [87]; [96]; [115]; [136]; [138]; [146]; [150]; [162]; [201] | [4]; [8]; [10]; [11]; [18]; [21]; [30]; [35]; [37]; [38]; [40]; [43]; [46]; [50]; [54]; [55]; [58]; [64]; [66]; [68]; [69]; [70]; [71]; [72]; [72]; [73]; [74]; [75]; [81]; [83]; [85]; [86]; [90]; [94]; [99]; [101]; [106]; [107]; [114]; [119]; [120]; [123]; [125]; [127]; [128]; [132]; [136]; [140]; [141]; [144]; [146]; [158]; [159]; [160]; [163]; [168]; [176]; [177]; [179]; [183]; [188]; [204]; [207]; [218] |
| **Tactical** | [2]; [5]; [6]; [8]; [9]; [12]; [14]; [16]; [19]; [22]; [24]; [28]; [29]; [34]; [37]; [38]; [41]; [43]; [49]; [59]; [60]; [64]; [66]; [68]; [70]; [80]; [94]; [95]; [99]; [100]; [101]; [107]; [115]; [126]; [130]; [132]; [134]; [139]; [148]; [149]; [153]; [162]; [164]; [169]; [174]; [182]; [184]; [187]; [190]; [198]; [202]; [203]; [209]; [211]; [214]; [220] | [28]; [68]; [70]; [147] | [6]; [8]; [14]; [19]; [49]; [96]; [115]; [134]; [162] | [4]; [6]; [8]; [18]; [36]; [37]; [38]; [40]; [43]; [50]; [64]; [66]; [68]; [70]; [91]; [94]; [99]; [101]; [107]; [128]; [132]; [134]; [158]; [159]; [160]; [179]; [218] |
| **Operational** | [25]; [134]; [135]; [169] | | [134] | [36]; [91]; [134]; [173] |

**Table 8**
Sustainability aspects assessed in each decisions level - Environmental pillar.

| Decision level | Environmental | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Waste | Recycling | Renewable energies | Biodiversity | GWP | $CO_2$ | Climate change | GHG | LCA |
| **Strategic** | [22]; [30]; [44]; [45]; [60]; [61]; [63]; [65]; [66]; [67]; [72]; [77]; [85]; [87]; [90]; [92]; [97]; [100]; [101]; [102]; [106]; [107]; [108]; [109]; [110]; [121]; [122]; [123]; [129]; [133]; [141]; [149]; [150]; [168]; [177]; [179]; [189]; [214]; [218] | [23]; [43]; [44]; [53]; [60]; [61]; [66]; [67]; [92]; [98]; [101]; [105]; [106]; [107]; [109]; [127]; [129]; [133]; [162]; [164]; [197]; [201] | [171] | [42]; [89]; [165]; [219] | [15]; [16]; [21]; [30]; [33]; [34]; [46]; [50]; [52]; [54]; [68]; [69]; [70]; [71]; [75]; [90]; [95]; [110]; [117]; [118]; [119]; [133]; [141]; [167]; [172] | [1]; [12]; [13]; [15]; [31]; [32]; [39]; [42]; [46]; [48]; [49]; [52]; [56]; [58]; [59]; [62]; [69]; [70]; [74]; [75]; [90]; [93]; [97]; [98]; [102]; [103]; [104]; [109]; [110]; [111]; [112]; [113]; [114]; [119]; [123]; [132]; [124]; [130]; [133]; [138]; [140]; [141]; [142]; [143]; [144]; [149]; [155]; [174]; [182]; [184]; [185]; [186]; [193]; [195]; [200]; [202]; [203]; [204]; [205]; [207]; [209]; [212]; [214] | [1]; [5]; [9]; [11]; [16]; [26]; [32]; [41]; [37]; [80]; [83]; [89]; [96]; [116]; [118]; [136]; [140]; [142]; [145]; [152]; [156]; [178]; [206]; [208]; [216]; [217] | [1]; [12]; [21]; [27]; [34]; [47]; [54]; [64]; [68]; [71]; [73]; [77]; [78]; [79]; [83]; [84]; [85]; [89]; [95]; [105]; [108]; [109]; [110]; [111]; [112]; [113]; [116]; [117]; [118]; [122]; [133]; [142]; [151]; [154]; [157]; [158]; [167]; [170]; [181]; [184]; [190]; [195]; [201]; [211]; [213]; [214]; [219] | [3]; [15]; [17]; [18]; [21]; [28]; [33]; [34]; [45]; [46]; [54]; [56]; [57]; [67]; [68]; [71]; [75]; [76]; [80]; [81]; [82]; [83]; [86]; [100]; [116]; [117]; [118]; [119]; [129]; [137]; [141]; [147]; [154]; [168]; [170]; [172]; [175]; [180]; [191]; [192]; [194]; [206]; [215] |
| **Tactical** | [14]; [22]; [36]; [60]; [66]; [100]; [101]; [107]; [149]; [179]; [214]; [218] | [36]; [43]; [60]; [66]; [101]; [107]; [162]; [164] | | [36] | [14]; [16]; [34]; [50]; [68]; [70]; [95] | [12]; [24]; [49]; [59]; [70]; [130]; [132]; [149]; [169]; [174]; [182]; [184]; [202]; [203]; [209]; [214]; [220] | [5]; [9]; [16]; [37]; [41]; [80]; [96] | [12]; [34]; [64]; [68]; [95]; [158]; [184]; [190]; [211]; [214] | [18]; [19]; [28]; [34]; [68]; [80]; [100]; [147] |
| **Operational** | [36]; [135] | [36] | | [36] | | [25]; [135]; [169] | | | [173] |

**Table 9**
Sustainability aspects assessed in each decisions level - Social pillar.

| Decision level | Social | | | | | | |
|---|---|---|---|---|---|---|---|
| | Job creation | Poverty | Safety | Nr. Working hours | Discrimination | Health | Satisfaction |
| **Strategic** | [11]; [12]; [13]; [18]; [26]; [49]; [53]; [57]; [62]; [74]; [83]; [85]; [111]; [119]; [140]; [145]; [147]; [148]; [165]; [180]; [186]; [205]; [211]; [213]; [219] | [65]; [119]; [147] | [26]; [30]; [37]; [41]; [49]; [53]; [77]; [85]; [96]; [105]; [115]; [119]; [122]; [144]; [181] | [26]; [122]; [144] | [96]; [105]; [122] | [30]; [37]; [77]; [96]; [119]; [144]; [165]; [178]; [219] | [144]; [201]; [218] |
| **Tactical** | [12]; [18]; [36]; [49]; [91]; [147]; [148]; [211] | [147] | [14]; [36]; [37]; [41]; [49]; [96]; [115] | [91]; [169] | [14]; [96] | [14]; [36]; [37]; [96] | [218] |
| **Operational** | [36]; [91] | | [25]; [36] | [91]; [169] | | [36] | |

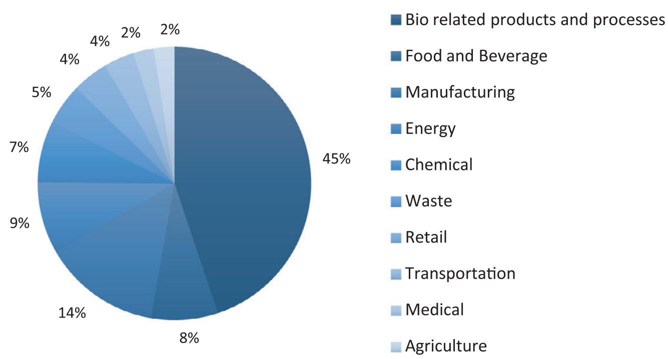


**Fig. 18.** Industrial sectors treated in SSC.

In Tables 7–9 the papers that have been using the previously mentioned categories are indicated, providing an overview of the authors that have been covering the different sustainability assessment measurements.

## 7. Industrial applications

One important point identified in the 4Wś analysis is related to what industrial sectors have been analyzed when applying OR methods to SSC. According to Fig. 18, the industrial process sector dominates (60%) the industrial applications as it includes bio-related (45%), food and beverage (8%) and chemical (7%). This is in line with the increasing trend of research that has been observed over the last years in bio-related products and processes. Moreover, the process industry is a sector where sustainability concerns are quite present since regulations on environmental aspects are very strict due to the type of processes and products involved, often associated with hazardous processes. Within this area, when looking at the type of problems addressed, the designing and planning of SSC are dominant, showing the concern of the authors to create SSC, a concern that is in line with industry concerns. As examples, we have the papers by Guillén-Gosálbez and Grossmann (2009), You, Tao, Graziano, and Snyder (2012) and Kostin, Guillén-Gosálbez, and Jiménez (2015). The process industry sector is followed by the manufacturing sector, which represents 14% of the contributions and where several types of industries have been contemplated, namely: automotive, electronics and consumer goods. From the comprehensive review by Brandenburg et al. (2014) an impressive increment on these applications has been verified (from the 220 papers analyzed, 165 presented an industrial application), demonstrating that authors working with OR methods trail its usage in real industrial applications.

## 8. Critical analysis and future research agenda

### *8.1. Conceptual map for sustainable supply chain and critical analysis*

This paper uses a systematic literature review to comprehend the usage of OR methods in the treatment of SSC. The increment of publications on model-based SSC research is confirmed and a diversification on the type of problems addressed was observed, revealing the authors' awareness to the area. The conceptual map shown in Fig. 19 translates graphically the literature focus and the interest devoted to the research community to each one of the SSC dimensions analyzed. The importance given to each dimension is deducted from the size of each circle representing roughly the number of papers published (number within the circles). Having sustainable supply chain in the center (SSC) – being this the focus of this paper – three main research streams emanate from the central point, representing the decision levels: strategic (Strat); tactical (Tact) and operational (Oper), and for each level the sustainability pillars addressed: economic (Ec); environmental (Env) and social (Soc); finally it is represented how the decision problems and sustainability pillars have been treated through OR methods (optimization (Opt); simulation (Sim); queuing theory (QT); data analysis (DtA); neural networks (NN); expert systems (ES); decision analysis (DA); metaheuristics (Mh); statistics (St)) when solving the SSC. The classification for the full set of papers is presented in Table A1 (see Appendix A).

On the decision levels dimension, the strategic level has been the most studied one, where attention was concentrated in forward supply chain addressing mainly network design problems that contemplate not only facilities' location and related capacities' decisions, but also tactical decisions associated with transportation, technologies' choices and inventory management policies. Moreover, aspects related to product development; facilities production allocation as well as resilience was scarcely treated. Also, supplier's selection and risk were not addressed, findings in line with the review by Brandenburg and Rebs (2015). The tactical level has been essentially addressed in conjunction with strategic decisions, and rarely with operational decisions. Few papers have considered only tactical aspects. The operational decision level has been the one less studied and only three papers have considered all three dimensions of sustainability at the operational level.

On the sustainability pillars, the concept of SSC has been by far the most improperly used, as the different authors have primarily focused their attention on the economic and environmental

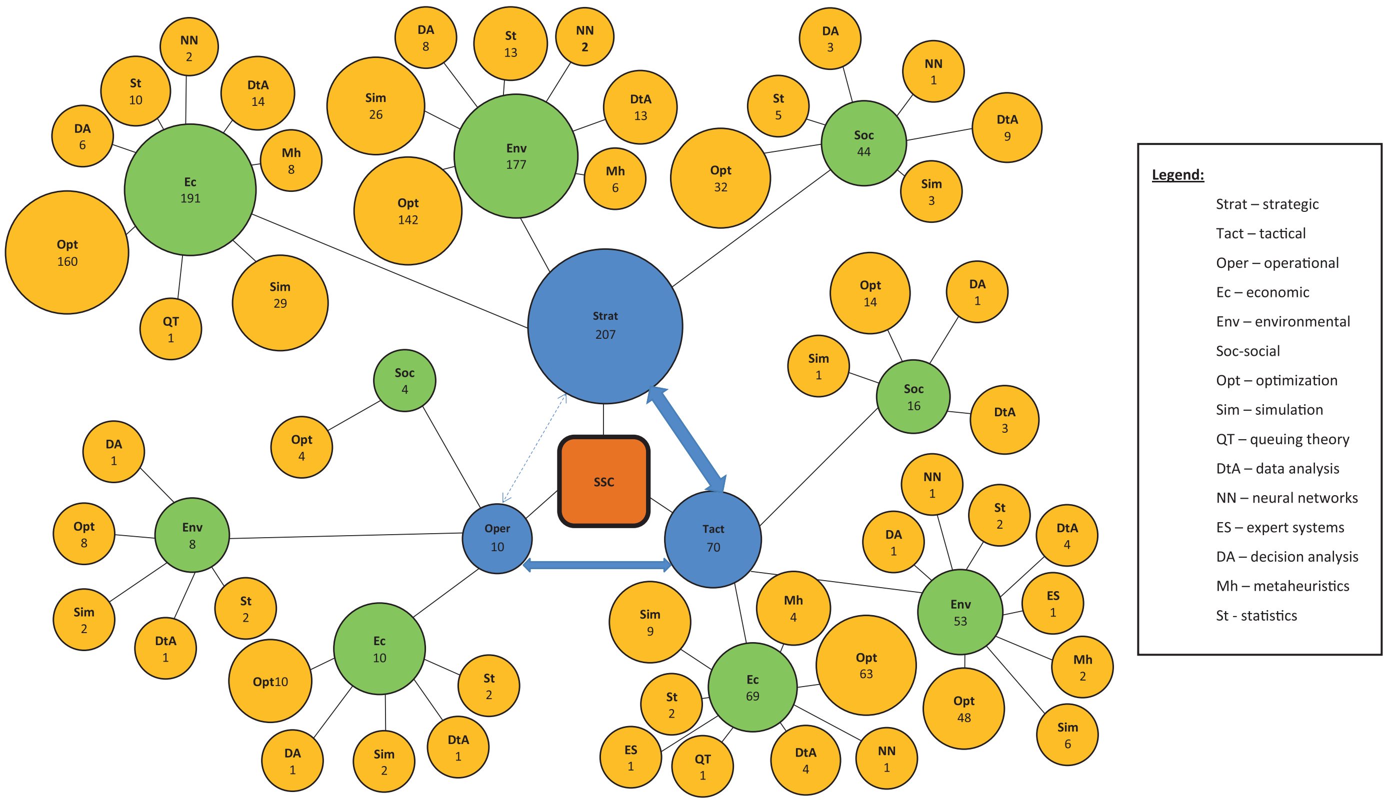


**Fig. 19.** Conceptual Map on Sustainable Supply Chain when OR methods have been used.

dimensions, often combined, but few addressed the social dimension simultaneously. These findings reinforce the ones provided by Brandenburg et al. (2014), Brandenburg and Rebs (2015) and Seuring (2013). The economic dimension has been fundamentally modeled through the minimization of costs or maximization of profit, and few authors have considered risk analysis even when investment decisions are involved. The environmental dimension has been largely treated as global warming, mainly through $CO_2$ based emissions, which is just a part of the big picture when environmental concerns are at stake. The social dimension was rarely approached, but when studied, the focus was on the job creation and safety aspects. Multifunctional activities have been recently explored by the authors when addressing SSC issues, in contrast with the findings of Brandenburg et al. (2014), where the authors were mainly focused on a single activity. Although an "accurate" treatment of SSC is still missing, as this implies the simultaneous consideration of the three sustainability pillars within a SC perspective, and the works presented are far from achieving this goal.

On the OR methods dimension, optimization approaches stand out from the remaining methods followed, but in a much smaller number, by simulation-based methods, decision analysis and statistics. This trend is common in the different problems addressed. The combination of methods is observed essentially with two main objectives: develop efficient solution techniques to deal with the increased solution complexity of the models derived (i.e. optimization and meta-heuristics); and treat the presence of often conflicting objectives related to the sustainability pillars (i.e. decision analysis and optimization). This conclusion complements the findings of Brandenburg et al. (2014), Brandenburg and Rebs (2015) and Seuring (2013) that generically identified the use of analytical-based models exploring multiple criteria decision making in SSC.

Additionally, regarding the main dimensions studied, our findings also concentrated on the study of: uncertainty; industrial sectors; and type of supply chain.

On uncertainty, and for each one of the decision levels, it was observed that the main problems studied were essentially deterministic. Uncertainty was rarely addressed, and when considered the main approaches were stochastic ones where uncertainty was essentially associated with product demand in strategic to tactical problems. This confirms the conclusion by Brandenburg et al. (2014) and Brandenburg and Rebs (2015) that deterministic approaches are by far employed more often than stochastic ones.

On the industrial sectors, our findings show that the process industry sector has been the most studied, involving the bio-related products; food; and chemical. These findings broaden the conclusions of Brandenburg et al. (2014) that identified the need for considering applications in sectors that they called as "sensitive" sectors, being these the bio, medical, chemical and energy-related sectors. Interestingly enough, our conclusions demonstrate that such sectors now occupy the large amount of applications revealing the interest of the SSC authors to study industrial sectors, where sustainability concerns are present and detail analysis are required. This need is also driving industries to participate in this kind of studies. Research on other sensitivity sectors, such as transportation and apparel, remains unchanged.

Finally, on the type of supply chain, there is a clear gap between the number of works that have treated sustainable forward chain versus sustainable closed loop or reverse supply chain. While closed-loop and reverse supply chain have been the focus of several works (Eskandarpour et al., 2015; Fleischmann et al., 1997; Sasikumar & Govindan, 2008a, 2008b, 2009), such works did not explicitly study the TBL pillars. The main reviews on SSC fail to capture this need, as they focused on forward SSC (Brandenburg & Rebs, 2015; Brandenburg et al., 2014; Seuring, 2013).

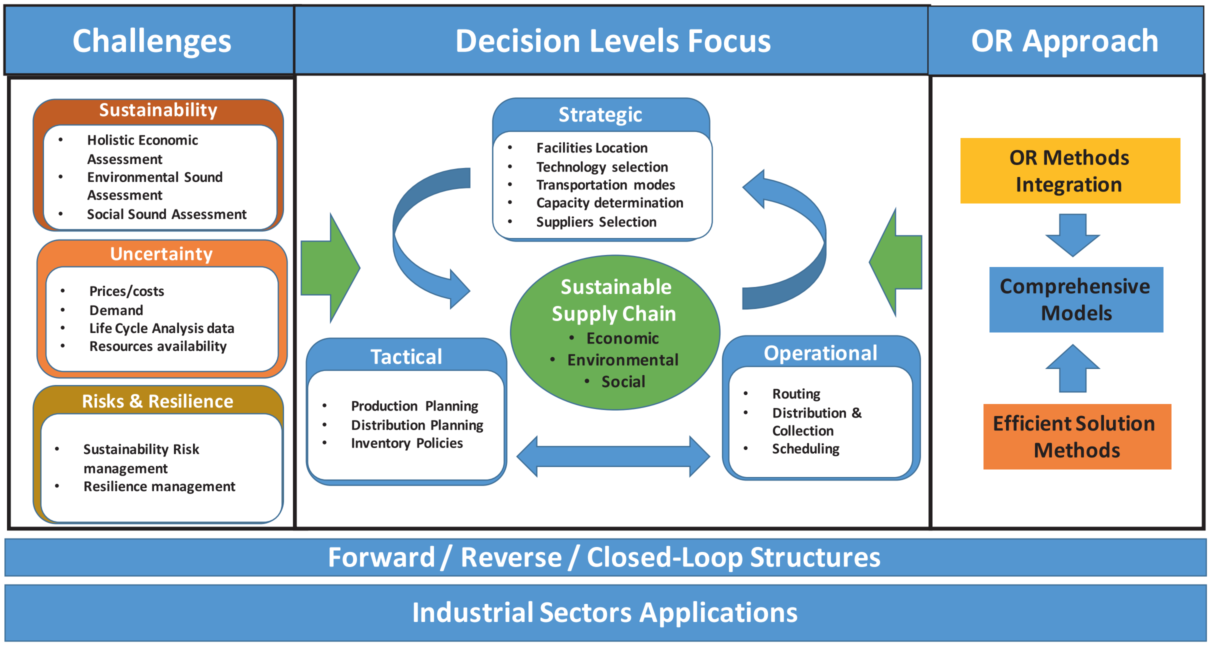


**Fig. 20.** Research Framework on Sustainable Supply Chain towards sound decision supporting tools.

### 8.2. Future research agenda

Following the rationale of this paper, where the focus is on how the different authors have treated different decision levels in sustainable supply chain and on how the sustainability pillars have been incorporated in such decision levels using OR methods, different aspects were identified far from being entirely studied. Consequently, there is a tremendous opportunity to invest further in the existent research and new research directions can be acknowledged in order to advance the knowledge in the area.

To define a future research agenda on the use of OR methods in SSC, we propose the research model presented in Fig. 20. This model identifies the needs and characteristics of OR methods that should be studied so as to foster the development of generic tools to inform decision makers when managing sustainable supply chain.

As a main research line, the development of sound models that will allow the integration of different decision levels should be pursued. This research ought to explore SC multi-functional activities contemplating sustainability issues in a comprehensive manner while fostering a supply chain holistic view. Trade-off versus win–win situations are to be reconnoitered (Brandenburg & Rebs, 2015) accounting for diverse and not yet addressed research challenges while making use of wide-ranging OR approaches. Research challenges should investigate three main research lines: sustainability modeling; uncertainty modeling and risk and resilience.

On the sustainability modeling, a holistic economic assessment, as well as a sound assessment of environmental and social aspects, are yet to be reached. Economic objectives should be carefully selected depending on the type of analysis under consideration. This means that problems involving investments should consider project assessment indicators (e.g. NPV), while problems focused on operational studies should consider costs minimization or profit maximization. Moreover, the economic assessment should be further explored to incorporate a broader view of the advantages of implementing sustainability practices and how these could be economically measured. $CO_2$ markets are an example of such economic value-added, but companies' image and wellbeing of workers are other forms that should be equally quantified in economic values. Regarding the environmental pillar, the use of LCA based methods presents a research potential not yet adequately explored. A wide-ranging analysis contemplating the different environmental impacts encountered when designing, planning and operating supply chain must be trailed. Irrevocably, the social component needs a huge investment, and it is crucial to understand how this can be adequately modeled. Social-LCA methods may be a research path open to exploration. Moreover, and corroborating Brandenburg et al. (2014), social aspects require interdisciplinary approaches, combining exact sciences and social sciences, as means to help quantify social impacts

On uncertainty, its treatment is vital as several parameters characterizing SSC are often subject to uncertainty and need to be modeled, ranging from product demand to products or raw materials prices and resources availability. Uncertainty on the available social and environmental data has been a field left unexplored, which represents a large limitation, as this data highly influences the decisions taken.

Furthermore, the presence of uncertainty leads to the need of managing risk and resilience in SSC, problems that have been scarcely studied. There is a need to comprehend what are the right risk and resilience metrics that should be incorporated into SSC based-model so as to guarantee adequate management decisions

Having identified the main problem to solve and the research challenges to account for, it is important to understand the OR approach(es) to use. The integration of different OR methods outlines further research opportunities, as this will support the development of comprehensive models. The presence of different objectives that may even appear conflicting call for the usage of OR methods as game theory approaches, fuzzy approaches and decision analysis in conjunction with multi-objective optimization. Such methods will allow the identification of win–win solutions without being excessively simplistic. Additionally, the presence of uncertainty ought to be explored and accordingly the development of stochastic approaches reflecting the dynamic nature of the problem (e.g. dynamic threes) is to be developed. Additionally, robust optimization approaches where the conservativeness of the solutions should be overcome may also be a research path to explore. The incorporation of all the aspects above into the OR models will result in complex computational problems that, when applied to real cases, may result intractable. Consequently, a new research line emerges, one that should explore the development of hybrid approaches combining meta-heuristics, math-heuristics and/or other types of methods in order to speed up the model solutions.

Another research path is derived from the fact that SSC have been essentially addressed as forward supply chain structures. Closed-loop and reverse chain, although subject to several studies, suffer from the lack of work that explicitly incorporates the TBL pillars into the derived models. Such incorporation may influence the definition and operation of these structures, as it is not always clear that a certain decision on the installation or operation of a reverse operation may result in an environmental or social benefit.

A final research path relates to the need of further expanding the industrial focus of SSC OR approaches. Sectors such as pharmaceutical, apparel, energy and transportation require additional study. Also, studies on the process industry sector are still needed.

## 9. Conclusions

Sustainable Supply Chain has becoming a critical issue to foster companies' activities towards sustainability. This paper reviewed the set of papers published on SSC using OR methods from 1999 onwards and concluded that the work in the area continues to increase when compared to previous reviews (Brandenburg & Rebs, 2015; Brandenburg et al., 2014; Seuring, 2013).

A systematic literature review methodology was followed, aiming at answering to a set of questions that help to understand how have been treated the three main research dimensions: decision levels; sustainability pillar; and OR method used. As main findings, it has been concluded that the authors publishing in the area are still far from having developed comprehensive models on SSC, and the notion of sustainable supply chain is still quite blurred. The authors have mainly been focused on the treatment of the economic and environmental aspects, and few works addressed the social aspect.

A conceptual map, representing the main studied dimensions of SSC (decision levels, sustainability pillars and OR methods), was proposed allowing researchers and practitioners to visualize what has been done in the area. This, coupled with the deep analysis performed, resulted in the definition of a future research agenda framework composed by five main future research avenues: development of integrated decision models; sound treatment of the sustainability pillars; incorporation of uncertainty, risk and resilience management aspects into the OR models; explore a combination of OR methods so as to develop generic and solution efficient SSC models; study further reverse and closed-loop structures; expand the industrial applications. This agenda opens several opportunities for research and collaboration between academics and industries.

## Acknowledgments

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## Appendix A

See Table A1

**Table A1**
Papers classification within the main categories: decision levels; sustainability pillars; and OR method used.

| Author | Strategic | Tactical | Operational | Economic | Environmental | Social | Simulation | Optimization | Queuing Theory | Markov decision Processes | Data Analysis | Neural Networks | Expert Systems | Decision Analysis | Metaheuristics | Statistics |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **[1]** (Accorsi, Cholette, Manzini, Pini, & Penazzi, 2016) | 1 | | | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[2]** (Alharbi et al., 2015) | | 1 | | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[3]** (Altmann, 2015) | 1 | | | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[4]** (Amin & Zhang, 2012) | 1 | 1 | | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[5]** (Amin & Zhang, 2013) | 1 | 1 | | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[6]** (Amorim et al., 2013) | | 1 | | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[7]** (Apaiah & Hendrix, 2005) | 1 | | | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[8]** (Aqlan & Lam, 2016) | 1 | 1 | | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[9]** (Arabatzis, Petridis, Galatsidas, & Ioannou, 2013) | 1 | 1 | | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| **[10]** (Ashayeri et al., 2014) | 1 | | | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[11]** (Awad-Núñez, González-Cancelas, Soler-Flores, & Camarero-Orive, 2015) | 1 | | | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| **[12]** (Ayoub et al., 2007) | 1 | 1 | | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[13]** (Ayoub et al., 2009) | 1 | | | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| **[14]** (Azadi et al., 2014) | | 1 | | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| **[15]** (Azapagic & Clift, 1999) | 1 | | | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| **[16]** (Babazadeh, Razmi, Rabbani, & Pishvaee, 2015) | 1 | 1 | | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[17]** (Babazadeh et al., 2016) | 1 | | | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[18]** (Bairamzadeh et al., 2016) | 1 | 1 | | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[19]** (Battini et al., 2014) | | 1 | | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[20]** (Bekkering, Broekhuis, van Gemert, & Hengeveld, 2013) | 1 | | | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[21]** (Bernardi, Giarola, & Bezzo, 2012) | 1 | | | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[22]** (Betz, Buchli, Göbel, & Müller, 2015) | 1 | 1 | | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| **[23]** (Bhattacharjee & Cruz, 2015) | 1 | | | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[24]** (Bortolini et al., 2016) | | 1 | | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| **[25]** (Bouchery et al., 2012) | | | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| **[26]** (Boukherroub et al., 2015) | 1 | | | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[27]** (Brown & Blanchard, 2015) | 1 | | | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| **[28]** (Brunet, Guillén-Gosálbez, & Jiménez, 2012) | 1 | 1 | | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| **[29]** (Burgholzer, Bauer, Posset, & Jammernegg, 2013) | 1 | 1 | | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[30]** (Büyüközkan & Berkol, 2011) | 1 | | | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| **[31]** (Byrne, Heavey, Ryan, & Liston, 2010) | 1 | | | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[32]** (Campana et al., 2015) | 1 | | | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[33]** (Cellura, Ardente, & Longo, 2012) | 1 | | | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |

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**Table A1** (*continued*)

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **[34]** (Chaabane et al., 2012) | 1 | 1 | | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[35]** (Chai & Ngai, 2015) | 1 | | | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| **[36]** (Chardine-Baumann & Botta-Genoulaz, 2014) | | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[37]** (Chen & Andresen, 2014) | 1 | 1 | | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| **[38]** (Chen & Kim, 2007) | 1 | 1 | | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[39]** (Chen, Wang, Wang, & Chen, 2015) | 1 | | | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[40]** (Chibeles-Martins, Pinto-Varela, Barbosa-Póvoa, & Novais, 2016) | 1 | 1 | | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| **[41]** (Choudhary & Shankar, 2012) | 1 | 1 | | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| **[42]** (Cobuloglu & Büyüktahtakın, 2014) | 1 | | | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[43]** (Corsano, Vecchietti, & Montagna, 2011) | 1 | 1 | | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[44]** (Cucchiella, D'Adamo, & Gastaldi, 2013) | 1 | | | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[45]** (Garcia & You, 2015) | 1 | | | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[46]** (Garcia & You, 2015) | 1 | | | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[47]** (d'Amore & Bezzo, 2016) | 1 | | | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[48]** (Daniel J. Garcia & You, 2015) | 1 | | | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[49]** (Dayhim et al., 2014) | 1 | 1 | | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[50]** (De Meyer, Cattrysse, & Van Orshoven, 2015) | 1 | 1 | | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[51]** (De Rosa, Gebhard, Hartmann, & Wollenweber, 2013) | 1 | | | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[52]** (De-León Almaraz et al., 2014) | 1 | | | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[53]** (Devika et al., 2014) | 1 | | | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| **[54]** (Duarte et al., 2016) | 1 | | | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[55]** (Dubey, Gunasekaran, & Childe, 2015) | 1 | | | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[56]** (Egilmez, Kucukvar, Tatari, & Bhutta, 2014) | 1 | | | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| **[57]** (Elghali, Clift, Sinclair, Panoutsou, & Bauen, 2007) | 1 | | | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| **[58]** (Elia, Baliban, & Floudas, 2014) | 1 | | | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[59]** (Elia, Li, & Floudas, 2015) | 1 | 1 | | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[60]** (Eskandarpour et al., 2013) | 1 | 1 | | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| **[61]** (Faccio, Persona, Sgarbossa, & Zanin, 2014) | 1 | | | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[62]** (Foran, Lenzen, Dey, & Bilek, 2005) | 1 | | | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| **[63]** (Galvez, Rakotondranaivo, Morel, Camargo, & Fick, 2015) | 1 | | | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[64]** (Garg, Kannan, Diabat, & Jha, 2015) | 1 | 1 | | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[65]** (Garrone et al., 2014) | 1 | | | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| **[66]** (Geldermann, Treitz, & Rentz, 2007) | 1 | 1 | | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[67]** (Gerber, Fazlollahi, & Maréchal, 2013) | 1 | | | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[68]** (Giarola, Zamboni, & Bezzo, 2011) | 1 | 1 | | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[69]** (Giarola et al., 2013) | 1 | | | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **[70]** (Giarola, Shah, et al., 2012) | 1 | 1 | | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[71]** (Giarola, Zamboni, & Bezzo, 2012) | 1 | | | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[72]** (Golroudbary & Zahraee, 2015) | 1 | | | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[73]** (Gonela, Zhang, & Osmani, 2015) | 1 | | | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[74]** (Gonela, Zhang, Osmani, et al., 2015) | 1 | | | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[75]** (Gong & You, 2014) | 1 | | | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[76]** (Gong & You, 2015) | 1 | | | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[77]** (Gopal & Thakkar, 2015) | 1 | | | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| **[78]** (Govindan, Jafarian, Khodaverdi, & Devika, 2014) | 1 | | | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| **[79]** (Govindan et al., 2015a) | 1 | | | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| **[80]** (Guillén-Gosálbez & Caballero, 2008) | 1 | | | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[81]** (Guillén-Gosálbez & Grossmann, 2009) | 1 | 1 | | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[82]** (Guillén-Gosálbez & Grossmann, 2010) | 1 | | | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[83]** (Günther et al., 2015) | 1 | | | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[84]** (Guo et al., 2015) | 1 | | | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[85]** (Hall et al., 2012) | 1 | | | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[86]** (Hanes & Bakshi, 2015) | 1 | | | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[87]** (Yu et al., 2014) | 1 | | | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| **[88]** (Harris et al., 2011) | 1 | | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[89]** (Henriques et al., 2015) | 1 | | | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| **[90]** (Hernández-Calderón et al., 2016) | 1 | | | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[91]** (Hsueh, 2015) | | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[92]** (Hu, Rao, Zheng, & Huang, 2015) | 1 | | | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[93]** (Huang & Xie, 2015) | 1 | | | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[94]** (Huang, Yan, & Qiu, 2009) | 1 | 1 | | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[95]** (Hugo, Rutter, Pistikopoulos, Amorelli, & Zoia, 2005) | 1 | 1 | | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[96]** (Hussain, Awasthi, & Tiwari, 2016) | 1 | | | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| **[97]** (Iakovou, Vlachos, & Toka, 2012) | 1 | | | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[98]** (Igarashi, Yamada, Gupta, Inoue, & Itsubo, 2016) | 1 | | | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[99]** (Ivanov & Mintchev, 2007) | 1 | 1 | | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[100]** (Gao & You, 2015b) | 1 | 1 | | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[101]** (Gao & You, 2015a) | 1 | 1 | | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[102]** (Jabbour, Jugend, Jabbour, Gunasekaran, & Latan, 2015) | 1 | | | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| **[103]** (Anicia Jaegler & Burlat, 2012) | 1 | | | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[104]** (Jaegler & Burlat, 2014) | 1 | | | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[105]** (Jakhar, 2015) | 1 | | | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| **[106]** (Ji, Ma, & Li, 2015) | 1 | | | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[107]** (Jindal & Sangwan, 2013) | 1 | 1 | | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[108]** (Joa, Hottenroth, Jungmichel, & Schmidt, 2014) | 1 | | | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

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**Table A1** (*continued*)

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **[109]**(Kannegiesser & Günther, 2013) | 1 | | | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[110]**(Kannegiesser, Günther, & Gylfason, 2013) | 1 | | | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[111]**(Kannegiesser, Günther, & Autenrieb, 2015) | 1 | | | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[112]**(Kantas, Cobuloglu, & Büyüktahtakn, 2015) | 1 | | | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[113]**(Kellner & Igl, 2015) | 1 | | | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[114]**(Kempener, Beck, & Petrie, 2009) | 1 | | | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[115]**(Kim et al., 2011) | 1 | 1 | | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[116]**(Klein, Wolf, Schulz, & Weber-Blaschke, 2016) | 1 | | | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| **[117]**(Kostin, Guillén-Gosálbez, Mele, & Jiménez, 2012) | 1 | | | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[118]**(Kostin et al., 2015) | 1 | | | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[119]**(Kravanja & Čuček, 2013) | 1 | | | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[120]**(Krejci & Beamon, 2015) | 1 | | | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[121]**(Kumar & Rahman, 2014) | 1 | | | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[122]**(Kuo, Wang, & Tien, 2010) | 1 | | | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 |
| **[123]**(Lam et al., 2013) | 1 | | | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[124]**(Lee & Wu, 2014) | 1 | | | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[125]**(Lee, Realff, & Ammons, 2011) | 1 | | | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[126]**(Lejeune, 2006) | 1 | 1 | | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| **[127]**(Li, 2013) | 1 | | | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[128]**(Lieckens, Colen, & Lambrecht, 2015) | 1 | 1 | | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| **[129]**(Lim & Lam, 2016) | 1 | | | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| **[130]**(Liotta et al., 2015) | 1 | 1 | | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[131]**(Liotta et al., 2016) | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[132]**(Longo, 2012) | 1 | 1 | | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[133]**(Manfredi & Vignali, 2014) | 1 | | | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[134]**(Mansoornejad et al., 2013) | | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[135]**(Mansouri et al., 2016) | | | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| **[136]**(Mansuy et al., 2015) | 1 | | | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[137]**(Manzini et al., 2014) | 1 | | | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[138]**(Mari et al., 2014) | 1 | | | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[139]**(Martínez-Guido et al., 2014) | 1 | 1 | | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[140]**(Martínez-Guido et al., 2016) | 1 | | | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[141]**(Mele, Kostin, Guillén-Gosálbez, & Jiménez, 2011) | 1 | | | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[142]**(Meneghetti & Monti, 2014) | 1 | | | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[143]**(Meneghetti, Borgo, & Monti, 2015) | 1 | | | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[144]**(Metta & Badurdeen, 2013) | 1 | | | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[145]**(Miret et al., 2016) | 1 | | | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[146]**(Moghaddam, 2015) | 1 | | | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| **[147]**(Mota, Carvalho, et al., 2015) | 1 | 1 | | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[148]**(Mota, Gomes, et al., 2015) | 1 | 1 | | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[149]**(Nagurney, 2015) | 1 | 1 | | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| **[150]**(Nagurney et al., 2015) | 1 | | | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

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**Table A1** (*continued*)

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **[151]**(Nguyen, Cafferty, Searcy, & Spatari, 2014) | 1 | | | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| **[152]**(Nunes, Bennett, & Marques, 2014) | 1 | | | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| **[153]**(Nunes, Oliveira, Hamacher, & Almansoori, 2015) | 1 | 1 | | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[154]**(O'Connor, Garnier, & Batchelor, 2013) | 1 | | | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[155]**(Oberhofer & Dieplinger, 2014) | 1 | | | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| **[156]**(Orji & Wei, 2015) | 1 | | | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[157]**(Orji & Wei, 2015) | 1 | | | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[158]**(Osmani & Zhang, 2014a) | 1 | 1 | | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[159]**(Osmani & Zhang, 2014b) | 1 | 1 | | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[160]**(Özkır & Başlıgil, 2013) | 1 | 1 | | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[161]**(Palander & Voutilainen, 2013) | 1 | | | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[162]**(Pishvaee & Torabi, 2010) | 1 | 1 | | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[163]**(Pishvaee, Jolai, & Razmi, 2009) | 1 | | | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[164]**(Pishvaee, Rabbani, & Torabi, 2011) | 1 | 1 | | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[165]**(Pishvaee, Razmi, & Torabi, 2014) | 1 | | | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[166]**(Zhang et al., 2014) | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[167]**(Zhang, Gong, Skwarczek, Yue, & You, 2014) | 1 | | | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[168]**(Neto, Walther, Bloemhof, van Nunen, & Spengler, 2009) | 1 | | | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[169]**(Ramos et al., 2014) | | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[170]**(Reich-Weiser & Dornfeld, 2009) | 1 | | | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[171]**(Ren et al., 2015) | 1 | | | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[172]**(Ruiz-Femenia et al., 2013) | 1 | | | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[173]**(Sabio et al., 2012) | | | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| **[174]**(Sahay & Ierapetritou, 2013) | 1 | 1 | | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[175]**(Sahebi, Nickel, & Ashayeri, 2014) | 1 | | | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[176]**(Sammons, Eden, Yuan, Cullinan, & Aksoy, 2007) | 1 | | | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[177]**(Sammons, Yuan, Eden, Aksoy, & Cullinan, 2008) | 1 | | | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[178]**(Santibañez-Aguilar et al., 2013) | 1 | | | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[179]**(Santibañez-Aguilar et al., 2014) | 1 | 1 | | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[180]**(Santibañez-Aguilar et al., 2014) | 1 | | | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[181]**(Sarkis & Dhavale, 2015) | 1 | | | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[182]**(Sarraj, Ballot, Pan, Hakimi, & Montreuil, 2014) | 1 | 1 | | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[183]**(Shahzad & Hadj-Hamou, 2013) | 1 | | | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[184]**(Sharma, Sarker, & Romagnoli, 2011) | 1 | 1 | | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[185]**(Shaw, Shankar, Yadav, & Thakur, 2012) | 1 | | | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[186]**(Sinclair, Cohen, Hansen, Basson, & Clift, 2015) | 1 | | | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| **[187]**(Singh, 2014) | 1 | 1 | | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[188]**(Sitek & Wikarek, 2015) | 1 | | | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |

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**Table A1** (*continued*)

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **[189]**(Šomplák, Pavlas, Kropáč, Putna, & Procházka, 2014) | 1 | | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[190]**(Soysal, Bloemhof-Ruwaard, & Van Der Vorst, 2014) | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[191]**(Su et al., 2015) | 1 | | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| **[192]**(Su, Chen, & Yang, 2016) | 1 | | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[193]**(Talaei, Farhang Moghaddam, Pishvaee, Bozorgi-Amiri, & Gholamnejad, 2016) | 1 | | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[194]**(Taskhiri, Garbs, & Geldermann, 2016) | 1 | | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[195]**(Tidy, Wang, & Hall, 2016) | 1 | | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| **[196]**(Tong, Joseph, Rong, & You, 2014) | 1 | | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[197]**(Trapp & Sarkis, 2016) | 1 | | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[198]**(Tsai & Hung, 2009) | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[199]**(Turrisi, Bruccoleri, & Canella, 2013) | 1 | | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| **[200]**(Ülkü, 2012) | 1 | | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[201]**(Vachon & Mao, 2008) | 1 | | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| **[202]**(Validi, Bhattacharya, & Byrne, 2014b) | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[203]**(Validi, Bhattacharya, & Byrne, 2014a) | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[204]**(Vance, Cabezas, Heckl, Bertok, & Friedler, 2013) | 1 | | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[205]**(Varsei & Polyakovskiy, 2016) | 1 | | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[206]**(Virtanen et al., 2011) | 1 | | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| **[207]**(Vujanović, Čuček, Novak Pintarič, Pahor, & Kravanja, 2015) | 1 | | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[208]**(Walther, Schatka, & Spengler, 2012) | 1 | | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[209]**(Wanke, Correa, Jacob, & Santos, 2015) | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[210]**(Wu, Sarker, & Paudel, 2015) | 1 | | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[211]**(You, Tao, Graziano, & Snyder, 2012) | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[212]**(Yue, Kim, & You, 2013) | 1 | | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[213]**(Yue, Slivinsky, Sumpter, & You, 2014) | 1 | | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[214]**(Yue, Gong, & You, 2015) | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[215]**(Yue, Pandya, & You, 2016) | 1 | | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[216]**(Zanoni & Zavanella, 2012) | 1 | | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[217]**(Zhang, Osmani, Awudu, & Gonela, 2013) | 1 | | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

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**Table A1** (*continued*)

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **[218]**(Zhou et al., 2000) | 1 | 1 | | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| **[219]**(Ziolkowska, 2014) | 1 | | | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **[220]**(Hoen et al., 2014) | | 1 | | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Notes. 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Li, 2013; Lieckens, Colen, & Lambrecht, 2015; Lim & Lam, 2016; Longo, 2012; Manfredi & Vignali, 2014; Mansuy et al., 2015; Manzini et al., 2014; Martínez-Guido et al., 2014; Mele, Kostin, Guilleń-GosaÍbez, & Jimeńez, 2011; Meneghetti & Monti, 2014; Meneghetti, Borgo, & Monti, 2015; Metta & Badurdeen, 2013; Moghaddam, 2015; Nagurney, 2015; Nguyen, Cafferty, Searcy, & Spatari, 2014; Nunes, Bennett, & Marques, 2014; Nunes, Oliveira, Hamacher, & Almansoori, 2015; O'Connor, Garnier, & Batchelor, 2013; Orji & Wei, 2015; Osmani & Zhang, 2014a; Osmani & Zhang, 2014b; Özkır & Başlıgil, 2013; Palander & Voutilainen, 2013; Pishvaee & Torabi, 2010; Pishvaee, Jolai, & Razmi, 2009; Pishvaee, Rabbani, & Torabi, 2011; Quariguasi Frota Neto, Walther, Bloemhof, van Nunen, & Spengler, 2009; Ren et al., 2015; Sahay & Ierapetritou, 2013; Sammons, Eden, Yuan, Cullinan, & Aksoy, 2007; Sammons, Yuan, Eden, Aksoy, & Cullinan, 2008; Sarraj, Ballot, Pan, Hakimi, & Montreuil, 2014; Shahzad & Hadj-Hamou, 2013; Sharma, Sarker, & Romagnoli, 2011; 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