Recent trends in sustainable supply chain optimization

Panagiotis Karakostas and Angelo Sifaleras

Abstract Supply chain sustainability refers to the optimal balance between economic, environmental, and societal criteria during decision-making processes. This chapter presents a comprehensive review of recent research contributions on sustainable supply chain optimization. The selected articles have been classified according to several criteria. More specifically, an initial classification has been performed based on the sustainability concerns taken under consideration in each study. Next, a classification has been provided based on decision levels, and finally, the reviewed works have been categorized according to the available solution methods. The chapter is closing with some main insights and suggestions for future research.

Key words: Supply chain management, Sustainability, Optimization

1 Introduction

Sustainable logistics activities are characterized by the coordinated efforts to efficiently incorporate socio-environmental concerns into traditional cost-efficient supply chain management approaches (26). Thus, the efficient decision-making for sustainable logistic networks is linked to the simultaneous optimization of economic (e.g., overall operational cost), environmental (e.g., energy consumption and CO_2 emissions) and societal (e.g., drivers' salaries and working hours) criteria (35).

Decision-making in logistics processes constitutes a complex managerial task, which requires the development and utilization of advanced mathematical mod-

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els and computational methods (53; 63). Optimization computational methods are typically divided into three classes. The first class includes exact optimization methods, that mathematically guarantee the optimality of the obtained solution. The second class refers to approximate optimization methods that are based on decomposition and relaxation techniques. The approximate optimization methods cannot guarantee the optimality of a produced solution, but they provide guarantees about its quality. The last class includes heuristic/metaheuristic optimization methods, that cannot guarantee either optimality or quality of the obtained solution. Despite heuristic/metaheuristic solution methods are not characterized by the mathematical validity of exact and approximate methods, they remain a powerful computational tool for tackling large-scale NP-hard logistics optimization problems (65).

However, selecting the proper solution method depends on the complexity of the problem under consideration. The complexity of a problem is proportional to the types of decisions that they should be addressed. Decisions are divided into strategic, tactical, and operational levels, according to their impact on the system (i.e., the supply chain). Barbosa-Póvoa et al. (2018) identified the main research gaps in the domain of sustainable supply chain management, that need to be addressed. More specifically, the authors mentioned the necessity of considering integrated supply chain design and planning frameworks, by incorporating simultaneously decisions of different levels (9).

Towards this goal, this chapter attempts to provide a comprehensive overview of recent research contributions on the optimization of sustainable logistics, by focusing on key elements such as sustainability concerns, decision levels, and optimization methods. The remainder of the present work is structured as follows. Section 2 provides the methodology followed to conduct the literature review. Section 3 presents the results of the conducted analysis, while Section 4 summarizes the findings and provides key future research directions.

2 Methodology

This section focuses on the design of a systematic literature review. To achieve that, a five-step methodology was applied. More specifically, these five steps are summarized as follows:

- **Step 1**: Identification of research gaps.
- **Step 2**: Formulation of research questions.
- **Step 3**: Locating studies.
- **Step 4**: Screening & selection.
- **Step 5**: Analysis of the literature.

2.1 Identification of research gap

The first step of the methodology includes the investigation of the most recent surveys on the optimization of sustainable logistics, to identify the potential research gaps. In this initial step of our methodology, the following four recent surveys, related to the topic under consideration were found.

- A survey on assessment and optimization of sustainable forest wood supply chains, conducted by Santos et al. (2019) (61).
- A survey on optimization methods for biomass supply chains, conducted by Sun and Fan (2020) (64).
- A survey on multi-objective optimization for sustainable supply chains, conducted by Jayarathna et al. (2021) (31).
- A survey on metaheuristic solution methods for sustainable supply chains, conducted by Faramarzi-Oghani et al. (2022) (16).

The first two surveys are industry-oriented, as they limited the reviewed material on research contributions focusing on the forest and biomass industry, respectively. Moreover, the review period was set between *1995-2017* for the first survey, and between *2009-2019* for the latter. The remaining two research surveys also limited their reviewed material, since they were focused on research contributions that utilized specific optimization methodological categories. More specifically, the authors of the third survey limited their investigation to research works utilizing multi-objective optimization approaches, while the authors of the fourth survey focused on research works that addressed metaheuristic only solution methods. Furthermore, both of the last two surveys covered the literature up to 2020.

To this end, the present work is differentiated from other previous surveys, as it is not strictly focused on specific industries, models, or solution methods.

2.2 Formulation of research questions

To address a comprehensive literature review of recent research contributions on sustainable logistics optimization, the following research questions were developed.

1. What types and indicators of sustainability concerns are addressed in logistics optimization problems?
2. What types of decision levels and which of them are considered in sustainable logistics optimization problems?
3. What types of optimization methods are developed to solve sustainable logistics optimization problems?

2.3 Locating studies

The search for relative literature was performed in the Scopus database which is considered the largest database of peer-reviewed literature. An advanced search using boolean operators was employed. The search keywords that were used are *("sustainable" AND ("logistics" OR "supply chain") AND "optimization")*. It was observed that, the application of search terms in the abstract and keyword sections could potentially lead to irrelevant results. Thus, the search terms were limited to the title section. The search period was set between *2018-2022* (up to 3/2022). In addition, the search was focused on scientific journal articles written in English language.

2.4 Screening & selection

The application of the previously mentioned filters led to 68 papers. To determine which of these results is relevant to the topic under consideration, two exclusion criteria were additionally developed.

- Research contributions focused on the assessment of sustainability indicators in supply chain activities, without an optimization perspective, were excluded from the present review.
- Research contributions focused on the consideration of only one pillar of sustainability concerns, rather than a combination of them, were excluded from this review.

2.5 Analysis of the literature

The analysis of the literature is mainly focused on the extraction of the required information from each selected research paper to answer the stated research questions. However, additional problem features were also recorded in this step. The findings of this analysis were summarized in a tabular representation and are provided in the following section.

3 Results

This section provides the results of the analysis conducted on the selected research contributions. Figure 1 provides an illustration of the taxonomic framework used for the analysis and classification of the literature on the optimization of Sustainable Supply Chains (SSC).

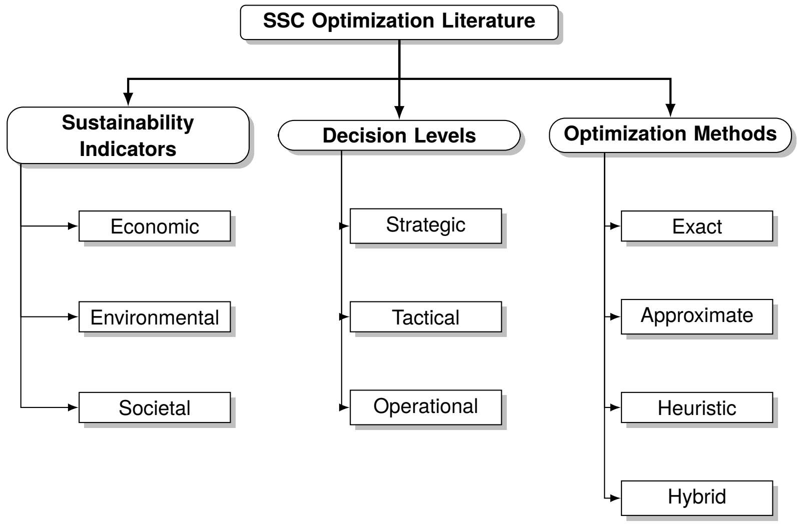

Fig. 1: Taxonomy of the literature

According to this framework and the key research questions of the present study, an overview of the literature is provided in Table 1. The first column refers to each research contribution included in the review. The next three columns focus on the three pillars of sustainability. More specifically, the second column, *ESC* (Economic Sustainability Concerns), includes binary values to represent the consideration or not of economic sustainability indicators in the study of each contribution. Similarly to the second column, the third and fourth one focus on the consideration of environmental (*EnvSC*) and societal (*SoSC*) concerns, respectively. The next three columns refer to the different decision levels addressed in each study. Headings *SDL*, *TDL*, and *ODL* refer to Strategic, Tactical and Operational Decision Levels, respectively. Binary values are also used in these columns to denote the consideration of each decision level in each research work. The next column provides information according to the objective function of the optimization problem addressed in each work. Thus, its potential values are *Single*, *Bi*, or *Multiple*. The column "Periods" records the number of time periods considered in each research contribution. Its possible values are *S* for single time period problems, or *M* in the case of multi-period optimization problems. The next column focuses on the type of the proposed solution method in each work. This column may include the values *E* for exact solution methods, *A* for approximation methods, *H* for heuristic solution approaches, *Hy* for hybrid solution techniques, and *M* when two or more types of solution methods were proposed in each scientific work, but not in a hybrid fashion. The next column provides the industrial domain on which each contribution relies on. Similarly, the next column summarizes the type of fleet utilized in each work. In each problem, the fleet can be homogeneous (*Ho*), heterogeneous *He* or mixed (*M*). Finally, the last column provides binary values to indicate whether any work considered the factor of time in its investigated problems or not. To clarify, the values *NS* and *NC* correspond to the absence of any direct statement or consideration of a feature in a particular study, respectively.

Despite all the surveyed papers focused on the design and optimization of sustainable logistics processes, only 50% of them simultaneously incorporate economic, environmental, and societal concerns in their decisions. Therefore, the reviewed contributions can be divided into two groups. The first group contains research contributions with an integrated sustainability approach, while the second group includes papers that combine economic criteria mainly with environmental concerns. Depending on the decision levels, most of the reviewed studies have been observed to address strategic, tactical, and operational decisions, while the next most common decision level synthesis is the strategic-tactical. Focusing on the proposed solution methods, almost 48% of the studies used exact optimization methods. Also, heuristic solution techniques constitute a highly utilized optimization method.

3.1 Sustainability concerns

This section presents the most common sustainability indicators utilized by the authors of the research contributions included in this survey, to address sustainability. Initially, an overview of these indicators is illustrated in the diagram of Figure 2. Figure 3 provides the distribution of publications for each type and element of sustainability indicators based on the reviewed papers. Finally, a classification of the reviewed articles is performed, based on their consideration of sustainability indicators.

Figure 3 illustrates what it has already been observed in the previous section, based on the literature review. Herein, it is critical to proceed to a classification of the reviewed research contributions based on the sustainability concerns which were addressed in each one. To clarify, a classification based on the types of sustainability is initially presented, and it is followed by a literature classification based on the particular indicators of sustainability.

Classification of the literature based on the types of sustainability:

- **Economic, Environmental & Societal Sustainability:** (19), (27), (24), (42), (25), (13), (50), (7), (59), (8), (28), (48), (43), (1), (44), (15), (60), (20), (49), (23), (40), (12), (57), (14), (54), (52), (38), (72), (10), (11)
- **Economic-Environmental Sustainability:** (3), (6), (68), (2), (46), (58), (22), (17), (36), (4), (55), (71), (67), (39), (51), (37), (30), (70), (45), (41), (32), (62), (5), (18), (21), (29), (69), (66)
- **Economic-Societal Sustainability:** (56), (47)

Classification of the literature based on the particular indicators of sustainability:

- **Economic Sustainability Indicators:**

Table 1: Overview of the literature

Study	ESC	EnvSC	SoSC	SDL	TDL	ODL	Objectives	Periods	Method	Industry	FT	TiC
(56)	1	0	1	1	1	1	M	M	Hy	Medical	He	1
(3)	1	1	0	1	1	1	M	M	E	Manufacturing	Ho	0
(19)	1	1	1	1	0	1	M	S	E	Manufacturing	He	0
(27)	1	1	1	1	1	1	M	S	E	Manufacturing	He	0
(24)	1	1	1	1	0	1	S	S	E	Manufacturing	He	0
(6)	1	1	0	1	0	1	B	S	M	Manufacturing	Ho	0
(68)	1	1	0	1	1	0	M	S	Hy	Oil Transportation	He	0
(42)	1	1	1	1	1	0	S	S	E	Medical	NS	0
(25)	1	1	1	1	1	0	M	S	E	Manufacturing	NS	0
(13)	1	1	1	1	1	0	M	S	A	Manufacturing	NS	0
(2)	1	1	0	0	1	0	M	S	E	Manufacturing	NS	0
(46)	1	1	0	0	1	0	M	M	M	Manufacturing	NS	0
(50)	1	1	1	1	1	1	M	M	M	Energy	NS	0
(58)	1	1	0	1	1	1	B	M	H	Manufacturing	Ho	0
(7)	1	1	1	1	1	1	M	M	H	Manufacturing	He	0
(59)	1	1	1	1	1	1	M	M	A	Petrochemical	NS	0
(8)	1	1	1	1	1	0	M	M	M	Forest Industry	NS	0
(28)	1	1	1	1	1	1	M	M	E	Forest Industry	He	0
(22)	1	1	0	1	1	1	M	M	M	Dairy	He	1
(48)	1	1	1	1	1	1	M	M	E	Logistics	Ho	0
(43)	1	1	1	1	0	1	M	M	M	Manufacturing	NS	0
(1)	1	1	1	1	1	1	M	M	E	Biofuel	He	0
(17)	1	1	0	1	0	1	M	S	M	Manufacturing	He	0
(36)	1	1	0	1	0	1	S	S	E	Manufacturing	NS	0
(44)	1	1	1	1	1	0	M	M	M	Automotive	NS	0
(4)	1	1	0	1	1	1	B	M	M	Food	NS	0
(15)	1	1	1	1	1	1	M	M	E	Biomass	NS	1
(55)	1	1	0	0	1	1	S	S	E	Manufacturing	NS	0
(60)	1	1	1	1	1	1	M	S	E	Manufacturing	Ho	0
(20)	1	1	1	1	1	0	M	M	H	Biofuel	NS	0
(71)	1	1	0	0	1	1	M	M	E	Natural Gas	NS	0
(67)	1	1	0	1	1	1	S	M	M	Manufacturing	NS	0
(39)	1	1	0	0	1	1	S	S	E	Biofuel	NS	0
(49)	1	1	1	1	1	1	M	S	E	Tanker	He	0
(23)	1	1	1	1	1	0	M	M	E	Biomass	NS	0
(51)	1	1	0	1	1	1	M	M	H	Manufacturing	NS	1
(40)	1	1	1	1	0	0	B	NS	H	Construction	NC	1
(37)	1	1	0	1	1	0	S	S	H	Mining	NS	0
(12)	1	1	1	0	1	1	M	M	H	Motor	NS	1
(30)	1	1	0	0	1	1	B	S	E	Biofuel	NS	0
(70)	1	1	0	1	1	0	B	S	E	Retail	NS	0
(57)	1	1	1	1	1	1	M	M	E	Manufacturing	He	1
(45)	1	1	0	1	1	1	B	M	H	Manufacturing	NS	1
(14)	1	1	1	1	1	1	M	S	H	Biofuel	NS	1
(41)	1	1	0	0	1	1	M	M	H	Manufacturing	NS	1
(47)	1	0	1	1	1	1	M	M	E	Medical	NS	1
(32)	1	1	0	1	1	0	M	NS	H	Construction	NC	1
(54)	1	1	1	1	1	1	M	M	E	Biofuel	Ho	0
(62)	1	1	0	1	1	0	M	M	E	Manufacturing	NS	0
(52)	1	1	1	1	1	0	M	M	H	Manufacturing	NS	0
(5)	1	1	0	1	1	0	M	M	E	Biofuel	He	0
(18)	1	1	0	1	1	0	M	M	E	GAS	NS	0
(21)	1	1	0	1	1	1	S	M	H	Manufacturing	He	0
(29)	1	1	0	1	1	1	B	M	H	Waste Collection	He	0
(38)	1	1	1	1	0	1	M	S	H	City Logistics	He	1
(72)	1	1	1	1	1	1	M	M	H	Manufacturing	NS	1
(69)	1	1	0	1	0	0	S	S	H	Urban Logistics	NS	1
(10)	1	1	1	1	1	1	M	M	E	Manufacturing	NS	1
(11)	1	1	1	1	1	0	M	S	E	E-Commerce	NS	0
(66)	1	1	0	1	1	1	M	M	NS	Manufacturing	He	1

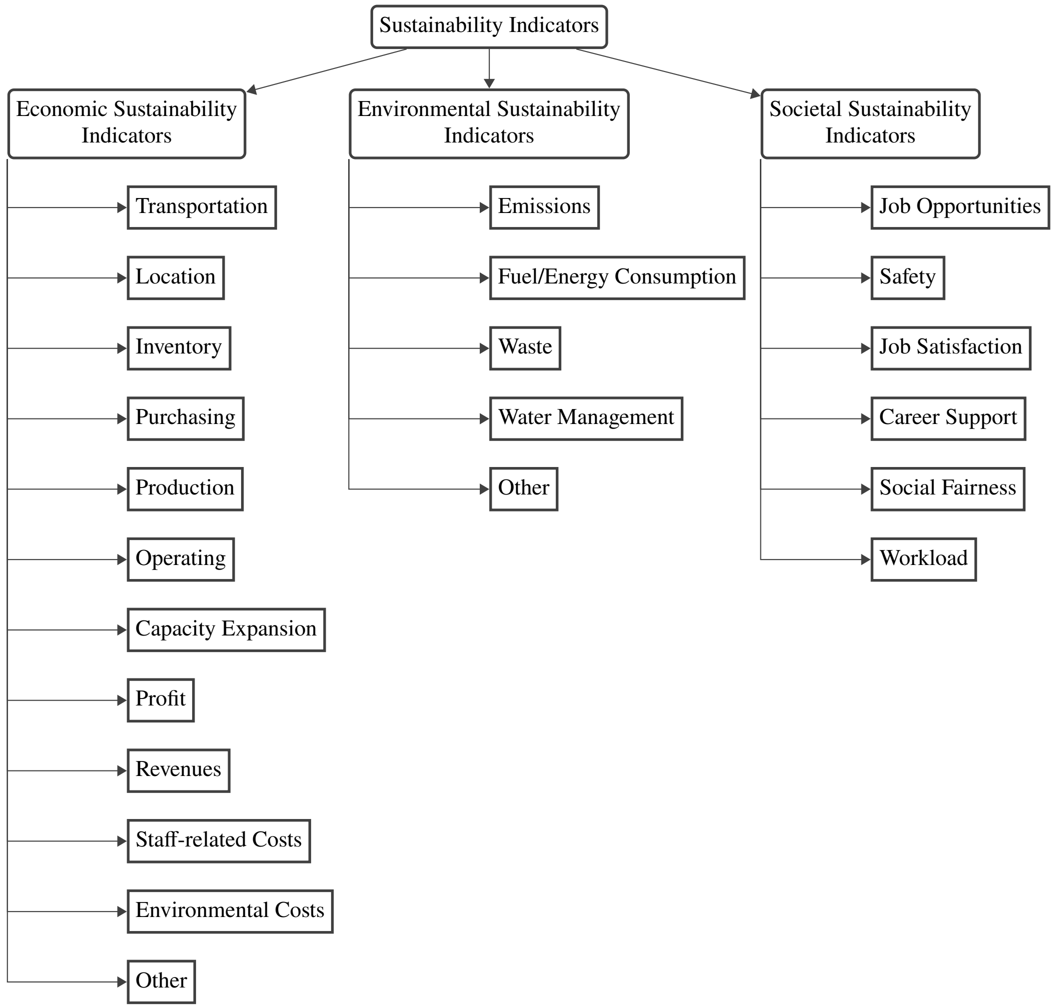

Fig. 2: Sustainability indicators in the reviewed literature

- ***Transportation.*** This indicator focuses on the supply chain network connections' costs, regrading the flow of materials and products. Transportation costs should be minimized. A list of the research contributions considered this indicator includes: (56), (3), (27), (24), (25), (13), (46), (50), (7), (59), (8), (28), (22), (48), (43), (1), (17), (36), (44), (4), (60), (20), (71), (67), (39), (49), (12), (30), (70), (57), (45), (14), (41), (47), (54), (52), (5), (21), (72), (10), (11), (66).
- ***Location.*** This economic indicator focuses on the costs generated by the location/opening of supply chain network facilities. Location costs should be minimized. The research contributions that considered this indicator are: (3),

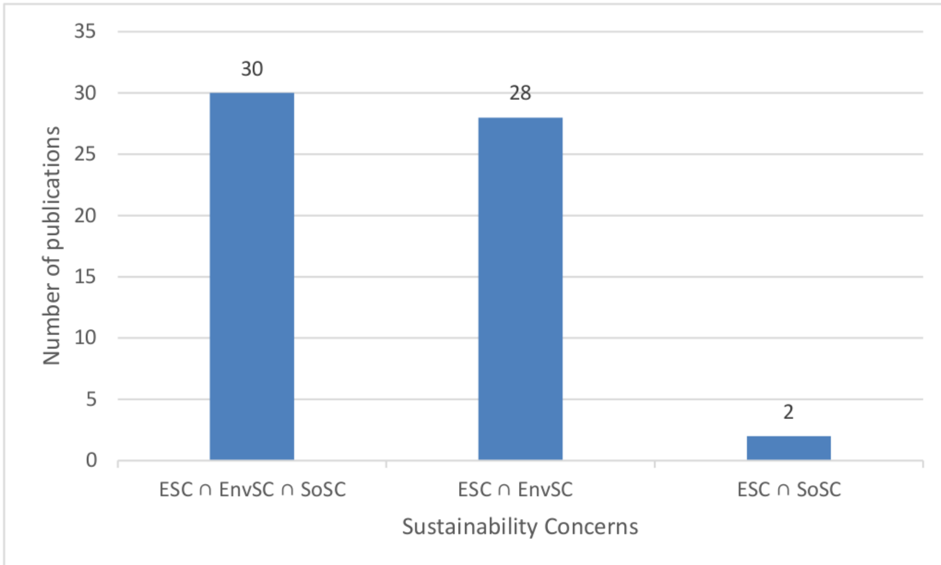

Fig. 3: Distribution of publications based on the sustainability indicators

(24), (25), (13), (50), (7), (59), (22), (43), (1), (17), (36), (44), (15), (60), (20), (67), (49), (23), (51), (70), (57), (45), (14), (47), (54), (52), (21), (29), (72), (69), (10), (11), (66).

– ***Inventory.*** Inventory-related costs such as holding costs, backorder costs, and stock maintenance costs constitute economic sustainability indicators. Decision makers should develop supply chain schedules that can minimize these costs. The research works that incorporate these types of economic sustainability indicators in their studies are: (3), (27), (68), (42), (25), (13), (2), (46), (50), (58), (59), (8), (28), (22), (48), (1), (4), (55), (67), (37), (12), (30), (57), (45), (41), (47), (54), (62), (72), (10), (66).
– ***Purchasing.*** Purchasing materials or equipment from suppliers is crucial in supply chains and generates significant costs, that should be minimized. The contributions that considered this indicator are: (3), (27), (24), (68), (42), (25), (13), (50), (58), (59), (8), (28), (22), (48), (1), (4), (15), (55), (60), (71), (67), (39), (23), (51), (12), (30), (45), (14), (21), (72).
– ***Production.*** Production-related costs consist of setup costs, manufacturing of product components or end products, and repair, reprocessing or disposal costs. Production costs should be minimized. A list of the research contributions that considered such indicators includes: (56), (27), (24), (25), (13), (50), (58), (7), (59), (28), (1), (17), (4), (15), (55), (60), (20), (71), (67), (39), (51), (30), (57), (14), (41), (62), (52), (5).
– ***Operating.*** Operating or operational costs are related to short-term logistic activities, that can significantly contribute to the overall supply chain system

cost. Thus, the objective scope for these cost components is their minimization. Some of the reviewed works refer to such economic criteria: (3), (22), (48), (71), (49), (23), (47), (10).

- ***Capacity Expansion.*** Capacity development is a critical strategic decision characterized by increased resources requirements and structural changes in the supply chain network. Thus, it is linked to high costs, that should be minimized by proper scheduling. However, limited research attention has been given to the sustainable optimization of the supply chain. In this review, only the following five contributions considered this economic indicator: (50), (1), (44), (71), (54).
- ***Profit.*** Improving profitability is a key strategic objective of every economic organization. Profits constitute the difference between the total revenues of a supply chain system and the total cost of the system. The objective goal of decision-makers according to profit is its maximization. Five of the reviewed research works considered the profitability of their supply chain systems: (19), (6), (2), (8), (22).
- ***Revenues.*** Revenues are the economic income of a company, generated by the sales achieved. Similarly to the criterion of profit, revenues should be maximized. The following eleven contributions took this economic indicator under consideration: (3), (50), (22), (1), (4), (55), (71), (49), (23), (12), (14).
- ***Staff-related Costs.*** Staff-related costs contain wages, costs of creating new jobs, and penalty costs for working accidents and overtime. These costs should be minimized. Only four works considered this economic indicator: (27), (24), (44), (57).
- ***Environmental-related Costs.*** Supply chain activities are linked to high environmental-related costs, such as fuel consumption costs, taxation over pollutants emissions, and recycling activities costs. Decision-makers should develop supply chain plans to minimize these economic indicators. Research contributions that considered such indicators are: (46), (22), (48), (36), (4), (55), (71), (40), (37), (57), (32), (62), (21), (29), (38), (72), (69).
- ***Other:*** Other economic indicators taken under consideration in the reviewed works are technical service fees, insurance fees, routing costs, and project-related costs (e.g., contractors' costs, infrastructure investments). The research contributions that considered such indicators are: (15), (67), (40), (37), (57), (32), (38).

- **Environmental Sustainability Indicators:**

  - ***Emissions.*** Supply chain activities are linked to high emitted pollutants (34). Therefore, greenhouse gas emissions, such as CO_2 emissions, constitute significant indicators of environmental sustainability. The main scope of decision-makers is the minimization of those emissions. Herein, the research contributions that considered such sustainability indicators are: (3), (19), (27), (24), (6), (68), (42), (25), (13), (46), (58), (59), (8), (28), (22), (48), (43), (1), (36), (44), (4), (15), (60), (20), (71), (49), (51), (40), (37), (12), (30), (70), (45), (14), (41), (32), (54), (62), (5), (18), (29), (38), (72), (69), (10).

- ***Fuel/energy consumption.*** Key logistic activities such as sourcing, production, and delivery have increased energy requirements. The main objective in such problem cases is the minimization of the consumed energy or the maximization of renewable energy sources in an effort to reduce hazardous pollutants. Several research contributions included in the present review incorporated this indicator in their studies: (27), (68), (42), (59), (48), (43), (1), (17), (44), (71), (51), (14), (62).
- ***Waste.*** A key environmental indicator of sustainability is the effective waste management. The proper management of waste focuses on activities which eliminate waste mainly through recycling and reprocessing schedules. Five of the reviewed papers addressed related to waste management decisions in their studies: (2), (7), (59), (1), (14).
- ***Water management.*** Supply chain activities may require water consumption, or can generate hazardous waste which can potentially lead to significant impacts on water quality. In both cases, it is necessary for the decision-makers to produce schedules that eliminate such risks. The following research contributions took water management decisions under consideration: (59), (1), (17), (39), (23), (14).
- ***Other.*** According to the reviewed papers, some additional environmental indicators of sustainability have been recorded, such as deforestation and consideration of protected areas. These works are: (59), (39), (23).

- **Societal Sustainability Indicators:**
  - ***Job opportunities.*** According to the social dimension of sustainability, the creation of jobs in a specific region constitutes the most common indicator of social sustainability. In this direction, the efforts focus either on the maximization of the new jobs or on the minimization of unemployment. The following works considered such decisions in their studies: (19), (24), (68), (42), (13), (50), (7), (59), (8), (28), (43), (1), (15), (60), (49), (54), (52), (72), (10), (11).
  - ***Safety.*** Employee safety is primarily addressed by eliminating work accidents or lost workdays due to accidents. The research works that considered such indicators are: (27), (13), (7), (59), (48), (1), (49), (57), (72), (11).
  - ***Job satisfaction.*** Another interesting indicator of social sustainability is the level of job satisfaction. The objective in such cases is to maximize job satisfaction of employees. Three research contributions considered this indicator in their studies: (13), (59), (1).
  - ***Career support.*** The leadership of a company should focus on addressing career development activities for its employees. Activities such as career counseling and training constitute significant indicators of social sustainability. The optimization of such criteria is linked to the maximization of these activities. The following research works took such decisions under consideration in their studied supply chains: (27), (59), (57), (72).
  - ***Social fairness.*** Social fairness is related to activities that eliminate types of discrimination, promote equity, and ensure transparency. Social fairness was

considered as a societal indicator only by two research contributions: (56), (59).

– ***Workload.*** Workload was considered only by one work in order to address societal sustainability (25).

3.2 Decision levels

Supply chain decisions are classified as strategic, tactical, or operational based on the planning horizon and their impact on the entire system (33). Recent studies have addressed the potential benefits of integrating different decision levels (73; 34). Figure 4 illustrates the distribution of the reviewed papers based on the decision levels that they tackled.

Fig. 4: Distribution of publications based on decision levels

It is clear that, the majority of the reviewed studies focused on the integration of strategic, tactical, and operational decisions. Location of facilities and capacity planning are two of the most addressed decisions. Production, transportation, and inventory planning are the most common tactical decisions addressed in supply chains. Focusing on operational level, sourcing and fuel consumption decisions were commonly made in the studied articles.

A classification of the studied research contributions based on the decisions that they considered, follows:

- ***Strategic-Tactical-Operational:*** (56), (3), (27), (50), (58), (7), (59), (28), (22), (48), (1), (4), (15), (60), (67), (49), (51), (57), (45), (14), (47), (54), (21), (29), (72), (10), (66).
- ***Strategic-Tactical:*** (68), (42), (25), (13), (8), (44), (20), (23), (37), (70), (32), (62), (52), (5), (18), (11).
- ***Strategic-Operational:*** (19), (24), (6), (43), (17), (36), (38).
- ***Tactical-Operational:*** (55), (71), (39), (12), (30), (41).
- ***Strategic:*** (40), (69).
- ***Tactical:*** (2), (46).

3.3 Optimization Methods

This section presents the classification of reviewed articles based on their developed solution methods for the optimization of sustainable supply chains. Initially, Figure 5 provides the distribution of works according to the type of their optimization methods.

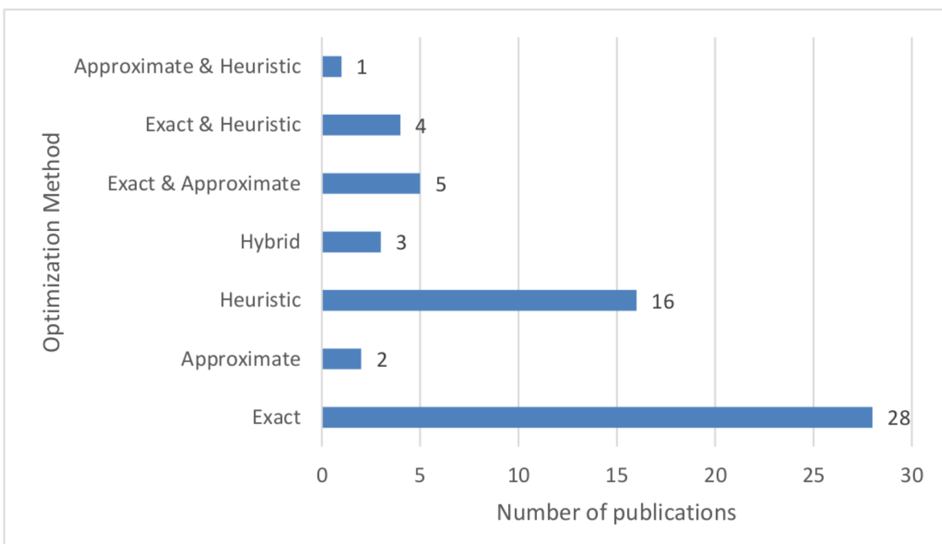

Fig. 5: Distribution of publications based on optimization methods

Exact optimization algorithms and heuristic solution methods are the most common solution approaches regarding the research contributions included in the present review.

The classification of the works based on their solution methods is made as follows:

- ***Exact:*** (3), (19), (27), (24), (42), (25), (2), (28), (48), (1), (36), (15), (55), (60), (71), (39), (49), (23), (30), (70), (57), (47), (54), (62), (5), (18), (10), (11).
- ***Approximate:*** (13), (59).
- ***Heuristic:*** (58), (7), (20), (51), (40), (37), (12), (45), (14), (32), (52), (21), (29), (38), (72), (69).
- ***Hybrid:*** (56), (68), (41).
- ***Exact & Approximate:*** (50), (8), (43), (17), (4).
- ***Exact & Heuristic:*** (6), (46), (22), (67).
- ***Approximate & Heuristic:*** (44).

A further classification of the surveyed research works can be performed by focusing on the specific solution methods developed in each contribution. To this end, the following classification is presented:

- **Exact methods.**
  - *$\epsilon-$ constraint methods:* (19), (6), (46), (50), (8), (28), (22), (71), (23), (30), (57), (47), (54), (5), (10).
  - *Weighted sum methods:* (19), (27).
  - *Compromise Programming methods:* (59), (60).
  - *Goal Programming methods:* (56), (68), (49), (62), (11).
  - *Fuzzy Programming methods:* (3), (2), (50), (1), (17), (40), (32), (69).
- **Approximate methods.**
  - *Benders Decomposition method:* (59).
  - *Lagrangian Relaxation method:* (8), (44).
- **Heuristic/Metaheuristic methods.**
  - *Genetic Algorithm:* (6), (46), (7), (20), (12), (14), (32), (52), (21), (38), (29), (72).
  - *Simulated Annealing:* (21).
  - *Variable Neighborhood Search:* (58).
  - *Bee Colony Optimization:* (29).
  - *Ant Colony Optimization:* (69).
  - *Particle Swarm Optimization:* (72).
  - *Evolutionary Algorithm:* (46), (7).

4 Conclusions

This survey provides a systematic literature review on research contributions focused on the optimization of sustainable supply chains, by following a five-step methodology. Based on four recent surveys on the domain of sustainable supply chains, the present survey present significant differences as it is not strictly focused on specific methods, industries, and optimization approaches. Moreover, the present survey provides several classifications of the considered studies according to different criteria, such as sustainability concerns, decision levels, and optimization methods.

According to sustainability concerns, the conducted analysis demonstrates that half of the selected studies focused on the triple bottom line of sustainability. However, several research contributions have studied only the integration between economic and environmental sustainability indicators. Based on the decision levels, the majority of the selected studies focused on the integration of strategic, tactical, and operational decisions. Finally, exact and heuristic solution approaches are the most commonly developed optimization methods to tackle sustainable supply chain optimization problems.

Future research directions can focus on further integration of societal indicators of sustainability in green supply chains, as an effort to address holistic sustainable supply chain systems. Moreover, it is necessary future research works to adopt further realistic features in their considered optimization problems. For instance, features such as time-windows, working hours, fuel consumption and refueling should be taken under consideration.

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