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From linear to circular sustainable supply chain network optimisation: towards a conceptual framework

Khadija Echefaj[a], Abdelkabir Charkaoui[a], Anass Cherrafi[b], Sunil Tiwari[c], Pankaj Sharma[d] and Charbel Jose Chiappetta Jabbour[e]

[a]Department of Mechanical Engineering, Faculty of Sciences and Technique, Hassan First University of Settat, Settat, Morocco; [b]Technical Analysis and Quality Control Department, EST-Safi, Cadi Ayyad University, Marrakech-Safi, Morocco; [c]Department of Operations Management & Decision Science, ESSCA School of Management, Lyon, France; [d]School of Business, UNSW Canberra, Australia; [e]Department of Information Systems, Supply Chain Management & Decision Support, NEOMA Business School, Mont-Saint-Aignan, France

ABSTRACT

Circular economy has the potential to counter sustainability challenges by moving towards a circular flow that enhances the efficiency of resource use. Government directives and stakeholders' pressures are forcing organisations to redesign their global supply chain network to fit sustainability and circularity aims. To fulfil this need, many models are proposed to integrate sustainability objectives in supply chain optimisation. However, designing a sustainable supply chain within the circular economy framework is lacking. This is a barrier for organisations to provide a circular and sustainable product. To fill this gap, descriptive and content analysis are used in this paper to scrutinise literature and develop a conceptual framework incorporating sustainability objectives and circular economy strategies to assist supply network design. The developed framework is a useful tool that helps in a better transition from a linear to a sustainable circular economy. Based on the results, research opportunities are identified and suggestions for future research are proposed. The findings are useful for researchers and managers to implement circular economy practices in a sustainable supply chain.

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KEYWORDS
Supply chain; sustainability; circular economy; quantitative model; mathematical programming; literature review

1. Introduction

Extreme weather events due to rising global temperatures have created havoc in various parts of the world in recent years. The freeze in Texas, sudden rise of water levels in the Rhine River, flooding in central China, British Colombia fires, and Hurricane Ida are some of the recent outcomes of the climate change crisis.[1] Although the COVID-19 pandemic has caused major disruptions in the global supply chain (SC) in the last two years, it is still a temporary phenomenon. The impacts of climate change are catastrophic, permanent, and need long-term plans to counter them (Liu and Kong 2021). Such increased frequency and the devastating impact of these extreme weather events have forced all sta keholders, citizens, organisations, and governments to increase their efforts to protect humanity from environmental threats (Bose 2010). These preventive actions are supposed to ensure a more sustainable and efficient way of using natural resources to achieve sustainable development (Ulucak, Danish, and Ozcan 2020) which aims to fulfil present and future generation needs (Keeble 1988). The environmental aspect has always been the main objective of sustainability initiatives, however, in recent decades, economic and social issues have also been adopted for greater attention (Tseng et al. 2015). Organisations are facing pressure to adopt sustainable manufacturing practices (Jabbour, Song, and Godinho Filho 2020). Although improving the sustainability of SC is challenging in a business environment (Chiappetta Jabbour, Mauricio, and Jabbour 2017), it is still imperative in manufacturing operations (Shibin et al. 2018). In this setting, SCs are evolving towards a more sustainable development model considering environmental issues and social performances (Siebenhüner and Arnold 2007; Marshall et al. 2015; Cherrafi et al. 2021).

In the recent past, considerable attention has been paid to circular supply chains (CSC) (Barreiro-Gen and Lozano 2020). This can be explained by the changing socio-economic and regulator insights, not only the environmental issues (De Angelis, Howard, and Miemczyk 2018). The traditional model (take-make-waste) has been found to be an unsustainable model of development. On the other hand, the Circular economy (CE) concept aims to maintain the product value, as long as possible, by reusing the technical material and regenerating biological resources (Awan, Sroufe, and Shahbaz 2021). In contrast to the linear economy, end-of-life strategies are defined, and waste is controlled and seen as a resource. Hence, virgin material extraction is minimised (Garza-Reyes et al. 2019; Mehmood et al. 2021; Kennedy and Linnenluecke 2022). CSC and closed loop SCs (CLSC) are closely related and often confused concepts. The integration of the CE concept extends the flow from linear to circular. It is a combination of closed loop (CL) and an open loop (OL) system. The CL network supposes

CONTACT Charbel Jose Chiappetta Jabbour c-j.chiappetta-jabbour@neoma-bs.fr, cchiappettajabbour@lincoln.ac.uk Department of Information Systems, Supply Chain Management & Decision Support, NEOMA Business School, Mont-Saint-Aignan, France.

that the company recovers all end-of-life products from customers. Thus, the manufacturer is maximising profit and minimising environmental impacts. One of the drawbacks of the CLSC is the disposal process which damages the environment. The disposal can be avoided in the OLSC, by collaborating with other companies to achieve "zero waste" (Farooque et al. 2019). Since a CE contributes to the three dimensions of sustainability (Schroeder, Anggraeni, and Weber 2019), circularity is seen as a condition of sustainable development (Geissdoerfer et al. 2017). The academic literature in the field has proved that CE practices increase long-term revenue (Khan et al. 2021; Antonioli et al. 2022), improve resource conservation (Agyemang et al. 2019), and contribute to job creation (Mehmood et al. 2021). As a result, sustainability in the SC cannot be achieved without CE implementation.

With an increase in the popularity of CE in industry, academic literature has also followed. Multiple studies (Seuring 2013; Brandenburg et al. 2014; Rajeev et al. 2017) have advanced the scholarship in this area. According to Barbosa-Povoa, Mota, and Carvalho (2018), these quantitative tools are effective in finding optimal solutions considering the triple bottom line of sustainability. Perceiving the contribution of CE to sustainability goals, optimisation models are being developed within the framework of the CE. As the extant literature in the field of CE increased, so did the number of literature reviews. Joshi (2022) reviewed 87 papers published between 2010 and 2021 to propose a framework incorporating the dimensions of sustainability in SC. Ansari and Kant (2017) posit that although most studies in the area of CE use qualitative techniques for research, quantitative research has also found many contributors. These quantitative studies are based on Linear programming modelling. Brandenburg et al. (2014) analysed 134 articles on forward flow to indicate that half of the articles published in the period 1994-2012 appeared after 2008. Genetic algorithms, dynamic programming, goal programming, and neural networks appear in very few articles. The paper highlighted that extant literature also needed more stochastic models to deal with uncertainties. The results obtained through a review of 185 papers published between 1994-2014 by Brandenburg and Rebs (2015) attest that deterministic approaches are used more than stochastic approaches. Quantitative models emphasise planning and manufacturing and neglect wholesalers and retailers. As for the application, electronics-energy industries, transport, and nutrition sectors are dominant. The broadness of study and level of detail limited this research. Eskandarpour et al. (2015) noticed that most of the 87 articles considered between 1990-2014 were published in 2008. The authors indicate that economic and environmental objectives are the most considered. Moreover, environmental factors are limited to the emission of Green House Gases (GHGs) and energy consumption while the social pillar is limited to job creation. Models are usually deterministic and solved with standard solvers. Consequently, heuristic and metaheuristic approaches are rarely used. This review paper only focused on mathematical models and did not consider the reverse flow. Mujkic, Qorri, and Kraslawski (2018) analysed 50 articles published between 2000– 2017 to find that linear and non-linear Mixed Integer Programming (MIP) are the most used in forward and reverse flow. The major drawback of this study is that the authors extracted articles from only one database. Asgharizadeh et al. (2019) focused on 261 quantitative and analytic models that appeared in academic literature from the period 1990-2016. Forward, reverse flow, and closed loop were considered. Outcomes indicate that researchers formulate more single-objective, linear, multi-product, multi-period, and limited capacity models. A key limitation of this research is not studying industrials application. 70 articles published between 2010 and 2020 were analysed by Flores-Sigüenza et al. (2021). The study finds that mathematical programming models are the most adopted. They proposed to consider risks and uncertainties, take into account the social dimension, and test the models in industries.

Despite the growth of publications on sustainable SC (SuSC) design, the literature lacks a framework supporting the design of SuSC within a circular flow. The increasing pressure to reduce waste and consumption of virgin raw materials drives organisations to operate in a circular flow instead of following sustainability objectives. Moreover, the crisis calls for the adoption of circular practices to deal with raw materials shortage. Achieving total circularity of materials requires collaboration with other companies which will lead to many intersections between supply chains. This implies that CLSC and OLSC are both supporting the transition towards CSC. Therefore, this paper reviews the proposed approach to design the SuSC in forward and reverse flow. The purpose is to identify the missing elements required to design a circular and SuSC (CSuSC) and build a conceptual framework incorporating sustainability and CE goals to assist the development of CSuSC models.

The remainder of the paper is organised as follows: Section 2 describes the methodology followed in conducting this systematic literature review. Section 3 provides the analysis of available literature on SuSC design according to sustainability objectives, modelling dimensions, solution approaches, and industrial applications (RQ1). Meanwhile, the fourth section focuses on analysing the circular aspect in quantitative models to answer RQ2. Section 5 develops a framework for CSuSC design. Directions for future research, theoretical and practical implications are proposed in section 6 to respond to RQ3. Finally, Section 7 concludes the paper.

2. Methodology

As defined by Rowley and Slack (Rowley and Slack 2004), the literature review is important in identifying questions, understanding concepts, developing a bibliography, suggesting research methods, and interpreting results. Systematic literature reviews must be accurate, transparent, and explicit. This study follows the five steps provided by Denyer and Tranfield (2009), explained in the following subsections and illustrated in Figure 1.

2.1. Question formulation

Starting with clear and well-formulated questions, the research process can reach the objectives more effectively (Denyer and Tranfield 2009). These questions shouldn't be

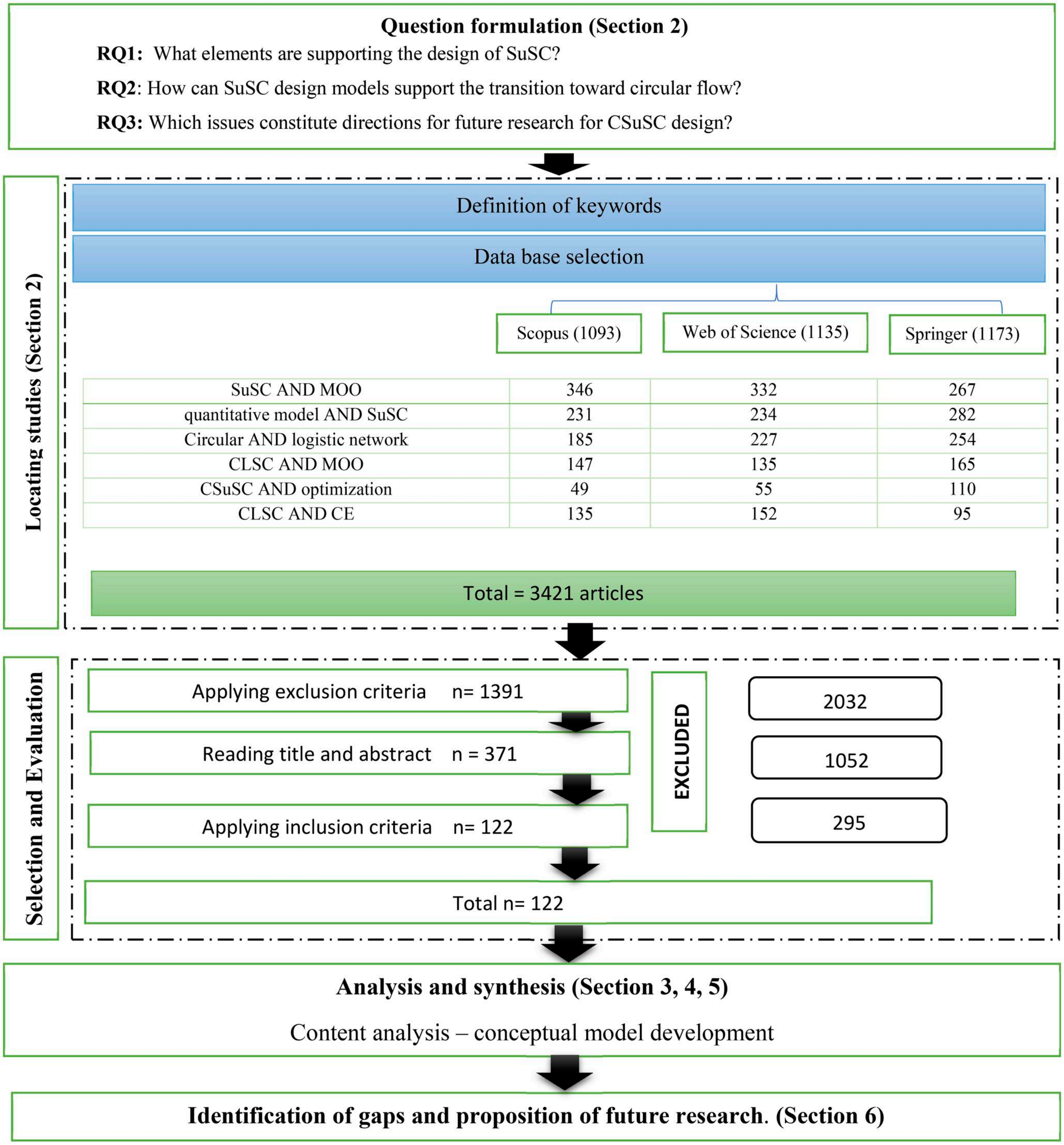


Figure 1. Research methodology.

too general or too specific (Mohamed Shaffril, Samsuddin, and Abu Samah 2021). First, we investigate, categorise, and assess the proposed models in the literature to design the SuSC. Consequently, we propose the following.

RQ1: What elements support the design of SuSC?

Second, we assess the ability of the current models to support the circular flow.

RQ2: How can SuSC design models support the transition toward circular flow?

Third, we identify opportunities for future research to enhance sustainability and circularity in SCs.

RQ3: Which issues constitute directions for future research for CSuSC design?

2.2. Locating studies

2.2.1. Select databases

According to Xiao and Watson (2019), no database covers global knowledge, so a review study has to be built from different sources. First, we opted for the most considered databases, Scopus and Web of Sciences, which are usually employed in exploring literature (Chadegani et al. 2013). They cover more scientific and engineering fields and have a great presentation of English language articles (Mongeon and Paul-Hus 2016). Then, we searched the Springer database to support and broaden our basic papers.

2.2.2. Keywords identification

Research questions can provide keywords. Subsequently, the researcher must enrich them by identifying synonyms, related terms, and variations (Mohamed Shaffril, Samsuddin, and Abu Samah 2021). For this study, we extract three keywords: "quantitative models", "SuSC" and "CE". In the search process, we added: "logistic network", "multi-objective optimization" (MOO), "Circular Network" (CN), and "Closed Loop" (CL).

We combine these keywords. First, the keywords "SuSC" and "Logistic network" provide articles considering the three pillars of sustainable development: economic, environmental, and social in SC management. Second, the keywords "quantitative models" and "MOO" deliver mathematical models with more than one single objective to optimise. Finally, "CE", "CN" and "CL" give works related to end-of-life strategies. Table 1 summarises the expected output of the keywords' combination.

2.3. Study selection and evaluation

To select quality publications, an article has to meet some qualifying criteria. First of all, all duplicate references were removed. Since research in this area peaked in 2008 (Brandenburg et al. 2014) and (Eskandarpour et al. 2015), all articles published before 2008 are excluded. The search also excluded all articles not written in English because this language is the most used in scientific research (Hamel 2007). Moreover, We only consider journal articles as the outcomes of most researchers' works (Rallison 2015). This process resulted in excluding 2032 articles.

Because the purpose of this study is to focus on SC optimisation considering the three pillars of sustainability, we include articles proposing a multi-objective mathematical model with at least two objectives. Works on the CSC are taken in with at least one objective since the end-of-life strategies also contribute to the sustainability of SC (Rentizelas, Shpakova, and Mašek 2018). By removing articles that did not meet the inclusion criteria, we obtained a total of 122 articles for this review. For a visual representation of the selection and evaluation process, the reader is referred to Figure 1.

2.4. Analysis and synthesis

In this step, we extracted several pieces of information from articles. First, we capture the academic journals and year of publication for each paper. Subsequently, we conduct a content analysis to analyse dimensions related to SuSC. The sustainability dimensions provide a classification based on the three pillars: economic, environmental, and social, the modelling dimension evaluates the types of models and the way uncertainty is handled, the dimension of the solution describes the approaches used to solve these models, and finally the industrial application.

Moreover, we opt for the keyword co-occurrence as a bibliometric method to map the research topics and identify trends. The generated graphs highlight the relationship between articles that share at least one keyword. The more the co-occurrence frequency is higher, the more relationship between papers is strong (Su and Lee 2010). To do so, VOSviewer software is used to create and cluster the extracted keywords.

3. The available literature on SuSC design in different flows

This section analyzes and classifies the identified papers according to sustainability dimensions, modelling techniques, solution approaches, and industrial applications (RQ1). First, a general descriptive analysis of the journal and year of publication is presented in Section 3.1, followed by keyword co-occurrence analysis in Section 3.2. All articles on SuSC design captured in this review are presented in Table 2 in Section 3.3 and classified according to network stages, objectives, model, uncertainty, solutions/tools, and validation. Section 3.4 analyses elements of sustainability objectives. Then, modelling dimension and solution approaches are investigated in Sections 3.5 and 3.6 respectively. Industrial applications are examined in section 3.7.

3.1. Descriptive analysis

An increasing interest in sustainability measures has led to an increase in publications and an upwards trend has been observed in the last four years. As shown in Figure 2, About 53% of papers are published starting in 2020. This is the result of the increasing community pressures on industries to ensure sustainability. Also, the importance of sustainability to ensure the viability of supply chains during the crisis is brought to light with the occurrence of the last pandemic event COVID-19.

The 122 articles selected covered 46 indexed journals. Figure 3 shows the top 10 journals publishing papers from the sample. Only seven journals account for more than 51% of articles. The *Journal of Cleaner Production* contributes 19.6%, followed by the *Computers & Industrial Engineering* (8%), *International Journal of Production Research* (7.3%),

Table 1. Keywords and their expected output.

Keyword	Expected Output
SuSC AND MOO	Articles that present a mathematical model of MOO (economic, environmental, and social) on SuSC.
Quantitative model AND SuSC	Work carried out on a SuSC using quantitative models
Circular AND logistic network	Works on the design of CSC networks
CLSC AND MOO	Articles that offer models with more than one objective relating to CLSCs
CSuSC AND optimization	Works that present optimization models on CSC
CLSC AND CE	Works that offer CLSC within the framework of the CE

Table 2. Review of previous related research.

	Network stage				Objectives					
	For	Rev	Uncertainty	Model	Eco	Envi	Soc	Other	Solution / Tool	Industrial Application
(Gholian-Jouybari et al. 2023)	S-M-DC-Cind		Stochastic	MILP	Profit – M-ST-T-lost sales- marketing	WTR	SC	Production capacity	Keshtel Algorithm	Argi-Food
(Al-Ashhab, 2023)	S-M-D-C	DIS-RD-DISP-Second C	Robust	MILP	Profit-Fxed-RW-M-SH-PUR-DIS-RM-RP-DISP-T-INVT		SC		GP-FICO Xpress Optimization software	
(Ahmed et al., 2023)	S-hM-DC-R-Primary MK-	COLL-DISP- Second MK-Applications	Fuzzy	MILP	Profit-Fixed costs-T-PUR-INVT- Cleaning-INS-PR-DISP	EM(S)-WTR(S)		Supplier importance Defect rate	Augmented EC- VPA: Value Path Analysis	Tire Industry
(Rajabi-Kafshgar et al., 2023)	S-PR-Pistachio, Oil & Cosmetic factories-Pistachiio, Oil & Cosmetic MK	Compost MK-Compositing MK		MILP	O-M-T				SA, GA, ICA, KA, SEO, GASA, ICASA, KASA	Agricultural Supply Chain
(Goodarzian et al. 2023)	Garden-DC-Citrus shop	REC-Compost shop		MILP	OP-T-Pack-REC-M-H	EM(OP-M-T)	Social Responsibility		EC- SPEA-II-PESA-II	Citrus Fruits
(Tirkolaee et al., 2023)	Blood donors-Donation center-Blood bank- regional & local hospital		Fuzzy	MILP	O-gathering-wastages-test-transshipment-subsidy-penalty		Job		Interactive possibilistic programming	Blood Supply Chain
(Mogale et al., 2022)	S-M-D-R-C	COLL/RM-DISP		MINLP	M-DISP-PR-T-O-Technology- Incentive-INVT	EM(M-PR-T-DISP)			EC- NSGAII + Co-Kriging	Household Appliance
(Asadi et al., 2022)	S-M-DC-C	COLL-DIS-RM-	Robust possibilistic	MIP	S-O-M-D-SH-T-COLL-RM	EM(M-RM-T)		Responsiveness ratio of the met demand	Meta GP Heuristic	Medical Device
(Soleimani et al. 2022)	S-M-DC-C	COLL-DISP-Second MK		MILP	Profit-O-M-T-INVT	ENG(T-M)	Job		LR reformulation-Heuristic	Tire Industry
(Tavana et al. 2022)	S-M-CD-C	RM-DISP		MILP	PUR-D-RM-DISP-Vihecle-SH-RW-Return- DEL-CD-H-shortage-DEL time window	EM(T-SH)	Job		F-GP GAMS	
(Kazancoglu et al., 2022)	M-W-DC-C	COLL-DIS		MILP	O-M-DC-W-C-COLL-DIS-T	EM(T-M)			IBM ILOG CPLEX	Home Appliances Industry
(Chouhan et al., 2022)	Farmers-Sugarcane mills- Compost MK-DC- MK-Cind	Sugarcane mills- Compost Units- Compost MK-Farmers		MILP	OP-T-M-PR-Pack-REPR-Tax				GA-SA- SEO-GASA-GASEO	Sugarcane Mills
(Salehi-Amiri et al., 2022)	Farm-Sorting&grading-Oil, leaf & seed factories-DC-Cind	DC-Coll/REC-Farm		MILP	O-PUR-OP-H-T		Unemployment rate		LP -Metric	Avocado
(Tirkolaee et al. 2022)	S-M-DC-C	COLL-Quarantine-REC-DISP		MILP	O-Employement of truck-T-OP-	EM(T-OP)	Humain risk		MOGWO - NSGA-II	Face Masks
(Foroozesh et al., 2022)	S-M-R-C		Robust-possibilistic	MILP	T-INVT-OP- Installation equipment-penality	EM(T)		Capacity Utilization of Facilities	GIVT2F AUGMECON2	Food Industry
(Vali-Siar and Roghanian 2022)	S-M-DC-C	COLL-REC-DISP–C	Robust-Stochastic	MILP	OP-T-M-D-COLL-REC-PUR-SH	EM(OP-M-D-T-COLL-DISP)	Job-LD	Responsiveness (CST)	LR- constructive heuristic	Tire Industry
(Baghizadeh et al. 2022)	Strawbery greenhouse-Warehouse-DC- M-C		Robust possibilistic	MINLP	Profit-T-ENG harvesting, irrigation-CTAX	WTR-ENG		M waiting –T time	EC-LR-GAMS	Agricultural And Food
(Boskabadi et al., 2022)	S-M-DC-C		Fuzzy	MINLP	Profit- OP-T-Fixed-RM-M-Penality	EM			NSGA-I & MOPSO	
(Tirkolaee and Aydin 2022)	S-M-DC-R		Probabilistic	MILP	OP-PR-deterioration costs of products	EM(S-M- deteriorated products)	Job		FWGP and Lp-metric CPLEX	
(Rajak et al., 2022)	S-M-D-R-C-INVT	COLL/DIS-REC-RP-DISP		MILP	Profit-RW-REC-DIS-M-COLL-H-RP-ENV				CPLEX	Remanufacturing Steering Column
(Bortolini et al., 2022)	M-DC-C			LP	M-D-ST-	EM(M-D-ST)		Stock		
(Pahlevan, Hosseini, and Goli 2021)	S-M-DC	COLL-REC		MILP	O-D-REC-RW(S)-RW(REC)-M-DISP-RV-REC-T-ENG-	En(M-D-REC)	Job-Health and Safety		MOGWO, MORDA	Aluminum Industry
(Goodarzian et al., 2021)	Foreign M-Internal M-DC-Hospital-pharmacy		Fuzzy	MILP	Penalty-tariff-T-M-H-Pack-O-PUR	EM(O-T)			HWO-SA, HFFA-SA, HSEO-FF	Medical

(*continued*)

Table 2. Continued.

	Network stage				Objectives					
	For	Rev	Uncertainty	Model	Eco	Envi	Soc	Other	Solution / Tool	Industrial Application
(Lahri, Shaw, and Ishizaka 2021)	S-M-DC-C		Possibilistic	ILP	Fixed- M-RW-PR-T	EM(RW-T)	Social Sustainability(S-M-DC)		EC	
(Jouzdani and Govindan 2021)	DC-R		CSP	RMCGP	Facility location-T-PUR-INVT	ENG(T)	Social Influence		VNS-CPLEX	Dairy Industry
(Yolmeh and Saif, 2021)	M-ASS-C	RM-Intermediate centers	Scenario-based	MINLP	OP-RM-ASS-Intermediate- SH				decomposition approach	
(Boronoos, Mousazadeh, and Torabi 2021)	M-W-C	RM-DIS	Robust possibilistic	MINLP RMFPP	O-M-H-COL-DIS-RM	EM(M-INVT-DIS-RM-T)			TH	Electronics Industry
(Gholizadeh et al. 2021)	S-M-W-DC-C	COL-REC-DISP	Robust	MILP	Profit OP-PUR-H-T-ENV	EM(O,ST-SH)			Augmented EC Heuristic-RO	Diary Industry
Hasani, Mokhtari, and Fattahi (2021)	S-M-W		Robust	MINLP	Profit	EM(T)		Min Centralize GSC Facilities	SPEA2-ALNS NSGAII EC	Medical Devices
Wang et al., (2021)	Garden–COL-CD-R			MIP	INV-T	EM(T)		Harvest-DEL Time	Weighted Balancing Objective-CPLEX	Fresh Fruit Supply
Shafiee et al. (2021)	S-M-R		Robust stochastic	MINLP RSP	SH-H-MT-PUR-M-ENV-T	EM(M-INVT-ST-T)	Job		***h*** HA & EC	Dairy (SC)
Sazvar et al. (2021)	M-DC-Pharma	RM-DISP	Stochastic	MILP	O-T-INVT-DISP-RM	EM(T-M-DISP)	Job		LP-metrics	Medical Industry
(Guo et al. 2021)	S-M-DC-C			MILP	M-OP-EM-O	EM-WST	Job-Accident		MNDTA CPLEX	Electronic Components
NoParast et al. (2021)	S-hM-C	COL		MILP	Fixed-var -T	EM(M) Virgen RW			NSGA-III MATLAB	Concrete Industry
Geng and Sun (2021)	Kitchen WST-PreTR - Refinery DmdP			MILP	O-ST-T	EM (COL- PreTR-M-T)	Unused Kitchen Waste		NSGAII	Biofuel Industry From Kitchen Waste
Ghasemzadeh, Sadeghieh, and Shishebori (2021)	S-M-DC-R	COL-CRT-enrRV- RETR	Stochastic	MILP	M-RM-T-REC- COL-PUR-ST-	Eco-indicator99			AUGMECON2 GAMS	Tire Industry
Khalili Nasr et al. (2021)	S-M-DC-CD-R	COL- RM-DISP	Fuzzy	MILP	COL-M-RM-DISP-PUR-SH-H-ST-ENR(T)	EM(O-T)	Job PUR from Sust S		Fuzzy goal programming approach	Suit Production And Distribution
(Salehi-Amiri et al. 2021)	Farms-PUR-C SEP	COL-RMK		MILP	PUR-OP-O-H-T				SA-SEO-KA-HKSA- HKSEO GAMS	Walnut Industry
Emamian, Kamalabadi, and Eydi (2021)	M-W-DC-C	COL-RM-DISP	Fuzzy	FMIP	O-EM	EM	Job		BCA- NSGA-II MATLAB	
Mohammed, Hassan, and Selim (2021)	S-M-DC-C	COL-DIS-DISP-REF-REC- RMK- MSP	Robust	RMILP	PUR-M-H-SH-INC-COL-REF-DIS-RP-REC-DISP-T EM				Branch and Bound CPLEX	
Eskandarpour, Dejax, and Péton (2021)	S-M-DC-C			MILP	O-OP-T	EM(PUR-T-M)			MLDS EC - C++	
(Mogale, Cheikhrouhou, and Tiwari 2020)	Farmer- procurement Center- W-Shop			MINLP	Fixed-T-INVT-H	EM(O-T-INVT-H)			MOPSO and NSGA-II	Food (SC)
Akin Bas and Ahlatcioglu Ozkok (2020)	S-hM-W-DC-C	DISP-REC	Fuzzy	MILP	PUR-M-H-REC-DISP-T	EM(OP-T)			Fuzzy approach	Diary Product
Atabaki, Mohammadi, and Naderi (2020)	S-M-DC-C	COL-DIS-REC-DISP-RM-REF-RMK	Robust possibilistic	MILP RPP	O-PUR-M-T	EM(O-OP-PUR-T) ENG(O-M-T)			EC CPLEX	
Liao et al. (2020)	***h***(M, REC)-DC-MK-C	COL		MILP	T-O-M-PUR-REC-COL-EM				HGSA-HKSA	Citrus Fruits Crates
Santander et al. (2020)	S-Plastic WST source	REC		MILP	Profit				CPLEX	Distributed Plastic Recycling For 3d Printing
Jayakumar et al. (2020)	S-M-DC-R-C	COL-DIS-REC		MILP	PUR-COL-RP-DIS-REF-T-O			Pollution cost	CPLEX	Electronics Industry
Bal and Badurdeen (2020)	S-hM-C	COL-RMK- Processing-DISP-RWmk		MIP	Profit T-M-O-COL-DISP		Region (SCR-EDC-INC-Med)	Time(T-M)	AUGMENTED EC CPLEX	
Vafaei et al. (2020)	S-W-C			MIP	T-PUR-O	EM(T-O-W)	Job		GP	An Online Retailer Platform

(*continued*)

Table 2. Continued.

	Network stage				Objectives					
	For	Rev	Uncertainty	Model	Eco	Envi	Soc	Other	Solution / Tool	Industrial Application
Abdolazimi et al. (2020)	S-M-DC-R-MK	COL-REC-DISP	Robust	RMILP	O-REC-SH-INC	EM(M-REC-T-INC)		Time delivery	WSM -EC-CPLEX	Tire Company
Pirnagh, Davari-Ardakani, and Pasandideh (2020)	S-M-DC-C	COL-DISP-REC	Fuzzy	MINLP	O-T-SHT			Responsiveness	NSGA-II-MOPSO-MINITAB	
Aljuneidi and Bulgak (2020)	hM-C	COL-DIS-REC-DISP		MILP	O- T-EM				CPLEX	
Yakavenka et al. (2020)	Loading P Entry P DC-MK			MILP	T	EM(T)	Delivery time		GP- minimax-Excel	Fruits Importer
Moslehi, Sahebi, and Teymouri (2020)	S-M-DC-C	COL-REC- DIS-RMK- DISP	Stochastic	MIP	O-COL-RV-DIS-REC-T-M	Score forward			Augmented EC-EC- GAMS	Electrical Devices.
(Zarbakhshnia et al. 2020)	S-M-DC-C	TC- DIS- CTR- RP-RM-DISP	Probabilistic	PMILP	TR-T-EM-W-PUR-O		Job courses & training -LD-accidents	Forward time	NSGA-II-MOPSO	
Jiang et al. (2020)	*h*M-DC-Mk	DIS- RD- DISP-RMK		MILP	O-T-M-TR-RV-RM-RP-DISP		SC		EC-fuzzy approaches MATLAB	
Gao and Cao (2020)	S-M-hM-DC-hDC-C	DISP	Stochastic	INP	O– PUR- M-T	EM(T-M-RV)	Job		WSM-Augmented EC	
Nayeri et al. (2020)	S-M-DC-C	COL-RP-RV-DISP- RMK	Fuzzy robust	MIP	O-OP-T	Asbestos (P-RP) EM(T-RV)	Job Damage		MCGP-UF-LINGO	Water Tank (SC)
Yun, Chuluunsukh, and Gen (2020)	M-DC-R-C	COL-RV-DISP		MIP	Fixed cost -HN-T	EM(M-RV-T)	Job LD		pro-HGA-MATLAB	
Tirkolaee et al. (2020)	S-W-R-TempW			MILP	PUR-H-O-Order	RW from Sust S		Reliability	WGP-CPLEX	Electronic Lamps
Gilani and Sahebi (2020)	Lands- biorefinery-ST-MK-domestic		Robust possibilistic	MILP	Construction harvesting sugarcane-T-M-H	Harvesting M-T– ST	Jobs		Fuzzy programming	Biofuel From Sugarcane
Ehtesham Rasi and Sohanian (2020)	S-M-DC-C			MILP	PUR-T-M-ST-DEL	EM(RW)			NAGA-II-MOPSO	
Das, Shaw, and Irfan (2020)	S-M-DC-C		CCP	MILP	Fix & var -O-PUR-T-HN-H	EM-WST- WTR	Sust S		AMPL CPLEX solver	
Govindan et al. (2020)	S-M-DC-C	COL-REC-DISP	Fuzzy	MILP	T-M- MT-PUR-EM-SH	Sust S			GAMS -fuzzy- CPLEX	Automotive Parts Industry
Gong et al. (2020)	S-M-C		CCP	MIP	O-OP-INV-M-H-T	EM(M-T)			NNCM- CPLEX	
(Zhen et al. 2019)	M-C-Logistics Center	RM	Stochastic	MINLP	M-PR-T-Holding				Improved TS	Air Conditioners
(Guo et al., 2019)	S-M-DC-C			MILP	PUR-M-T-OP-	EM-WTR			Distributed Approximation Approach	
Darbari et al. (2019)	S-*h*M-*h*DC-MK	DIS-REF-RMK-DISP	Fuzzy	FMILP	OP-T-LAB-Training	EM(ASS-DIS-T)	Job-training		WFGP	Laptop Manufacturer
Vimal, Rajak, and Kandasamy (2019)	S-*h*M-DC-R-C	COL-REF-M(C)		MILP	Profit T	EM(T)			CPLEX	Paper Industry
Mardan et al., (2019)	S-ASS-W-C	SEP-RM-DISP		MILP	O-PUR-OP-H	EM(O-T)			ABDA CPLEX	Wire & Cable Industry
Kaboli Chalmardi and Camacho-Vallejo (2019)	S-M-DC-R			MIP	S-O-T-M Fin incentives	EM(S-O-M-T)			SA-CPLEX	
Vafaeenezhad, Tavakkoli-Moghaddam, and Cheikhrouhou (2019)	S-M-DC-C			MILP	Ownership-M-T	ENG- WST EM	Travel Hires		AUGMENTED EC GAMS	Pulp And Paper Industry
Sherafati et al. (2019)	M-DC-C		Robust	MINLP	O-M-T-INVT- ENV- Lost sale		Regional Develop		EC GAMS	Cable Industry
Govindan, Jafarian, and Nourbakhsh (2019)	M-DC-R			MIP	O-M-T-HN-penalty	EM(O-M-T)	Job-SC damages		HPV- HEV-HAV-MATLAB	
Farrokhi-Asl et al. (2019)	*h*M-DC-C	COL-REC-DISP		MINLP	Design -O- T-COL-REC-DISP	EM(M-REC-DISP-T)		Responsiveness	MOHGASA- MATLAB	
Rahimi, Ghezavati, and Asadi (2019)	S-M-DC-C		Stochastic	MINLP	Design stage T-M-financial risk	EM(M-T-H-SH)	Job LD		EC-GA Gams	
Papen and Amin (2019)	S-*h*M-*h*R-C			MILP	PUR-T	ENG EM(S,T)			WSM-dist-EC-GAMS	Plastic Bottled Water
Resat and Unsal (2019)	S-M-C			MILP	O-T-M-H	RW from Sust S		Time	EC-GAMS	Packaging

(*continued*)

Table 2. Continued.

	Network stage				Objectives					
	For	Rev	Uncertainty	Model	Eco	Envi	Soc	Other	Solution / Tool	Industrial Application
Taleizadeh, Haghighi, and Niaki (2019)	S-M-R-C	COL-REC-DISP		MILP	Rw-H-OP-SH Discount- emp	EM(T-OP) ENG-WTR	Job- health self-sufficiency		TH-GAMS	Fluorescent Bulbs
Alizadeh Afrouzy et al. (2018)	S-M-DC-C			MIP	PUR-T-M-design Pd		SC	Devlop New Pd	NSGA-II-NRGA	
Mohammadi et al., (2018)		Col -SEP - C RM- REC-DC		MILP	M-INVT-COL-SH-T-DISP-ENV				GAMS-CPLEX	
Sadeghi Rad and Nahavandi (2018)	S-M-DC-C	RV-COL-DISP		MILP	O-M-RV-OP	EM(M-RV-COL-T)	SC		LP-metrics-CPLEX	
Yadav, Tripathi, and Singh (2018)	S-M-DC-C			MILP	OP-T	EM(OP-T)			GAMS-CPLEX	
Nujoom, Wang, and Mohammed (2018)	S-M-W			MIP	INVT-RW-T-M	ENG EM(OP)			EC-LP-metrics LINGO	Plastic And Woven Sacks
Mota et al. (2018)	S-*h*M-W-MK		Stochastic	MILP	RV-T-LAB	EM(O-M-T)	Job		GAMS	Electronic Components
Pourjavad and Mayorga (2018)	S-M-DC-C	COL-REC-RP-DISP	Fuzzy	FMILP	O-M-REC-RP-DISP-T	EM(M-SH-DISP)	Job		NSGAII-NRGA	
Rezaei and Kheirkhah (2018)	S-M-DC-CD-C	COL-RV-RM- REC-DISP-RMK		MILP	M- PUR-OP- SH- COL	EM(M-OP-T-DISP) Pd damage	Job Damages		COA	
Bortolini et al. (2018)	S-DC-Poolers	DISP-REC		MILP	DC-poolers, SH-PUR-INC -REC-ST Packaging	EM(CD-poolers- sh SH-M-COL- INC-REC-ST-Pack)			NNCM- AMPL solver	Fruit And Vegetables
Samadi et al. (2018)	S-M-DC	COL-REF-REC-DISP		MILP	O-PUR-M-H-T-COL	EM(T-M-H-DISP)	Job Damage		GA-RDA	
Sahebjamnia, Fathollahi-Fard, and Hajiaghaei-Keshteli (2018)	S-M-DC-C	COL-REC		MILP	O-M-D-COL- REC	EM(O-M-D-COL-REC)	Job Security		H-RS/ H-WG/ H-WT/H-RW-EC	
Fathollahi-Fard, Hajiaghaei-Keshteli, and Mirjalili (2018)	S-M-DC-C	COL-REC-REF-DISP	Stochastic	SMIP	O-PUR-M-H-T-DISP-RM-REC		Job Damage		RDSAGA KAGASA-RDKAGA -EC	
Rabbani et al. (2018)	M-W-C	COL-REC	Robust possibilistic	MINLP	Fixed-Var -T-O-M-H-HN-COL-REC	EM(M-H-COL- REC-T)	SC		AUGMENTED EC	
Sarkar, Omair, and Choi (2018)	S-M			LP	M-H-W-MT-ENR- ENV	EM(OP)			WGP-MATLAB	Automobile Industry
Balaman et al. (2018)	Source-pre-processing-storage-conversion-M-demand node		Fuzzy	MILP	INV-OP-PUR-T	EM(ENG-T)		T(distance-time)	*h*(fuzzy & EC)-CPLEX	Biomass Industry
John et al., (2018)		MK-COL-RM-DIS-REC-RP-DISP		MILP	COL-T-TR-DISP GRADING				LINGO	Mobile Phones & Digital Cameras
Tsao et al. (2017)	S-M-DC-C		Fuzzy	MILP	O-M-ST-T	EM(T-M)	Job		TSP-fuzzy-TH	
Nurjanni, Carvalho, and Costa (2017)	*h*M-*h*W-*h*DC-C			MILP	T	EM(M-H-DIS- RM-T)			WSM -WTM- CPLEX	
Jindal and Sangwan (2017)	S-M-DC-R	COL-DIS- REF-DISP- REC	Fuzzy	FMILP	Max Profit	EM(T)			EC-Lingo	
Arampantzi and Minis (2017)	S-M-DC-C			MILP	INV-OP-ENV	EM(Plants) WST	Dev Local Satisf emp T -job		GP-EC	Refrigerator Producer
Kumar et al. (2017)	S-M-R			MIP	S-M-G	EM(M-T)		Risk	NSGA-II	
Roni et al. (2017)	Preprocessing-W-M-Bulk-C			MILP	T, INV Penalty	EM (O-OP-T)	Local jobs		Augmented EC	Biofuel Supply
Soleimani et al. (2017)	S-M-DC-C	REC-RD	Fuzzy	FMIP	MAX profit		LD SC		GA-EC-LINGO	
Zhao et al. (2017)	S-M-DC	REC-DISP- INC		MIP	M-PUR -T-Risk- EM	EM(M,T,DISP)		Risk	MODM-MADM	Sanitary Producer
Varsei and Polyakovskiy (2017)	S-M-DC-C			MILP	O-M-T-PUR-ST	EM(T)	Job Reg GDP		Augmented EC-CPLEX	Wine Industry
Zhang et al. (2016)	S-M-DC-C			MILP	O-DEL-T	O-T	Customer service		MOABC	
Yu and Solvang, (2016)		C-COL-T- MK		MILP	OP- TR-T- Electricity & heat	EM(TR-T)			LINGO	

(*continued*)

Table 2. Continued.

	Network stage				Objectives					
	For	Rev	Uncertainty	Model	Eco	Envi	Soc	Other	Solution / Tool	Industrial Application
Afshari et al. (2016)	*h*M-W-C	COL-DISP	Stochastic	SMILP	T-O-ST-SH		SC		GA-SAM	
(Chen et al., 2015)	S-M-W-R-C	COL-REC-DISP		MILP	Profit- fixed- T-PRO- COL-REC- DISP				GA LINGO	
Govindan, Jafarian, and Nourbakhsh (2015)	S-M-DC-CD-R		Stochastic	MILP	S-O-PUR-T-M-HN-SH	EM(S,O,M,T)			MOHEV	Automobile Producer
Sitek, (2015)	U-DC-C	REC		HSF = MP + CLP	DEL-M- REC- fossil fuels & EM(T,REC)				LINGO-ECLIPSE	
Tognetti, Grosse-Ruyken, and Wagner (2015)	S-M-MK			LP	O- T- CONFIG- RW-M- LAB	EM(M,T)			EC	Automotive Industry
Zhang et al. (2014)	S-M-C			MILP	PUR- M-TR(WST)-T	EM		Time	EC- CPLEX	Chemical Industry
Chen and Andresen (2014)	S-M-C			MILP	PUR-M-T	EM	Injury Disease		WSM-LINGO	Steel Industry
Jindal and Sangwan (2014)	S-M-DC-R	COL-DIS-REF-REC- DISP	Fuzzy	FMILP	PUR–T				LINGO	
Devika, Jafarian, and Nourbakhsh (2014)	S-M-DC-C	COL-INS-RV- RM-REC-DISP		MILP	O-PUR-M-HN-T	EM(O-M-T-H)	Job Damages		HIV-TIV -NIV	Glass Producer
Tseng and Hung (2014)	S-M-DC			MINLP	PUR-M-T- EM(M,T)				LINGO	Textile Company
Pishvaee, Razmi, and Torabi (2014)	M-C	COL-INC- REC	Possibilistic	MILP	O-T-M	Damages	Job - damages Dev local		ABDA-CPLEX	Medical Industry
Lee et al. (2013)	S-W-*h*M-C	COL		MINLP	O–SH-M-T-HN			Time	GAMS	
(Özceylan and Paksoy 2013)	S-M-R-C	COL-DIS-REF-DISP	Fuzzy	LP	Fixed- M-PUR-T-REF				Liang and Cheng's (2009) method GAMS-CPLEX	
Chaabane, Ramudhin, and Paquet (2012)	S-M-DC-C	REC		MILP	LOC-PUR-T- ENV	EM(M,T)			LINGO	Aluminum Industry
Pishvaee, Razmi, and Torabi (2012)	M-DC-C		Robust possibilistic	MINLP	O-M-T		Job – WST-HAZ-LD		LINGO–EC	Medical Device Manufacturer
Wang, Lai, and Shi (2011)	S-M-C			MILP	O-ENV-T-HN	EM(facility)			NNCM –CPLEX	
Pishvaee and Torabi (2010)	M-DC-C	COL-RV-REC-C materiel	Possibilistic	PMILP	O-T-M			Delivery	FA & TS-SO	

Forward: S = supplier, M = manufacturer, DC = Distribution Centre, R = Retailer, MK = market, C = Customer, CD = Cross-docks, Cind = Customer industry.
Reverse: COL = Collection Centre, SEP = Separation Centre, RETR = Retreatment Centre, RDC = Redistribution, REC = Recycling Centre, W = Warehouse, REF = Refurbishing, DIS = disassembly Centre, DISP = disposal, RV = Recovery Centre, RM = Remanufacturing Centre, INC = incineration, T = treatment, RMK = Reuse Market, RP = Repair Centre, TC = test centre, MSP = Spare Part Market, CTR = Centralised Return Point, LOC = location.
Operation: T = Transportation, ST = storage, H = handling, O = opening, SH = shipping, PUR = purchase, OP = operating, MT = maintenance, DEL = delivery, INV = Investment.
Environmental: EM = emission GHG, ENG = Energy, WST = Waste, ENVI = environmental.
Others: LAB = Labour, SC = Satisfaction des clients, RM = Raw material, HAZ = hazardous products, LD = lost day, Pd = product, h = hybrid.
Model: MIP = Mixed Integer Programming, MILP = Mixed integer Linear programing, MINLP = Mixed integer Non-Linear programing, FMLIP = Fuzzy Mixed-integer Linear programing, RMILP = Robust Mixed Integer Linear Programing, RPP = Robust Possibilistic Programming, MPP = multi-objective possibilistic programming, MP = mathematical programming, CLP = constraint logic programming, RMCGP = Revised Multi-Choice Goal Programming, CSP = Chance-constrained Stochastic Programming.
Solving methods: FA = Fuzzy approaches EC = epsilon constraint, WSM = weighted sum model, WTM = Weighted Tchebycheff method, WGP = Weighted goal Programming, COA = cuckoo optimisation algorithm, NNCM = normalised normal constraint, VNS = Variable Neighbourhood Search, H-RS = hybrid RDA & SA, H-WG = hybrid WWO & GA, H-WT = hybrid WWO & TS, H-RW = hybrid RDA & WWO, MDLS = Multi-directional local search, ABDA = accelerated Benders decomposition algorithm, BCA = Bee colony algorithm, HIV = Hybrid ICA and VNS, TIV = Two-phase ICA and VNS, NIV = Nested ICA and VNS, MOABC = multi- objective ABC algorithm, MOHGASA = multi-objective hybrid genetic algorithm and simulated annealing algorithm, MOHEV = adapted multi-objective electro magnetism mechanism algorithm (AMOEMA) & the adapted multi-objective variable neighbourhood search (AMOVNS), MODM = Multi-objective decision making, MADM = multi-attribute decision making, LR = Lagrangian relaxation, VPA = Value Path Analysis, SPEA-II = Strength Pareto Evolutionary Algorithm II, PESA-II = Pareto Envelopebased Selection Algorithm II, SEO = Social Engineering Optimiser - GASEO = Social Engineering Optimiser, MOGWO = Multi-Objective Grey Wolf Optimisation, GIVT2F = generalized interval-valued type-2 fuzzy.

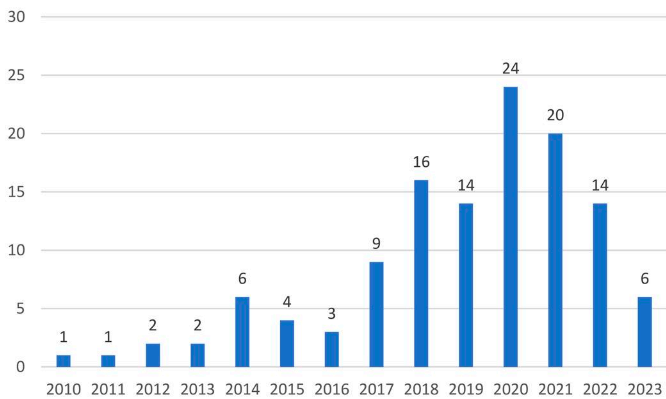


Figure 2. Time distribution of reviewed papers.

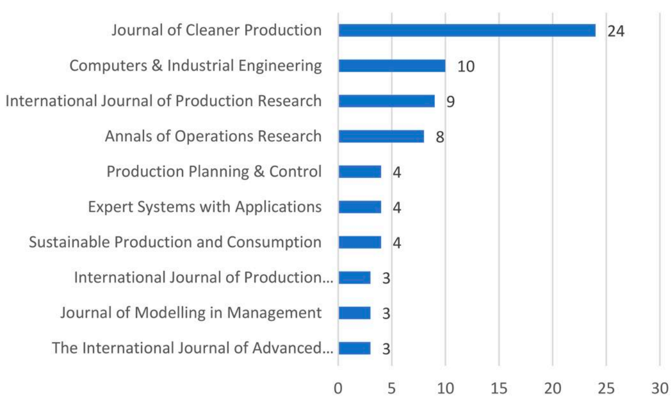


Figure 3. Top 10 journals of reviewed papers.

Annals of Operations Research (6.5%), *Production Planning & Control* (3.2%), *Experts Systems with Applications* (3.2%), and *Sustainable Production and Consumption* (3.2%). According to Scimago Journal and Country Rank, these journals are classified in Quartile 1 (Q1) with high impact factors. Additionally, the main subject areas are engineering, business, management, clean technology, decision science, computer science, and others. The support of such high-quality journals indicates the importance of this research field and encourages academics to advance scientific production.

3.2. Keyword co-occurrence analysis

The sample provided 367 keywords. 19 keywords appear at least in four papers. The most appearing ones are: CLSC (28), MOO (24), sustainability (21), SuSC (14), Reverse logistics (10), and network design (10). Figure 4 shows the keywords occurrence network. This analysis identifies three important clusters. The green cluster shows the importance of sustainability and SuSC management. The grey cluster relates to the CLSC and Reverse Logistics. The rose cluster encompasses MOO and SC design network. Then, this network is coloured in overlay visualisation using a timescale in Figure 5. In this graph, the darker the shade of yellow, the more the keyword is used recently. As we may see, uncertainty, CLSC, responsive SC, agriculture, and food, COVID-19, hybrid meta-heuristic and circularity are the recent trends in this field. It has been observed recently that while designing a SuSC, resilience objectives and constraints are integrated.

3.3. Literature classification

Table 2 categorises all identified literature on the design of SuSC in different flows. Papers are classified chronologically based on the year of publication. It is observed that papers modelling a CLSC under the triple bottom line of sustainability comprise only 16.3% (Devika, Jafarian, and Nourbakhsh 2014; Pishvaee, Razmi, and Torabi 2014; Pourjavad and Mayorga 2018; Rabbani et al. 2018; Rezaei and Kheirkhah 2018; Sahebjamnia, Fathollahi-Fard, and Hajiaghaei-Keshteli 2018; Samadi et al. 2018; Darbari et al. 2019; Gao and Cao 2020; Nayeri et al. 2020; Yun, Chuluunsukh, and Gen 2020; Emamian, Kamalabadi, and Eydi 2021; Khalili Nasr et al. 2021; Pahlevan, Hosseini, and Goli 2021; Sazvar et al. 2021; Soleimani et al. 2022; Tavana et al. 2022; Tirkolaee et al. 2022; Vali-Siar and Roghanian 2022; Goodarzian et al. 2023). In linear flow, 14% papers are developed considering economic, environmental, and social objectives (Chen and Andresen 2014; Geng and Sun 2021; Gholian-Jouybari et al. 2023; Gilani and Sahebi 2020; Govindan, Jafarian, and Nourbakhsh 2019; Guo et al. 2021; Jouzdani and Govindan 2021; Lahri, Shaw, and Ishizaka 2021; Mota et al. 2018; Rahimi, Ghezavati, and Asadi 2019; Roni et al. 2017; Shafiee et al. 2021; Tirkolaee and Aydin 2022; Tsao et al. 2017; Vafaeenezhad, Tavakkoli-Moghaddam, and Cheikhrouhou 2019; Vafaei et al. 2020; Varsei and Polyakovskiy 2017; S. Zhang et al. 2016). More detailed analyses are presented in the following subsections.

3.4. Sustainability dimension

Perceiving the interconnection between sustainability and circularity (Geissdoerfer et al. 2017), the transition towards total circular flow needs a deep understanding of sustainability dimensions. The aim is to identify economic, environmental, and social elements ensuring both sustainability and circularity. In this respect, the proposed mathematical models are scrutinised according to the three dimensions of sustainability. Findings indicate that economic and environmental objectives still receive more interest with 37% of articles. 11% are maximising economic and social performance. There is no article aiming to optimise social and environmental factors. All three dimensions appear in 40% of articles. The social dimension continues to be less considered. This is justified in literature by the difficulty of quantifying the social indicators (Mujkic, Qorri, and Kraslawski 2018) as they are qualitative criteria. While there are popular assessment tools for economic (e.g., cost/benefit analysis) and environmental (e.g., Life cycle analysis) objectives, few assessment tools developed for social objectives can be adapted in the industry field and integrated into models.

3.4.1. Economic objective

Because companies are business-oriented, the economic objective is always present. This objective is associated with two main indicators: maximising profit or minimising costs, or both. Profit is always expressed in terms of gain from selling new products or selling recycled, repaired, or reused

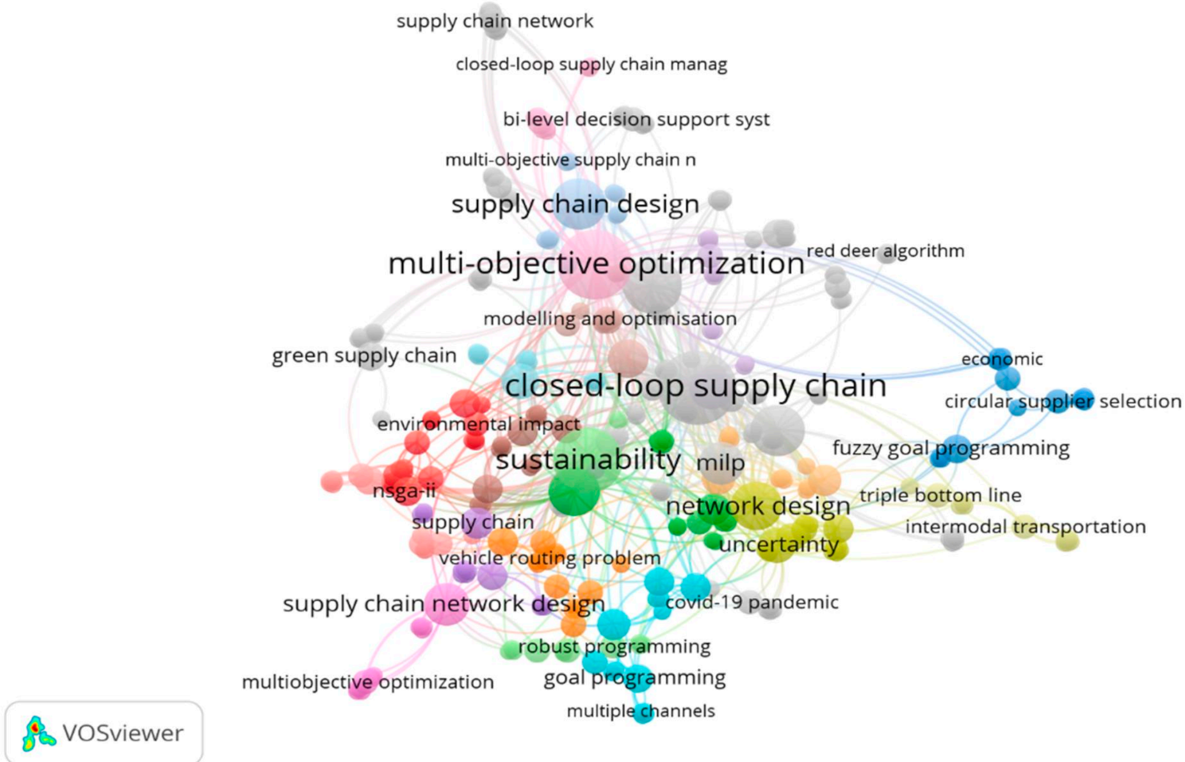


Figure 4. Keywords co-occurrence network.

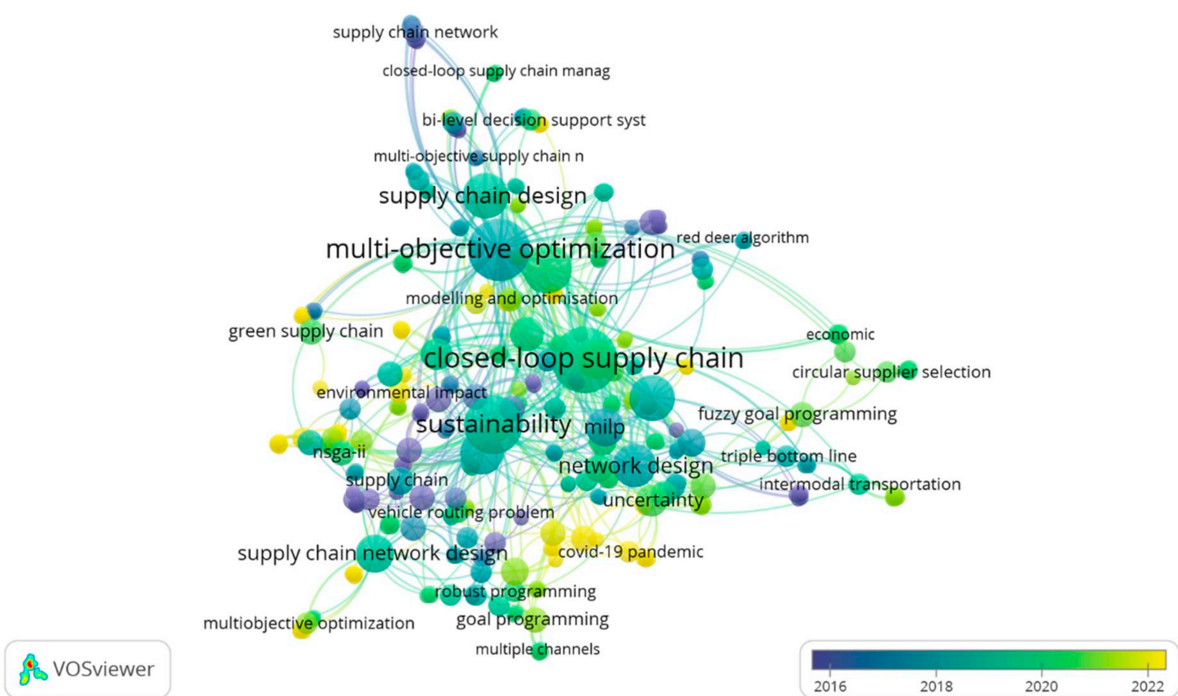


Figure 5. Keywords co-occurrence frequency by timescale.

ones. Kaboli Chalmardi and Camacho-Vallejo (2019) introduced a way of getting a profit gain because of using clean technologies. Minimising costs is expressed differently. As shown in Figure 6, the main costs of the SC are the most apparent. First, Transport cost appears in 78.6% of papers, followed by Manufacturing with 55% of models. Opening is ranked third with 47% of models, followed by Inventory cost 36%, and finally Purchase cost with 33% of models. Meanwhile, reverse costs appear less. The collection costs appear in 14.7%, followed by recycling 13.1%, disposal 13.1%, remanufacturing 9%, recovery 4%, and finally repairing and recovery costs 4%. Emissions cost as the penalty paid by a company that exceeds the allowable limit of GHG emissions (Chaabane, Ramudhin, and Paquet 2012;

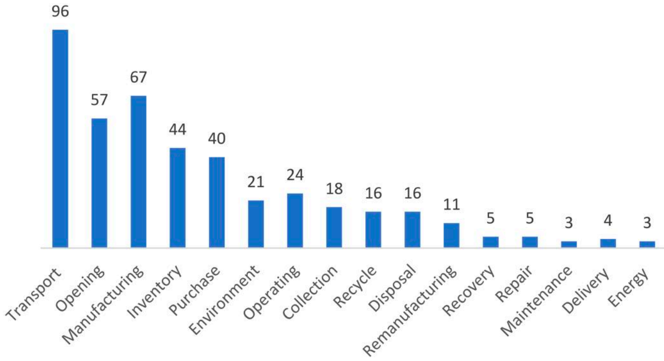


Figure 6. Frequency of costs in SuSC models.

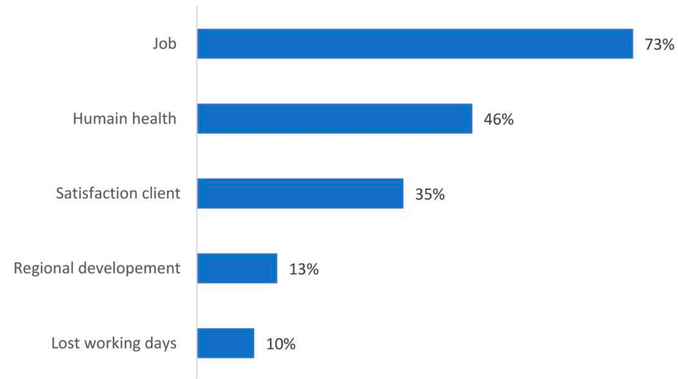


Figure 7. Percentage of appearance of the main social factor.

Table 3. Frequency of environmental factors.

Environmental factors		Number of publications	Percentage
Emissions GHG		75/85	88%
Emissions GHG	Transport	56/75	74,6%
	Manufacturing	40/75	53,3%
	Opening	17/75	22,6%
	Inventory	6/75	8%
	Reverse	17/75	22,6%
Energy consumption		**8/85**	**9,4%**
Water		**6/85**	**7%**
Raw material consumption		**3/85**	**3,5%**
Waste		**3/85**	**3,5%**

Arampantzi and Minis 2017; Zhao et al. 2017; Sarkar, Omair, and Choi 2018; Baghizadeh et al. 2022). The social cost of CO2 emissions presents damage to human health (Tseng and Hung 2014). Finally, there is the cost of waste treatment (Zhang et al. 2014).

3.4.2. Environmental objective

Environmental impacts are included in 93 articles. Table 3 highlights that authors are usually minimising GHG emissions in transport, production, the opening of new facilities, recycling, and disposal. Consumption of non-renewable energy receives less interest, modelled in only 7 papers (Nujoom, Wang, and Mohammed 2018; Papen and Amin 2019; Taleizadeh, Haghighi, and Niaki 2019; Vafaeenezhad, Tavakkoli-Moghaddam, and Cheikhrouhou 2019; Atabaki, Mohammadi, and Naderi 2020; Jouzdani and Govindan 2021; Baghizadeh et al. 2022; Soleimani et al. 2022). Waste and raw material consumption appear in only three articles. (Vafaeenezhad, Tavakkoli-Moghaddam, and Cheikhrouhou 2019) Considering the waste resulting from production, solid waste is minimised in papers by Das, Shaw, and Irfan (2020) and Guo et al. (2021) reducing wastewater and solid waste discharge.

3.4.3. Social objective

Almost half of the articles consider the social dimensions. As can be seen from Figure 7, the creation of fixed and variable job opportunities comes first with 73%. Second, impacts on human health are related to hazardous waste, damage, injuries, disease, and accidents 46%. Third, customer satisfaction in quality or in delivery time 35%, followed by local and regional development 13% and lost working days 10%.

3.5. Modelling dimension

Modelling a SuSC can be classified into deterministic and non-deterministic models. Non-deterministic modelling is related to the uncertain environment of business and end-of-life strategies. Table 4 illustrates different modelling approaches adopted in a SuSC. The most popular mathematical models are mixed integer linear programming (MILP) with 58% of papers. Moreover, five papers present a Fuzzy MILP (Jindal and Sangwan 2017, 2014; Pourjavad and Mayorga 2018; Darbari et al. 2019), two stochastic MILP (Govindan, Jafarian, and Nourbakhsh 2015; Afshari et al. 2016), two possibilistic MILP (Pishvaee and Torabi 2010; Zarbakhshnia et al. 2020), and three robust MILP (Abdolazimi et al. 2020; Gholizadeh et al. 2021; Mohammed, Hassan, and Selim 2021). MIP is adopted in 11% of articles (Kumar et al. 2017; Zhao et al. 2017; Alizadeh Afrouzy et al. 2018; Nujoom, Wang, and Mohammed 2018; Bal and Badurdeen 2020; Vafaei et al. 2020; Yun, Chuluunsukh, and Gen 2020). Some articles also use Fuzzy MIP (Soleimani et al. 2017; Emamian, Kamalabadi, and Eydi 2021) and stochastic MIP (Fathollahi-Fard, Hajiaghaei-Keshteli, and Mirjalili 2018). The mixed integer non-linear programming (MINLP) is considered in 17 papers (Boronoos, Mousazadeh, and Torabi 2021; Farrokhi-Asl et al. 2019; Hasani, Mokhtari, and Fattahi 2021; Lee et al. 2013; Pirnagh, Davari-Ardakani, and Pasandideh 2020; Pishvaee and Torabi 2010; Rabbani et al. 2018; Rahimi, Ghezavati, and Asadi 2019; Shafiee et al. 2021; Sherafati et al. 2019; S.-C. Tseng and Hung 2014; Zhen et al. 2019). Besides, Gao and Cao (2020) developed a stochastic integer non-linear programming (INP). Özceylan and Paksoy (2013), Sarkar, Omair, and Choi (2018) and Tognetti, Grosse-Ruyken, and Wagner (2015) opt for LP.

Findings indicate that the most ill-known parameters are customer demand, return rate, and capacities. The uncertainty related to these parameters is handled differently. The most used methods are fuzzy approaches (Özceylan and Paksoy 2013; Tsao et al. 2017; Balaman et al. 2018; Akin Bas and Ahlatcioglu Ozkok 2020; Govindan et al. 2020; Pirnagh, Davari-Ardakani, and Pasandideh 2020; Khalili Nasr et al. 2021), fuzzy robust (Nayeri et al. 2020), possibilistic (Pishvaee,

Table 4. Distribution of articles by models and uncertainty approach.

Model			Uncertainty approach	
MIP	MIP	14	Fuzzy approaches	17
	FMIP	2	Stochastic approaches	12
	SMIP	1	Robust possibilistic programming	8
MILP	MILP	71	Robust programming	6
	FMILP	5	Possibilistic programming	3
	RMILP	3	Robust stochastic programming	2
	PMILP	2	Probabilistic programming	2
MINLP		17	Chance constrained programming	2
LP		3	Fuzzy robust programming	1
INP		1	Chance-constrained Stochastic Programming.	1
RMCGP		1		
MP + CLP		1	***Total***	***54***

Razmi, and Torabi 2014), robust possibilistic (Pishvaee, Razmi, and Torabi 2012; Rabbani et al. 2018; Atabaki, Mohammadi, and Naderi 2020; Gilani and Sahebi 2020; Boronoos, Mousazadeh, and Torabi 2021) robust programming (Sherafati et al. 2019; Gholizadeh et al. 2021; Hasani, Mokhtari, and Fattahi 2021), robust stochastic (Shafiee et al. 2021), and stochastic (Govindan, Jafarian, and Nourbakhsh 2015; Mota et al. 2018; Rahimi, Ghezavati, and Asadi 2019; Gao and Cao 2020; Moslehi, Sahebi, and Teymouri 2020; Ghasemzadeh, Sadeghieh, and Shishebori 2021; Sazvar et al. 2021). Chance-constrained programming is used in only two papers (Das, Shaw, and Irfan 2020; Gong et al. 2020). According to Nayeri et al. (2020), there are three levels of uncertainty: randomness, epistemic and deep. The authors are focused on the first and the second. Deep uncertainty appears in none of the papers.

Bi-level models propose a process of supplier selection. These two levels of models use multi-criteria decisions making methods. Resat and Unsal (2019) start with the analytical hierarchical process (AHP) method to calculate the efficiency score of each supplier based on indicators such as delivery, quality, and safety. Govindan et al. (2020) calculates weight with fuzzy AHP, determines the dependence with fuzzy decision making trial and evaluation laboratory (FDEMATEL), and calculate the score of each supplier. Tirkolaee et al. (2020) prioritise suppliers with the Fuzzy Analytic Network Process (FANP), DEMATEL, and Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS). Khalili Nasr et al. (2021) evaluate suppliers with the Fuzzy Best Worst Method. Once the selection phase is finished, the second phase related to the optimisation begins.

Among SuSC models, deterministic are the most popular. These models provide a unique solution that can be dramatically different if the parameters or the initial conditions are perturbed slightly. Uncertainty is not considered because the governing parameter is supposed to be known. In practice and when dealing with such a complex problem, we cannot trust the proposed solution because several parameters are not deterministic such as demand and return rate. In contrast, stochastic models use random variables or statistical distributions and lead to a manifold of solutions. This can allow us to evaluate the uncertainty of the system (Renard, Alcolea, and Ginsbourger 2013). Unlike stochastic models, in robust optimisation, the probability distributions of random parameters are not known. It optimises for the worst case within a set of uncertain values (Cuvelier et al. 2018).

Table 5. Frequency of solutions.

Solution	Frequency
EC & versions	23
EC + Fuzzy	1
EC + heuristic	3
WSM	5
NNCM	3
NSGA & versions	7
NSGAII & NRGA	2
NSGAII & MOPSO	4
LP-metrics	2
TH	2
ABDA	2
GP & versions	11
Meta-heuristic	9
Hybrid	11
FA	5

3.6. Solution approaches

Exact, heuristic, metaheuristic algorithms, algorithm hybridisation, and the creation of new methods are different proposed solutions. Table 5 highlights the frequency of solutions. Epsilon Constraint (EC) and variations are the most popular. EC considers a single objective and transforms the other objectives into constraints. Consequently, the economic objective is always taken as the main objective. Meanwhile, environmental, and social become constraints. This method is used as a minimising solution (Pishvaee, Razmi, and Torabi 2012; Zhang et al. 2014; Tognetti, Grosse-Ruyken, and Wagner 2015; Jindal and Sangwan 2017; Rahimi, Ghezavati, and Asadi 2019; Resat and Unsal 2019; Sherafati et al. 2019; Atabaki, Mohammadi, and Naderi 2020) or comparative (Fathollahi-Fard, Hajiaghaei-Keshteli, and Mirjalili 2018; Sahebjamnia, Fathollahi-Fard, and Hajiaghaei-Keshteli 2018; Eskandarpour, Dejax, and Péton 2021; Hasani, Mokhtari, and Fattahi 2021). 9 papers upgrade to augmented EC which gives more efficient Pareto solutions and overcomes the shortcomings of the EC (Roni et al. 2017; Varsei and Polyakovskiy 2017). The improved augmented AUGMECON2 is used by (Rabbani et al. 2018; Vafaeenezhad, Tavakkoli-Moghaddam, and Cheikhrouhou 2019; Bal and Badurdeen 2020; Ghasemzadeh, Sadeghieh, and Shishebori 2021). EC and Augmented EC are used together by Moslehi, Sahebi, and Teymouri (2020) to compare nominal and stochastic approach outcomes. Additionally, the EC is combined with other methods or approaches such as EC and LP-metrics (Nujoom, Wang, and Mohammed 2018), (GP) and (EC) (Chaabane, Ramudhin, and Paquet 2011; Arampantzi and Minis 2017), EC and FA (Balaman et al. 2018; Jiang et al. 2020). Another proposed solution consists of combining EC and the heuristic approach to relax the binary variable and linearise the MILP (Gholizadeh et al. 2021; Shafiee et al. 2021).

The weighted sum model (WSM) (5 papers) allows for expressing the preference for an objective (Chen and Andresen 2014; Colicchia et al. 2016). It is often applied to the EC (Papen and Amin 2019; Abdolazimi et al. 2020; Gao and Cao 2020). WSM is also used with the Weighted Tchebycheff method (WTM) and augmented WTM (Nurjanni, Carvalho, and Costa 2017). Normalised normal constraint is applied by 3 papers (Wang, Lai, and Shi 2011; Bortolini et al.

2018; Gong et al. 2020). LP-metrics method appears in 2 papers (Sadeghi Rad and Nahavandi 2018; Sazvar et al. 2021). 2 papers adopt the Tahiri and Tourabi method (Taleizadeh, Haghighi, and Niaki 2019; Boronoos, Mousazadeh, and Torabi 2021)

The multi-objective evolutionary algorithms Non-dominated Sorting Genetic Algorithm (NSGA) is widely used: NSGAII Geng and Sun 2021), NSGAIII (NoParast et al. 2021), NSGAII and MOPSO (Ehtesham Rasi and Sohanian 2020; Mogale, Cheikhrouhou, and Tiwari 2020; Pirnagh, Davari-Ardakani, and Pasandideh 2020). NSGAII and NRGA (Alizadeh Afrouzy et al. 2018; Pourjavad and Mayorga 2018). Besides, This algorithm is used to validate other methods' results (Emamian, Kamalabadi, and Eydi 2021; Hasani, Mokhtari, and Fattahi 2021). Another powerful evolutionary algorithm named Cuckoo Optimisation Algorithm is proposed by Rezaei and Kheirkhah (2018).

Goal Programming (GP) approaches appear in eleven papers. The classical GP is used by Vafaei et al. (2020) and Yakavenka et al. (2020). Four versions of GP are exploited, Weighted GP (WGP) (Sarkar, Omair, and Choi 2018; Tirkolaee et al. 2020), Weighted fuzzy GP (WFGP) (Darbari et al. 2019), Multi choice GP with utility function (MCGP-UF) (Nayeri et al. 2020), and fuzzy goal programming approach (Khalili Nasr et al. 2021).

As for metaheuristic methods, Emamian, Kamalabadi, and Eydi (2021) solved sample trial simple problems in small, medium, and large sizes with Bee Colony Optimisation Algorithm (BCOA). A modified Multi-Objective Artificial Bee Colony (MOABC) is introduced by Zhang et al. (2016) to solve the optimisation problem with multiple distribution channels. Eskandarpour, Dejax, and Péton (2021) propose a multi-directional local search (MDLS) to solve a bi-objective model. An algorithm based on Simulated Annealing (SA) is used to solve a bi-level program considering upper and lower levels (Kaboli Chalmardi and Camacho-Vallejo 2019). A genetic Algorithm (GA) with multiple scenarios is used by Soleimani et al. (2017) to solve the multi-objective model in a CLSC. Yun, Chuluunsukh, and Gen (2020) suggest a Hierarchical GA (HGA) approach integrating GA for global searches with tabu search for local searches to strengthen the hybrid search capability.

Many authors propose hybrid algorithms. To solve the Multi-objective MILP (MOMILP) model in CLSC, Devika, Jafarian, and Nourbakhsh (2014) propose three hybrid algorithms named Hybrid ICA and Variable neighbourhood search (VNS) (HIV), Two-phase ICA and VNS (TIV), and Nested ICA and VNS (NIV). In the paper, the NIV algorithm proves its dominance. Salehi-Amiri et al. (2021) opt for the hybridisation of several meta-heuristics like Simulated Annealing (SA), Social Engineering Optimiser (SEO), Keshtel algorithm (KA), Hybrid Keshtel and SA (HKSA), and Hybrid Keshtel and SEO to improve problem outcomes. Applying the same approach, Liao et al. (2020) proposed two-hybrid metaheuristic algorithms Hybrid genetic and SA and HKSA (HGSA-HKSA). Govindan, Jafarian, and Nourbakhsh (2019) proposed three hybrid swarm intelligence metaheuristic algorithms hybrid of PSO and VNS (HPV), a hybrid of EMA and VNS (HEV), and a hybrid of ABC and VNS (HAV). Sahebjamnia, Fathollahi-Fard, and Hajiaghaei-Keshteli (2018) developed four hybrid meta-heuristic algorithms based on VNS and GA. Fathollahi-Fard, Hajiaghaei-Keshteli, and Mirjalili (2018) applied a hybrid red deer algorithm (RDA), GA and SA; Hybrid KA, GA and SA and Hybrid RDA, KA, and GA (RDSAGA KAGASA-RDKAGA). The last one provides the best results for small problems. Farrokhi-Asl et al. (2019) developed a new multi-objective hybrid meta-heuristic algorithm with GA and SA (MOHGASA). Compared to NSGA-II, experimentation has proven that this algorithm generates Pareto solutions which dominate 39% of NSGA-II solutions. Hasani, Mokhtari, and Fattahi (2021) propose a novel metaheuristic evolutionary algorithm that combines Strength Pareto Evolutionary Algorithm II (SPEA2) and Adaptive Large Neighbourhood Search (ALNS) for green and resilient (SC) modelling. Govindan, Jafarian, and Nourbakhsh (2015) propose MOHEV which is the hybridisation of two multi-objective algorithms, namely the adapted multi-objective electromagnetism mechanism algorithm (AMOEMA) and adapted multi-objective variable neighbourhood search (AMOVNS). Samadi et al. (2018) use GA and RDA to solve the problem. Afshari et al. (2016) integrate GA and sampling average method (SAM) to solve a closed-loop model. 5 papers adopt (FA) (Pishvaee and Torabi 2010; Tsao et al. 2017; Akin Bas and Ahlatcioglu Ozkok 2020; Gilani and Sahebi 2020; Govindan et al. 2020). Note that several works are solved through the commercial solver CPLEX based on the Branch and Bound algorithm (Mohammed, Hassan, and Selim 2021), Branch and Cut (Yadav, Tripathi, and Singh 2018; Vimal, Rajak, and Kandasamy 2019; Aljuneidi and Bulgak 2020; Jayakumar et al. 2020; Santander et al. 2020).

3.7. Industrial application

Looking at the validation of the proposed models, 59% of models are validated in an industrial setting. Table 6 categorises the articles based on the industry sectors. The agricultural and food sector displayed the highest frequency with 18 works (23%). The second most referenced sector is electronics and electrical representing nearly 17% of total cases, followed by automotive and components (14%) and healthcare sector (11%). It is observed that the agricultural, food, and medical sectors have been gaining more importance in the last three years. This is due to the impact of COVID-19 on food security (Alabi and Ngwenyama 2023) and the increasing demand for medical products. The link between sustainability and resilience increased the number of publications modelling specific structures for food and medical SC. The interest in the electronics and electrical sector can be explained by its negative environmental impacts such as waste, emissions, and toxic chemicals (Elheddad et al. 2021).

4. Towards circular network design

In this section, we investigate the introduction of circularity in the proposed model of SuSC (RQ2). Despite the immense interest that the CE has known in recent years (Lahane, Kant, and Shankar 2020), we have found that quantitative models

Table 6. Industry sectors.

Industry sector	Number of papers
Agriculture and Food sector	18/72
Electronic and Electric Equipment	12/72
Automotive and components	10/72
Health care equipment and supplies	8/72
Biofuel	4/72
Household Durables	3/72
Plastic	3/72
Metals & Mining	3/72
Paper & Forest Products	2/72
Textile	2/72
Containers and Packaging	2/72
Concrete	1/72
Online Services	1/72
Chemical Industry	1/72
Glass Industry	1/72
Sanitary Production	1/72

dealing with circular logistics chains aiming at zero waste are somewhat absent. According to Farooque et al. (2019), a CN is a combination between a closed-loop and an open-loop SC. In doing so, the disposal process is avoided through a collaboration between companies from the same or different sectors. In the sample, few authors are proposing a CN. Jayakumar et al. (2020) introduce the notion of sharing networks where collected products are resold, repaired, or recycled. To manage end-of-life products Vimal, Rajak, and Kandasamy (2019) propose the "manufactures customers" as a part of reverse flow. This layer refers to other companies using returned and collected obsolete products. Vali-Siar and Roghanian (2022) open the loop towards other factories and consider the disposal. Goodarzian et al. (2023) avoid disposing of waste by converting it to worms for soil fertilisation.

As for network stages, ensuring the circularity of materials means integrating other levels into the global SC. In addition to forward and reverse flow, managing efficiently the organization's waste should open this CL flow to other companies. Besides, a supplier as a critical node in the SC is supposed to be selected based on circular criteria.

Morseletto (2020) defines five targets for the CE, design, resource efficiency, reduction, recovery, and recycling. The eco-design approach reduces the consumption of virgin materials and increases their reuse. This practice is considered the key approach for the CE, the product must be designed with materials that can be returned to the environment safely to feed biological processes, or technical materials (Mendoza et al. 2017). In the sample, it was observed that reverse flow is less considered. This can be explained by the difficulty of estimation and control. In this setting, the transition to eco-design eases the strategic management of end-of-life products. In the proposed models in the literature, other than minimising greenhouse gas emissions, environmental impacts are not well covered in the analysed papers. Hörisch et al. (2015) introduces five environmental impacts of companies, greenhouse gas emissions, consumption of raw materials, consumption of energy, production of waste, and withdrawal of water. Therefore, no transition towards a circular flow without enriching the environmental objective with resources energy efficiency, and waste reduction. On the other hand, the social dimension of CE is discussed by many authors. A recent literature review conducted by Mies and Gold (2021) indicates that major social issues are: Employment opportunities, education, and awareness, health and safety, and government involvement. Padilla-Rivera, Russo-Garrido, and Merveille (2020) added eradicating poverty, food security, and gender equity. However, many models supporting sustainability are lacking in the integration of the CE social dimension.

As for models, an important objective is to get the best solutions and reduce the execution time. Consequently, authors try different methods, hybridising heuristics/metaheuristics. However, according to Bengio, Lodi, and Prouvost (2021), these methods remain expensive to compute due to their hard nature and propose Machine learning to decide in a more optimised way. Moreover, Consumer behaviour cannot be deterministic and exact. Uncertainties related to demand influence processes and force the SC to be more flexible (Angkiriwang, Pujawan, and Santosa 2014). Only 40% of the analysed articles consider uncertainty, especially in demand, return rate, and transport cost. Moreover, environmental, and social objectives and constraints generate more uncertainties. Developing a model in the context of a CE increases the complexity of the model and raises uncertainties. Esbensen and Velis (2016) state that an effective transition to a CE is unrealisable without understanding and measuring uncertainty and variability. Hence, the transition towards a CSC model must be done through a non-deterministic approach.

In the CE philosophy, organisations from the same sector or other sectors should be connected to create a circular flow of material where product value is maintained (Govindan and Hasanagic 2018). This means that future research should be developed within real case studies to provide powerful tools for circular flow evaluation.

5. A conceptual framework for the CSuSC

In literature, many works are investigating the interactions between sustainability and circularity (Geissdoerfer et al. 2018; Pieroni, McAloone, and Pigosso 2019). In this section, a conceptual framework is developed to combine sustainability and circularity in (SC) for modelling aims. The proposed model in Figure 8 is a circular structure considering sustainability objectives and CE strategies.

The first component of the framework is the circular flow. The concept adopted from Farooque et al. (2019) combines a CL and an OL to ensure the continuity of material (waste) use. The CL consists of six echelons: source, make, distribute, use, collect, and disassemble. In the last echelon, materials are oriented based on their state. The OL creates an intersection with the rest of the SC to achieve efficient resource use. As for the triple bottom line of sustainability, the proposed objectives are deduced based on the systematic review results and discussion. The economic objective minimises forward, and reverse flow related to facilities and transport costs and maximises profit from selling new and reused products. The economic incentive provides the requisite boost to the circular economy transition plans of the companies. The environmental objective focuses on minimising GHG emissions, raw material extraction, waste, energy, and water in the whole network. This helps the companies in answering both to the governments as well as the stakeholders. The social objective is formulated as indicators grouped under actors, workers, customers, the local community, value-chain players, and society. The actions taken by the companies in both environmental and social sustainability fields help them to prevent any reputational damage to their brand name. Regarding CE strategies, (10 R) is collected from many studies such as (Kalmykova, Sadagopan, and Rosado 2018; Morseletto 2020; Rezvani Ghomi et al. 2021). R1, R2, and R3 should be integrated into the whole network. R4 ensures that materials are redistributed for a second use. R5, R6, R7, and R8 suppose that materials are returned to the manufacturing facility for renewing their capabilities for further usage. R9 and R10 ensure that the waste and extracted raw materials are removed from the products that are at the end of their lives. In sourcing and making levels, the eco-design is adopted to anticipate end-of-life strategies and ease the orientation during the disassembly. Uncertainty is present in the whole network. The organisations must ensure that their strategic and tactical decisions related to the complete supply chain follow the tenets of a circular sustainable supply chain.

6. Directions for future research and implications

6.1. Directions for further research

This section highlights various observed shortcomings in current literature regarding sustainable (SC) modelling in forward, reverse, and closed-loop flow. A systematic review of sustainability modelling approaches is conducted to orient the transition towards CSuSC modelling. In light of our discussion of the sample, some crucial gaps have been identified and synthesised as follows (RQ3). Avenues of research are summarised in Table 7 according to analysis dimensions and identified clusters.

According to Geissdoerfer et al. (2017), researchers focus on the environmental benefits of a CE rather than developing CE practices for social well-being. The social dimension of CE concerns workers, customers, the local community, society, and value-chain players (Walker et al. 2021). In current literature, few works consider indicators for the last three actors. Modelling within the CE context calls for the development of a social assessment tool for each actor. This gap could address the questions (R1.1) and (R1.2) in Table 7. According to Lu, Zhao, and Liu (2022), industry 4.0 influences positively the social dimension of CE by increasing safety, job satisfaction, and opportunities. Therefore, updating the knowledge of social indicators is required.

The environmental dimension in the CSuSC should incorporate environmental sustainability objectives and CE strategies. As mentioned before, the current literature focuses on the minimisation of GHG emissions rather than reducing the consumption of resources. This shortcoming can be handled through the adoption of the 10Rs of CE. To do so, the design should incorporate a CLSC and an OLSC to achieve efficient resource use. Moreover, opening the loop will create intersections with other supply chains. This will enhance the efficiency of resource use (improve waste management and take advantage of recycled material as inputs) but it can

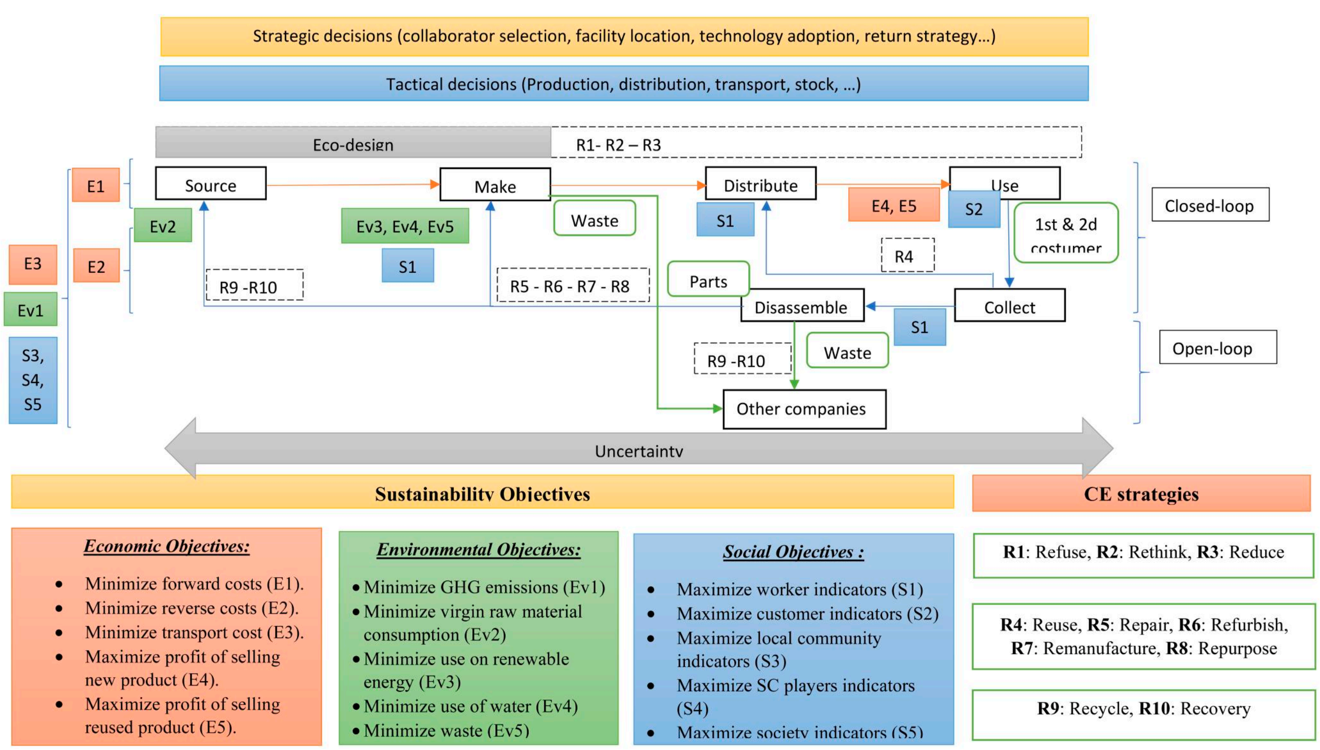


Figure 8. Conceptual framework for the integration of CE strategies (10 R) into the SuSC.

Table 7. Research avenues.

Area of gaps	Research gaps	Research questions
Sustainability optimization objectives	• There is a need to develop indicators for each actor in the social dimension. • Future research could focus on the integration of eco-design in models to manage end-of-life products and predict the reverse flow of material. • Identify and model environmental impacts that can be mitigated through the circular flow without appearing in the environmental objective. • Require collaborating with sustainable partners in the models. • There is a need to enrich economic function by costs generated through the adoption of CE.	R1.1 What are the indicators of social performance for each actor? R1.2 How social practices of each actor can be introduced in optimization models? R1.3 Which technical strategies to integrate eco-design in optimization models? R1.4 What criteria for supplier selection to perform eco-design? R1.5 How circular flow could minimize environmental impacts in optimization models? R1.6 How to select the optimal partner to manage waste? R 1.7 How can CE adoption influence global cost?
Modeling dimension	• Develop new tools based on artificial intelligence to predict uncertain parameters. • There is a need to move toward an interconnected system where decision-making tools are integrated.	R 2.1 Which artificial intelligence tools can be used to improve solution quality and minimize uncertainty? R 2.2 How can the decision-making tools of partners be integrated?
Industrial application	• Apply and validate the optimization models in the global (SC) combining many companies to reach zero waste.	R 3.1 Which sectors are interconnected to achieve zero waste? R 3.2 Which criteria for partner selection to improve sustainability and circularity?
Conceptual framework	• Validate and expand the proposed framework. • Integrate resilience as an important factor for (SC) sustainability and circularity. • Introduce Industry 4.0 elements such as: IoT, Blockchain, and Big Data.	R 4.1 Is the current proposed conceptual framework adaptable to all sectors? R 4.2 Which resilience factors influence sustainability and circularity in optimization models? R 4.3 Which relation between 10R and industry 4.0 technologies? R 4.4 How can Industry 4.0 influence sustainability objectives?
CE & network design	• Scarce research focused on (CE) enablers for sustainable production. • There is a need to increase the resilience of the circular network.	R 5.1. How can multi-objective optimization include CE practices during the manufacturing process? R 5.2 Which techniques to build a resilient and circular network?
Intertwining	• There is a need to investigate the impacts of intertwining on circularity. • Investigating the ability of intertwining to improve the sustainability of the whole network. • Modeling an ISN where supply chains are achieving zero waste.	• R6.1: How can intertwining impact the circularity of materials? • R6.2: How can intertwining impact the sustainability of supply chains? • R6.3: Which tools can be employed to model an ISN incorporating CSCs?

reduce the environmental performance (GHG emission) if the collaboration is established with companies operating unsustainably. Hence, models should incorporate other constraints or levels to ensure the selection of the right partners. To investigate this area of research, we propose (R 1.5 and R1.6).

In the context of a CE, the reverse flow remains critical. In the food sector, the adoption of CE focuses on managing waste instead of avoiding waste generation (Lopes de Sousa Jabbour et al. 2021). Eco-design is seen as an anticipative strategy that ensures efficient control and management of end-of-life products. Prieto-Sandoval et al. (2018) state the importance of innovation in product design. A circular process starts with a well-developed product. Circular product design aims to slow and close the resources loop by assigning extension to product-life (Burke, Zhang, and Wang 2021). Integrating the eco-design in models seems to be a gap in the literature that calls for more research (R 1.3). For the bi-level model, this approach will add other criteria to the supplier selection process (R 1.4). A CF is supposed to reuse end-of-life products of the same company or exploit waste from another company to keep product value as long as possible.

The implementation of CE in SC generates new costs such as investment costs, redesigning costs (Govindan and Hasanagic 2018), and partnership costs. The development of a new design that fits the circularity model has inherent costs associated with it. It also requires investments in changing the machines that can produce the new designs. As the CE markets are not mature, it is very difficult to get suitable partners. Companies have to work with limited partners, and it entails higher partnership costs. These costs should be optimised and controlled (R 1.7).

Modelling and solving approaches are interesting fields of research. The integration of the machine learning algorithm and operation research domain is a promising combination that can improve the solution. Additionally, another apparent shortcoming of the considered literature is the consideration of uncertainties. The use of artificial intelligence tools with learning ability could lead to better results with the prediction of uncertainty parameters. This path can be investigated by responding to the question (R

2.1). Further, a partnership among sectors could lead to a global system combining different CSCs. Integrated decision-making tools may increase visibility and information sharing (R2.2).

A further gap is related to the validation of models through a real case study. Most studies in the field are tested on a numerical example. These numerical examples cannot reflect reality since data is generated randomly. The model must be dedicated and applied in a specific sector to ensure a practical integration in companies of the same sector. This gap is further aggravated by the limited number of sectors which seems to be restricted to four or five main ones. Collaboration among related companies in the global SC could lead to achieving zero waste. Therefore, the case study chosen for validation should combine many companies from the same or different sectors. In doing so, a process of selection based on criteria should be implemented to evaluate partners in the open loop (R3.1 and R3.2).

Future research can expand the proposed framework to integrate industry 4.0 elements. At present, the business model and manufacturing system should adapt to new dynamic systems (Hennelly et al. 2020). The literature supports the positive impact of Industry 4.0 enablers on CE and sustainability (Rajput and Singh 2019; Fatorachian and Kazemi 2021; Papadopoulos et al. 2022). Industry 4.0 supports the transition towards CE (Kamble and Gunasekaran 2021) and overcomes associated risks (Kazancoglu et al. 2021). In this respect, organisations are employing several technologies to deal with changing environmental requirements (Wamba and Queiroz 2020). These technologies could improve the performance of sustainable objectives and perform the 10Rs of circularity more efficiently. As such, Big Data analysis could improve environmental performance (Papadopoulos et al. 2017; Belhadi et al. 2021) and IoT addresses issues like improving green aspects and managing inventory (Hughes et al. 2022). Scholars can investigate the introduction of IoT, Big Data, and blockchain in the conceptual model (R 4.3 and R 4.4). Further, the conceptual framework can also be enriched with resilience elements. According to Negri, Cagno, and Colicchia (2022), sustainability and resilience should be developed simultaneously. As a dynamic capability, resilience has a significant positive effect before and after disturbance (Altay et al. 2018). The occurrence of unexpected events influences the continuity of operations. Hence, resilience objectives have to be integrated with the optimisation model (R4.2).

CE paradigm is usually related to circular flows where the value of obsolete products is supposed to be maintained. This is ensured through various Rs (Reuse, Repair, Refurbish, Remanufacture, Repurpose, Recycle and Recover). The same has been the focus of academic studies as well. However, CE also aims to maximise the use of resources during the production process. The literature has not shed enough light on improving the production process in CE models to ensure maximisation of resource use. These areas in the optimisation model have yet to be advanced (R 5.1).

According to Park et al. (2021), CNs are vulnerable to suffering deeply during the disturbance period. The ripple effects caused due to disruptions have a greater impact on the CNs as compared to non-circular supply chains. In other words, CFs are hidden as a potential danger that could influence all partners. This could have a much greater impact on the network if it is not resilient and may cause its collapse. Hence, designing a CF under sustainability objectives should first develop a resilient structure (R5.2).

Different interconnections and intersections have led to forming the intertwined supply network (ISN). Such complex networks increase collaboration between supply chains. This can enable SCs to improve the efficiency of resource use through collaborative management which will impact the sustainability of the whole network. The impact of intertwining on circularity and sustainability is a potential area of research (R6.1, R6.2). Since circular and sharing economies increase the intersections between supply chains, conceptual frameworks for ISN modelling should be developed to guide the transition towards modelling a sustainable ISN to achieve the CE goal (R6.3).

6.2. Theoretical and practical implications

This study contributes to the literature in SC management and sustainability fields. The paper analyzes open-loop and closed-loop models under sustainability objectives. The objective is to identify key elements to transition from linear to circular flows. The outcomes offer academic support to improve circularity in SC modelling. Namely, the proposed framework offers a better understanding to develop a circular model under sustainability objectives. A graphical representation is employed to combine elements for modelling. Scientifics can build a decision-making tool based on the proposed framework. Researchers can analyse this framework and indicate whether it is adaptable to all sectors or not (R 4.1). In this study, economic, environmental, and social goals are deeply studied. Therefore, researchers can detect missing factors and enrich objective functions. Another important contribution is related to solving methods. This study proves that authors are looking for more reliable methods to solve such complex models. Thus, researchers in the mathematical and informatics areas are invited to develop new tools to improve solution efficiency.

In practice, the outcomes of this study can guide managers to move towards CSuSC. The proposed framework helps to design a SC ensuring sustainability and circularity goals. Moreover, it underlines the necessity to integrate the process of selecting partners for the OL into the models. This can drive decision-makers to host empirical studies aiming to develop decision tools for partner selection and updated sustainability assessment tools. Managers can use the findings to assess the way they integrate sustainability into their SC design and enhance it.

7. Conclusion

The purpose of this paper is to identify missing elements in SC design needed for a successful transition from a linear to a circular flow under sustainability objectives. The 122 collected papers are studied in view of three research questions. The first research question (RQ1) focuses on analysing available literature on SuSC design in different flows. In this regard, network stages, modelling methods, solution approaches, and industrial applications are studied. The second research question (RQ2) investigates the circularity of the proposed models and evaluates their ability to support CE principles, strategies, and practices. The third research question (RQ3) constitutes a combination of both previous questions and provides elements that call for more research in the way of a global circular flow.

The findings of the review reveal that the CLSC dominates meanwhile very few authors model a CN. For the objectives, we noticed an increasing interest in the social pillar in recent years limited usually to job creation. The economic goal joins environmental benefits or costs to operational costs. In contrast, reverse costs need more interest from the researchers. The environmental objective is usually expressed in terms of GHG emissions. The resolution phase generates several methods, combined, or improved. Half of the work has been tested in real cases, in food, electronics, automobiles, medical, and others.

An important contribution of this paper is the development of a conceptual framework for a CN under sustainability objectives. The proposed model is a result of this review and other works in the literature.

Directions for further research recommend extending the integration of social and environmental objectives to cover many aspects of sustainability and circularity. Plus, this study suggests the adoption of eco-design, consideration of uncertainty, and improvement of quality solutions through the adoption of artificial intelligence tools. The industrial application of the proposed model should encompass multiple organisations of the global SC and related companies to ensure a circular flow of materials. The contribution of this study is essentially related to the development of a conceptual and then mathematical model for CSuSC optimisation.

The outcomes of this systematic review could help researchers to point out the needed elements to design a CSuSC. It is intended to open new areas for research. The paper results should encourage decision-makers to contribute, collaborate, and embrace research projects to validate the proposed models.

The limitation of this search is related to the selection criteria. We excluded articles in languages other than English, conference articles, and book chapters. In doing so, we point out to investigate high-quality models. Additionally, even if we extend keywords to synonyms, related terms, and variations, other keywords might not be included. Moreover, only three databases are interrogated. Hence, we may have missed other papers published in other scientific databases. Plus, we only considered mathematical models, and we did not study the constraints of the models. Future research can study the design of the SC considering the resilience paradigm. Based on the promising findings presented in this paper, the next stage of our research will be to develop a design for a CSuSC.

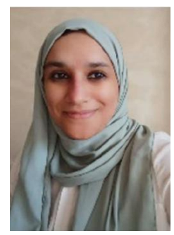
Note

1. https://www.pbs.org/newshour/world/climate-change-is-already-disrupting-the-global-supply-chain-heres-how/accessed date June 07, 2022.

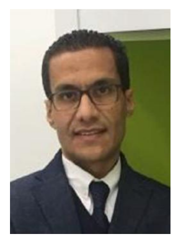
Disclosure statement

No potential conflict of interest was reported by the author(s).

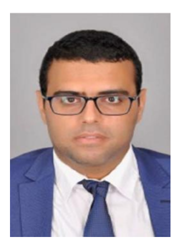
Notes on contributors



Khadija Echefaj is a research scholar at the Laboratory of Innovation and Industrial Management of Hassan First University of Settat –Morocco. Her research interest include sustainability, circular economy, survivability of supply chains, interwining, industry 4.0/5.0, digital twin and Artificial intelligence.



Abdelkabir Charkaoui PhD in Logistics & SCM. Professor in Hassan 1st University, Faculty of Science and Technology - Settat, Morocco. Department of Mechanical Engineering, Laboratory Industrial Management and Innovation (LIMMII). He is the Editor-in-Chief of Journal of Operations Management, Optimization and Decision Support (JOMODS) and the team leader of Operational Management and Supply Chain. Research interests are in operations management, logistics performance, maturity of Lean Manufacturing, supply chain resilience, sustainability and circular economy.



Anass Cherrafi is an Associate Professor at EST-Safi, Cadi Ayyad University, Morocco. Holding a Ph.D. in Industrial Engineering, he has nine years of industry and teaching experience. In 2022, Anass Cherrafi has received the Moroccan Scopus award from the ministry of higher education, CNRST and Elseiver as the first research in Morocco in "Business, Management, and Accounting". He has published a number of articles in leading international journals including Production Planning and Control, International Journal of Production Research, International Journal of Production Economics, Business Strategy and the Environment, Journal of Cleaner Production and many others. He has been a Guest Editor for special issues of various international journals. His research interests include Industry 4.0/5.0, Green manufacturing, Circular Economy, Lean Six Sigma and Supply Chain Management.

Sunil Tiwari is an Associate Professor of Supply Chain Management, in the Operation Management & Decision Science Department at ESSCA School of Management. His research revolves around the areas of Supply Chain and Inventory Management, Healthcare Operations, Warehouse Operations Analysis and optimization, E-commerce Logistics, and Simulation-Based Optimization. He has published articles in various international journals of repute such as the *European Journal of Operational Research, International Journal of Production Economics, International Journal of Production Research, Transportation Research Part E, Computer & Operations Research,* *Computers & Industrial Engineering, Annals of Operations Research, Journal of Cleaner Production, IEEE TEM*, and others.

Pankaj Sharma is a Senior Lecturer of Supply Chain Management, at the School of Business, University of New South Wales, Canberra, ACT, Australia. His research revolves around the areas of Asset Management, Logistics and Supply Chain Management, Humanitarian Logistics, Spare parts supply management. He has published articles in various international journals of repute such as the *International Journal of Production Economics, Transportation Research Part E, Reliability Engineering & System Safety, IEEE TEM*, and others.

Charbel Jose Chiappetta Jabbour is a Head of the Information Systems, Supply Chain Management & Decision Support Department and Professor of Green, Circular, and Responsible Supply Chains at NEOMA Business School, France. He is one of dozens of French-based scholars to have been included in the prestigious Clarivate/Web of Science Highly Cited Researcher awards due to having multiple articles ranked among the top 1% of most cited papers globally. His international career includes both teaching and research in Latin America (Brazil), Asia (Japan), and Europe (Scotland, England, and France). He has published articles in numerous top-tier journals according to a wide range of rankings. In 2019, he received a British Academy of Management best paper award in Responsible Management (BAM Conference). He has been an Associate Editor at the Journal of Cleaner Production. He was one of the youngest academics in the history of the University of Sao Paulo (USP) to receive Habilitation in Management. He has served as PI/Co-I of a number of large-scale externally funded research projects, including Innovate UK, Midlands Engine UK, and FAPESP. He has supervised dozens of early-career researchers, both PhDs and post-docs. Charbel Jose is passionate about the application of the latest research in his teaching in the pursuit of creating more responsible future business leaders.

ORCID

Charbel Jose Chiappetta Jabbour http://orcid.org/0000-0002-6143-4924

Data availability statement

The data that support the findings of this study are available on request from the corresponding author.

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