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Evolution and modeling in sustainable supply chain management research

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Abstract

Numerous researchers and practitioners are attracted to sustainability in supply chains (SC_S) and it has become one of the favorite topics among academics and industries. The purpose of this paper is to review and analyze the research studies that have been published in the field of sustainable supply chain management (SSCM). A total 242 articles published between 2000 and 2019 reviewed. Content analysis and descriptive analysis were applied in order to analyze the modeling approaches, evolution of models and methodologies, as well as sustainability metrics. The content analysis in terms of modeling approaches is based on analytic categories that provided by Brandenburg et al. (2014). The present study identified gaps and potential opportunities in SSCM to develop knowledge. The results indicate that methods such as genetic algorithm, nonlinear programming, goal programming, dynamics programming are less used by researchers. The multi-criteria decision making (MCDM) technique has the most application in the field of SSCM research. Researchers are more inclined to use analytical and mathematical models. The sustainability metrics with the highest frequency include "energy consumption", "cost", "health & safety".

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1. Introduction

Nowadays, competition is oriented from the level of companies to the competition among their SC_S (Ketchen and Hult 2007). Supply chain management has become an important tool for increasing economic performance and cost control(Hong, Zhang, & Ding, 2018). Sustainability is a new and highly effective topic in the supply chain which is recently attracting the attention of SCM researchers. Due lot of pressure from different stakeholders, especially non-government organizations (NGO_s) government regulators, global competition and community activists, a lot of companies have accepted a surface of obligation to sustainability practices. A number of these obligations are non-compulsory and superficial (Searcy et al., 2009). Porter & Kramer (2002) stated that companies persist on integrating the concept of sustainable development into the supply chain management designs to achieve sustainable development. Sustainable supply chain management is resulting from composition of supply chain management and sustainable theory (Hong et al., 2018; Signori, Flint, & Golicic, 2015).

Recently, implementing sustainable practices in the supply chains is not voluntary act. However, the use of sustainable practices in the supply chains is the essential for organizations and companies to achieve competitive position. Implementing SSCM practices will reduce costs and improve product quality (Zailani et al., 2012), promote the economic performance and environmental performance and eliminate waste (Esfahbodi et al., 2017), prevent waste generation and create innovation for new and eco-friendly products and services (Gunasekaran & Spalanzani 2012), help retain the position of leading in companies and improve Profitability (Hong et al.,2018).

There is a requirement for a greater recognition and understanding of the modeling aspects, metrics and research methodologies, etc., in SSCM to help accelerate and facilitate future research in this area and the present article made substantial contribution in this regard. A number of literature reviews have been conducted in sustainability and SCM but a shortage of studies in the field of classifying the articles and reviewing the literature on SSCM is felt.

For instance, Brandenburg et al., (2014) focused on quantitative models in SSCM. Beske-Janssen et al., (2015) and Taticchi, et al., (2013) focused on performance measurement in SSCM and Ahi & Searcy (2013) identified definitions of SSCM and GSCM. Seuring (2013) reviewed the modeling approaches in SSCM. Gold et al., (2010) focused on the case studies in the field of SSCM. The main objective of present paper is to analyze quantitatively and qualitatively the content of articles. The analysis is aimed to identify sustainability metrics, modeling approaches, etc., in SSCM. The other sections in this paper are presented as follows: The second section provides a summary of previous literature reviews in the field of SSCM. The third section contains purposes and questions. Section 4 describes the research methodology and its procedures. In the Fifth section, the analysis and the results of the selected articles are fully expressed. In Section 6, the findings and the research gaps are identified, and the research directions and limitations are discussed, and finally section 7 presents the conclusion.

2. previous literature Reviews on SSCM

By searching in valid databases and journals, we found that 15 articles reviewed on SSCM literature, which mainly evaluate the topics in the field of SSCM.

The literature review was evaluated with the following specific specifications:

1. Number of reviewed articles
2. Time horizon
3. Research methodology
4. Research objectives
5. Author(s) and year

Research in the field of sustainable supply chain management has increased over the last decade and gaining large attention from academic community. Hence, some literature reviews are conducted in the field of sustainability and supply chain management. However, a shortage of studies in the field of classifying articles and literature review on sustainable supply chain management is felt. Many studies either focus on one particular aspect or some special aspects. Thus, there is no comprehensive literature review in this field.

For instance, Brandenburg et al., (2014) focused on quantitative models in SSCM. (Beske-Janssen et al., (2015) and Taticchi, et al., (2013) focused on performance measurement in SSCM and Ahi & Searcy (2013) focused on GSCM and SSCM definitions. Winter & Knemeyer (2013) dealt with integration of sustainability in supply chain management. Seuring (2013) reviewed the modeling approaches in SSCM. Gold et al., (2010) focused on the case studies in the field of SSCM.

Hassini et al., (2012) reviewed literature in the field of sustainable supply chain management with a focus on metrics, and Ahi & Searcy (2015) conducted an analysis on performance measurement metrics in green supply chains and sustainable supply chains. Each of the above mentioned articles consider a particular dimension in the field of SSCM. The existence of a literature review that simultaneously focuses on different dimensions is limited. Therefore, it is necessary to conduct classification of papers and a comprehensive literature review in sustainable supply chain management. Thus the present study seeks to bridge this gap and efforts to identify numerous opportunities for improving and extending knowledge in sustainable supply chain management.

Table 1. A brief overview of the literature review since 2008 onwards in SSCM

source	Time horizon	Number of papers	Methodology used	objectives
Ardian Qorri et al (2018)	2005-2018	104	Literature review and 5 step process by Tranfield et al (2003)	The purpose of this study is to analyze, classify and synthesize performance measurement approaches in SCCM research.
Sauer & Seuring (2017)	2007-2015	67	The literature review based on content analysis (Mayring 2010)	This paper Purposes to review studies in SSCM for minerals. They also recognize knowledge gaps and provide suggestions for future studies.
Rejeev et al (2017)	2000-2015	190	The literature review based on content analysis (Mayring 2003)	This article aims to investigate and analyze the evolution of sustainability in supply chains, as well as analyze trends in different industries and methodologies and economies.
Ansari & Kant(2017)	2002-2016	286	The literature review based on content analysis (Mayring 2002)	This article aims to review studies in SSCM and determine the current status of the research conducted through analysis and classification.
Beske et al (2015)	1995-2015	140	A systematic literature review	This article aims to fill the knowledge gap by a systematic literature review on research conducted regarding the measurement of sustainability performance in
Brandenburg et al., (2014)	1994-2012	134	The literature review based on content analysis (Mayring 2002،2008)	This article Purpose to review the literature in the field of SSCM with a focus on mathematical models.
Ahi & Searcy (2015)	1989-2012	445	The literature review based on content analysis	The aim of this article is to recognize and analyze performance measurement metrics in SSCM and GSCM.
Winter & Knemeyer (2013)	1995-2010	456	Literature review and 6-step process by Soni & Kodali (2011).	The aim of this article is to investigate the present status of studies in SSCM and they also identify potential opportunities for academic research in the field of sustainability in SC.
Stefan Seuring (2013)	1997-2010	36	The literature review based on content analysis	This article aims to summarize existing papers on quantitative models in the field of SSCM and they also propose research directions for future research.
Paolo Taticchi et al (2013)	2002-2012	205	The literature review based on Citation/co-citation analysis	This article Purposes to review studies pertaining to performance measurement in SSCM and they also provide suggestions for future research.

Ahi & Searcy (2013)	2002-2012	56 articles for SSCM and 124 articles for GSCM	The literature review based on content analysis	This article aims to recognize the presented definitions of SSCM and GSCM. Twenty-two definitions of GSCM and Twelve definitions of SSCM have been identified for definitions analysis.
Hassini et al (2012)	2000-2010	87	literature review	This study aims to review literature in the field of SSCM within a 10-year time process and they also propose a conceptual framework in this field.
Carter & Easton (2011)	1991-2010	80	A systematic literature review	This study aims to conduct a literature review in SSCM during the 20-year process.
Gold et al (2010)	1994-2007	70	The literature review based on content analysis (Mayring 2003)	The aim this paper is to assess the literature all case studies in the SSCM and evaluating the area of current SCM issues.
Seuring & Muller (2008)	1994-2007	191	The literature review based on content analysis (Mayring 2003)	This study aims to review the literature related to SSCM and they also provide a conceptual framework in this field.

3. Objectives and questions

The aim of this study is to conduct a systematic literature review in SSCM through collecting and extracting data, classifying, analyzing, explaining and interpreting the results. This article answers the following questions through content analysis:

1. Which industries have been more considered by researchers in the field of SSCM?
2. Which TBL metrics have been employed to measure sustainability?
3. Which models, techniques, and solutions have been employed for modeling in sustainable supply chains?
4. How is the evolution of models based on the model type and model technique in SSCM research?
5. Which research methods have been used by researchers in the field of SSCM?
6. How is the evolution of research methods in SSCM research?
7. Which data analysis techniques have been broadly used in SSCM research?
8. What are the research gaps and opportunities in SSCM research?

4. Methodology

The present research is based on the systematic literature review for answering research questions.

4.1. Content analysis

The systematic literature review in the present study consists of qualitative content analysis and four steps proposed by Mayring (2003) (Ansari and Kant 2017; Brandenburg et al., 2014; Gao et al., 2017; Seuring and Müller 2008; Gold et al., 2010; Rajeev et al., 2017; Sauer and Seuring 2017).

Steps of content analysis according to the model proposed by Mayring 2003 are as follows:

Step1. Material collection: at this step, the material is prepared and collected for analysis, and the analysis unit is defined.

Step2. Descriptive analysis: A descriptive analysis is performed to assess formal aspects and characteristics. The results of descriptive analysis provide a basis for content analysis.

Step3. Category selection: structural dimensions and analytic categories are chosen which analytic categories are to be applied for content analysis of collected material.

Step4. Material evaluation*:* The collected materials are analyzed based on structural dimensions and selected analytic categories and the results of the analysis are discussed and interpreted.

4.2. Material collection

The process of searching articles was conducted on databases such as Elsevier, Emerald, Springer Link, Wiley, IEEE and Taylor & Francis in the present research. The review process was started with advanced

search the title, abstract, and keyword with keywords such as “sustainable supply chain,” “sustainability,” “supply chain,” “social,” “environmental,” “Economic”. Numerous articles were obtained in the initial search. This paper investigated all the searched articles in terms of inclusion and exclusion criteria and finally, 242 articles were selected for analysis among the searched articles.

Inclusion and Exclusion Criteria:

1. The articles should be written in only English language and published between 2000 and 2019.
2. The articles should be relevant to sustainability topics and their dimensions in the supply chain.
3. The articles should focus only on the forward supply chain, and articles focusing on remanufacture and reverse logistics were not considered.
4. The articles were considered with management topics and articles with non-management topics such as math, technical, political, medical, etc., were excluded from the analysis.
5. The technical reports, working papers, market reports, news reports, book chapters and industry reports were excluded from the analysis.

4.3. Category selection

There are two inductive and deductive approaches in content analysis to select the type of data classification system. In the deductive approach, the codes (dimensions and categories) are defined and selected before the analysis of the materials. In the present study, a deductive approach was used to select analytic categories and structural dimensions before the analysis of the materials. Table 2 shows the dimensions of the structural and analytic categories. Sustainability dimensions were selected deductively according to modeling dimensions (e.g. model type, model technique and solution approaches) deduced from Brandenburg et al., (2014), and the research methodology derived from Rajeev et al., (2017); Seuring (2008); Winter and Knemeyer (2013). The analytic categories and structural dimensions ensure the validity of the paper's structure through the deductive approach.

Structural dimensions		Analytic categories/ Description
Dimensions of sustainability metrics		Environmental metrics, Social metrics, Economic metrics
Modeling dimension	Modeling technique	MCDM, systemic, game theory, artificial intelligence, meta-heuristic, multi-objective, discrete-event simulation (DES), system dynamics
	Solution approaches	DEMATEL, TOPSIS. mixed integer linear programming/linear programming (MILP/LP), data envelopment analysis(DEA), analytic network process/Analytic hierarchy process (ANP/AHP), life cycle analysis(LCA), genetic algorithm(GA), fuzzy logic, input–Output analysis(IOA), rough set Theory, Grey Theory, nonlinear programming/mixed integer nonlinear programming(NLP/MINLP), dynamic Programming/nonlinear dynamic programming(DP/NLDP), variational inequality(VI), goal programming(GP), balance score card(BSC) etc.
Research dimension	Research methodology	Model, literature review, survey, case study, conceptual/theoretical
	Industry sector	Automotive/automobile, apparel, food, electric/electronic, pharmaceutical, energy, agriculture, computer, communication, furniture, paper etc.

Year	Analysis from 2000 to 2019
data analysis techniques	sensitivity analysis, descriptive analysis, factor analysis, content analysis, Structural equation modeling (SEM), regression analysis, etc.
Evolution of the modeling techniques	Analysis of model evolution based on model techniques
Model evolution	Analysis of model evolution based on model type
Evolution of the research methodology	Analysis of the research methods evolution

5. Analysis

This section presents the analysis of the peer-reviewed articles in terms of characteristics and formal aspects. To this purpose, Tables and figures are presented for each structural dimension for the better understanding of results.

5.1. Analysis and classification of SSCM studies according to year of publication

Figure 1 indicates the frequency distribution of 242 reviewed papers based on the year of publication.

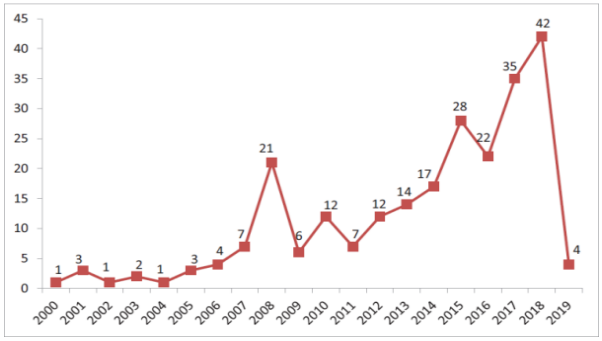

Figure 1. Distribution of reviewed articles over time

Sustainable SCM is a relatively young and increasingly growing research field. The robust growth of studies in the field of SSCM is illustrated by the time distribution of the reviewed articles. More than 74.8% of published papers in SSCM were published within the last nine years. The process of search was accomplished only in the beginning in 2019, so the number of reviewed papers in 2019 is less.

5.2. Analysis and classification of SSCM studies according to the applied research methodologies

Research methodology is divided into five main categories, including model, survey, literature review, case study, conceptual/theoretical. Figure 2 indicates the frequency distribution of articles according to the research methodology.

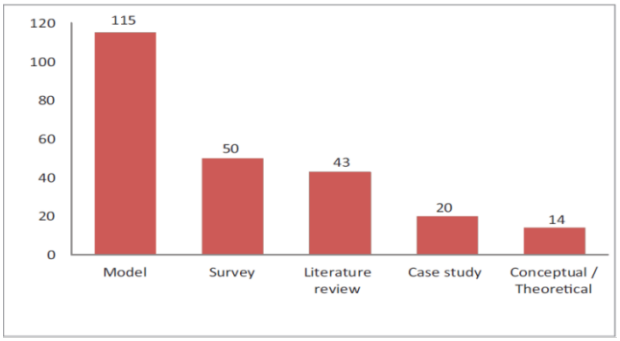

Figure 2. Distribution of reviewed articles according to research methodology

"Model" is the most common research method employed by researchers with 115 papers. "Survey" is the second most common method applied with 50 papers and "Literature Review" is ranked the third research methodology in studies with 43 papers. "Model" methodology accounts for approximately 47.5% of the applied research methods in studies.

5.3. Evolution of research methodology from 2000 to the end of 2018

Table 3. indicates the evolution of research methodology from 2000 to the end of 2018 in the field of SSCM.

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Model	1	3		1	1	1	2	2	7	3	5	4	4	7	8	18	11	15	20
Survey			1	1		1	1	1	3		3	1	3		3	2	7	9	14
Literature review								1	3		1		3	6	4	8	2	10	4
Case study						1	1	1	6	2	2		1	1	1		2		2
Conceptual / Theoretical								2	2	1	1	2	1		1			1	2

The evolution of research methodology indicates that the modeling approach was increasingly conducted from 2000 to the end of 2018, and in the last four years, modeling approach was intensely used by researchers. The survey methodology was also incrementally employed by researchers, such that researchers further used this method in 2017 and 2018. The evolution of research methodology indicates that conceptual/theoretical articles were less conducted and the number of literature review articles in SSCM has been increased in recent years.

5.4. Analysis and classification of SSCM studies according to the type of model

Figure 3 illustrates a summary of the frequency of types of models used by researchers in the field of SSCM research. The classification of different types of models is derived from Brandenburg et al., (2014).

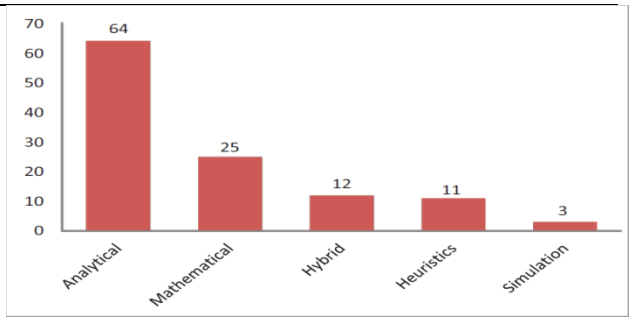

Figure 3. Distribution of reviewed articles according to type of model

Analytical models (64 papers) account for almost 55.6% of the models used by researchers in the sustainable supply chain, followed by mathematical models with 25 papers, hybrid models with 12 papers, Heuristic models with 11 papers and simulation with 3 paper. As seen in figure 3, Simulation models were less used by researchers.

5.5. Evolution of models based on model type from 2000 to the end of 2018

Table 4 indicates the evolution of models based on the type of model for the time period 2000 to the end of 2018 in the field of SSCM research.

Table 4. Evolution of models according to model type over time in SSCM research

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Analytical		1		1	1	1	1	2	4	1	2	2	2	5	5	7	6	10	12
mathematical							1		2	2	1		1	1	2	5	2	1	7
Heuristics		2									2	1	1	1		3		1	
hybrid	1								1			1			1	3	2	3	
Simulation																	1		1

The results of analysis indicate that the analytical models have been utilized from 2001 onwards and the use of analytical models is on the rise, so that in the last two years, analytical models have been used by researchers with 22 articles. The results indicate that mathematical models have been used in research from 2006 onwards and the use of mathematical models has been increased in year 2018.

5.6. Analysis and classification of SSCM studies according to the model technique

Figure 4 indicates a summary of the frequency of model techniques used by researchers in SSCM research.

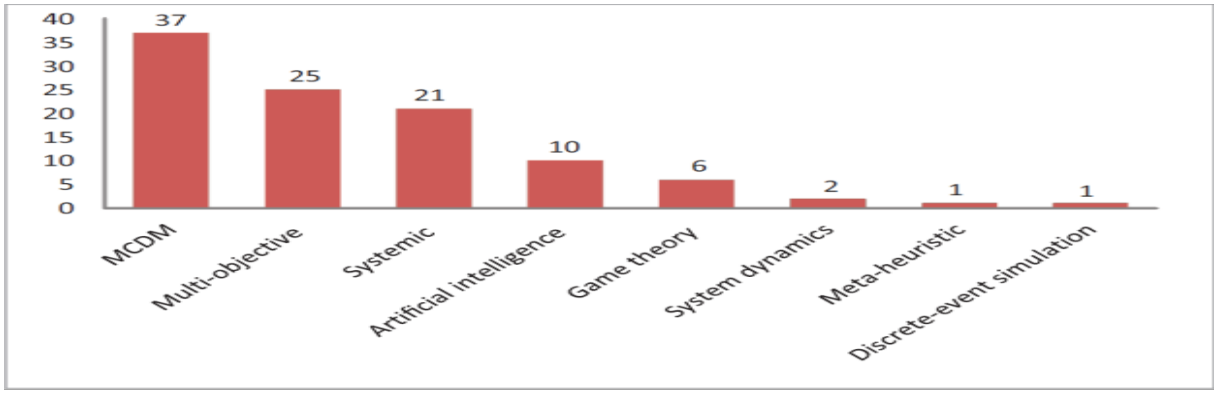

Figure 4. Distribution of reviewed articles according to the model technique

Out of 64 analytical models-related papers, 37 papers focused on MCDM techniques and 21 papers dealt with systemic techniques, while only 6 papers of game theory were used. It is clear that MCDM techniques are the most popular methods adopted in analytical models. Among the heuristic models, 10 papers focused on artificial intelligence technique and only 1 paper focused on meta-heuristic technique. Among mathematical models, 25 papers focused on the multi-objective technique. While, among simulation models, only one paper focused on the discrete event simulation technique and system dynamics have been used in 2 papers.

5.7. Evolution of models based on modeling technique from 2000 to the end of 2018

Table 5 indicates the evolution of models based on the modeling techniques for the time period 2000 to the end of 2018 in the field of SSCM research.

Table 5. Evolution of models based on modeling techniques over time in SSCM research

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
MCDM									1		1	2	2	2	4	4	5	7	9
Systemic				1		1	1	2	3	1	1			3	1	2	1	2	1
Game theory		1			1													1	3
Multi-objective							1		2	2	1		1	1	2	5	2	1	7
Artificial intelligence		2									2	1	1	1		2		1	
Meta-heuristic																1			
Discrete-event simulation system dynamics																	1		1

The results of analysis indicate that among the analytical techniques, the systemic technique has been used from 2003 to 2018 and the researchers have used MCDM techniques from 2008 onwards and the use of MCDM techniques is on the rise. Of course, evolution of MCDM techniques indicates that the MCDM techniques are more used by researchers than the systemic technique. Only one paper of meta-heuristic technique was used in 2015 among the heuristic models, and the artificial intelligence technique has been used by researchers in studies since 2010. Only one paper of Discrete-event simulation technique was used in 2016.

5.8. Analysis and classification of SSCM studies according to the solution approaches

Table 6. Distribution of reviewed papers based on data analysis technique

Data analysis technique	No. of articles
Sensitivity analysis	31
Content analysis	23
SEM	19
Descriptive analysis	18
Factor analysis	12
Regression analysis	8
ISM	7
Thematic analysis	3
Coding analysis	3
Matrix analysis	3
ANOVA	3
Gap analysis	2
path analysis	2
Comparative analysis	2
contingency analysis	1
Correlation analysis	1
Cluster analysis	1
T test	1
U Mann Whitney Test	1
Cross-case analysis	1
Delphi	1

This section provides a summary of frequency of solution approaches used by different researchers to promote knowledge in the field of SSCM research. Figure 5 presents the solutions used in SSCM research.

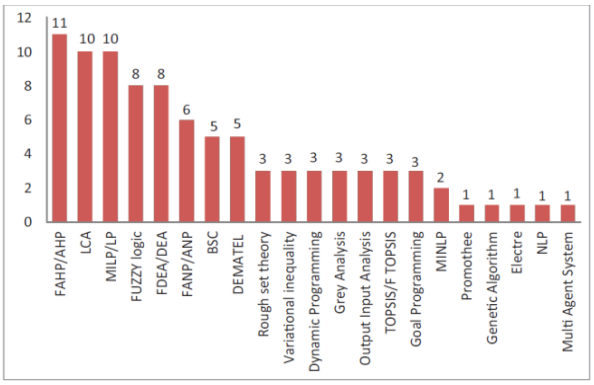

Figure 5. Distribution of reviewed articles according to the solution approaches

"Analytic hierarchy process"/"fuzzy analytic hierarchy process" (AHP/FAHP) are the most common solution approaches employed in SSCM research, followed by "life cycle assessment" (LCA), "fuzzy logic", "data envelopment analysis"/"fuzzy data envelopment analysis" (DEA/FDEA), "mixed integer linear programming (MILP/LP). The findings indicate that linear programming was more used by researchers than nonlinear programming.

5.9. Analysis of reviewed articles based on data analysis technique

The process of data analysis aims at extracting useful information and obtaining conclusion on the data. Some of the data analysis techniques include: sensitivity analysis, descriptive analysis, factor analysis, content analysis, Structural equation modeling (SEM), regression analysis, etc. The frequency of data analysis technique used by researchers is shown in Table 6.

The most common data analysis technique in SSCM is sensitivity analysis with 31 papers (21.7%) followed by content analysis with 23 papers (16.1%), SEM with 19 papers (13.3%), descriptive analysis with 18 papers (12.6%), factor analysis with 12 papers (8.4%) and Regression analysis with 8 papers (5.6%).

5.10. Analysis and classification of SSCM studies according to the industry type

Various industries are considered by the researchers in their studies in the field of SSCM.

Table 7 presents the various industries considered as well as the number of studies conducted in each industry. The findings

show that most articles in the field of SSCM have been conducted in various manufacturing industries. Researchers simultaneously considered several different manufacturing industries in their studies that clearly indicating the significance of implementation of sustainability concepts in the manufacturing industries. Some other industries that are most considered by researchers in studies include: Automobile/Automotive industries, food industry, Apparel industry, Electric/Electronic industries.

5.10. Analysis and classification of SSCM studies according to sustainability metrics

A sustainability report is "a report published by an organization or company about the environmental, social and economic impacts caused by its everyday activities" (GRI, 2018). These reports include indicators and measures that build the company's performance confirmable through global standards and external agencies (Hassini et al., 2012). These metrics are often presented in sustainability reports of companies. Therefore, various sustainability metrics exist for each of the three dimensions of sustainability. These metrics are used by many organizations around the world (Searcy, 2012). Also, Sustainability metrics are being known as practical tools for decision-making,

policy and communication aims in several contexts (Ahi & Searcy 2015).

Table 7. Distribution of reviewed papers based on industry type

Industry type	No. of articles
Various manufacturing industries	34
Automobile/ Automotive	25
Food	25
Apparel	11
Electric/Electronic	11
Plastic and Polymer	8
Health care /Pharmaceutical	7
Petrochemical/Oil and gas	6
Steel /aluminum/minerals/metal	5
Transportation	4
Energy	3
Chemical	3
Wood / paper	2
Agriculture	2
Tourism	2
Computer	2
Fashion	2
Education	2
Communication	1
Construction	1
leather	1
piping	1
Furniture	1

Hassini et al., (2012) reviewed 87 articles from 2000 to 2010. They focused on metrics in sustainable supply chains and expressed that there is no deficiency in the environmental indices, also they proposed frameworks for SSCM and performance measures. Searcy et al., (2007) provided a system of sustainable performance indices for a Canadian electric utility company that they focused on social and environmental issues. Ahi & Searcy (2015) conducted a study to identify the metrics in the GSCM and SSCM literature. Their findings show that 5 metrics were applied more than twenty times, such as

Gunasekaran & Kobu (2007) conducted a literature review on the performance metrics and measures in the logistics and SCM. quality, air emissions, Greenhouse gas emissions, energy use and energy consumption. Also their analysis indicates that environmental issues are intensely considered by researchers.

17 metrics were identified in the environmental dimension, which are presented in Table 8. As seen in the Table, metrics such as “energy consumption”, “waste minimization/waste management” and “recycling” have the highest frequency among the environmental metrics.

Table 8. Environmental sustainability metrics used in the literature review

Environmental metrics	Author(s)	No. of articles
Energy consumption	(Ahi, Jaber, and Searcy 2016; Azadi et al. 2015; Costantino et al. 2012; Erol, Sencer, and Sari 2011; Fahimnia and Jabbarzadeh 2016; Hemdi, Zameri, and Saman n.d.; Hutchins and Sutherland 2008; Isaksson and Steimle 2009; Izadikhah and Farzipoor Saen 2016; Pimenta and Ball 2015; Vimal, Xu, Jiang, and Wu 2016; Ziout et al. 2013)	11
Waste minimization/Waste management	(Amrina and Yusof 2011; Bourlakis et al. 2014; Dehghanian, Mansoor, and Nazari 2011; Faisal, Al-Esmael, and Sharif 2017; Harik et al. 2015; Uysal 2012; Wang and Gunasekaran 2015; Ahi, Jaber, and Searcy 2016)	8
Recycling	(Barros and Azevedo 2016; Dou and Sarkis 2010; Harik et al. 2015; Jellali and Benaissa 2015; Lim et al. 2017; Vachon and Mao 2008; Wang and Gunasekaran 2015)	7
Pollution control/ Pollution prevention/ pollution emissions	(Azadi et al. 2015; Azadnia, Saman, and Wong 2015; Bai and Sarkis 2010; Boukherroub et al. 2015; Garbie 2014; Govindan, Khodaverdi, and Jafarian 2013)	6

Air Emissions/CO2 emissions	(Azadnia, Saman, and Wong 2015; Azevedo et al. 2016; Büyüközkan and Berkol 2011; Fallahpour et al. 2017; Firoozi et al. 2014; Gopal and Thakkar 2015)	6
Environmental Management System	(Fallahpour et al. 2017; Hussain and Al-Aomar 2017; Izadikhah and Farzipoor Saen 2016;Svensson 2007; Uysal 2012; Vachon and Mao 2008)	6
Resource consumption	(Bai and Sarkis 2010; Boukherroub et al. 2015; Dou and Sarkis 2010; Garbie 2014; Ziout et al. 2013)	5
waste disposal	(Dou and Sarkis 2010; Gopal and Thakkar 2015; Svensson 2007; Yakovleva 2007)	4
Solid wastes/Liquid wastes	(Büyüközkan and Berkol 2011; Chardine-Baumann and Botta-Genoulaz 2014; Veleva et al. 2003; Xu, Jiang, and Wu 2016)	4
Water consumption	(Fahimnia and Jabbarzadeh 2016; MATOS and HALL 2007; Selvanathan 2015)	3
ISO 14001 certification	(Ahi and Searcy 2015a, 2015b; Motevali Haghighi, Torabi, and Ghasemi 2016; Vachon and Mao 2008)	3
Wastewater/effluent waste	(Husgafvel et al. 2015; Reefke and Trocchi 2013; Singh et al. 2012)	3
Renewable energy	(Azadi et al. 2015; Erol, Sencer, and Sari 2011; Jellali and Benaissa 2015)	3
Carbon footprint	(Ageron, Gunasekaran, and Spalanzani 2012; Fritz, Schöggl, and Baumgartner 2017; Vimal, Vinodh, and Muralidharan 2015)	3
Environmental costs	(Nadine, Kafa 2013; Wang and Gunasekaran 2015)	2
Source reduction	(Fritz, Schöggl, and Baumgartner 2017; Gopal and Thakkar 2015)	2
Reuse	(Fritz, Schöggl, and Baumgartner 2017; Vimal, Vinodh, and Muralidharan 2015)	2

10 metrics were identified in the economic dimension, which are presented in Table 9. As seen in the Table, metrics such as “cost”, “quality” and “flexibility” have the highest frequency among economic metrics.

Table 9. Economic sustainability metrics used in the literature review

Economic metrics	Author	No. of articles
Cost Including materials, Production, Energy, Recycle, waste, Operational, Fixed, Warehousing, Financial...	(Ahi, Jaber, & Searcy, 2016; Azadnia, Saman, & Wong, 2015; Bai & Sarkis, 2010; Bourlakis, Maglaras, Gallear, & Fotopoulos, 2014; Büyüközkan & Berkol, 2011; Costantino, Dotoli, Falagario, & Sciancalepore, 2012; Dehghanian, Mansoor, & Nazari, 2011; Fallahpour, Udoncy Olugu, Nurmaya Musa, Yew Wong, & Noori, 2017; Firoozi, Siadat, Salehi, & Mousavi, 2014; Garbie, 2014; Gopal & Thakkar, 2015; Govindan, Khodaverdi, & Jafarian, 2013; Husgafvel et al., 2015; Izadikhah & Farzipoor Saen, 2016; Kumar & Garg, 2017; Motevali Haghighi, Torabi, & Ghasemi, 2016; Reefke & Trocchi, 2013; Wang, Jing, Zhang, & Zhao, 2009; Xu, Jiang, & Wu, 2016)	19
Quality	(Azadi et al., 2015; Azadnia et al., 2015; Bai & Sarkis, 2010; Boukherroub, Ruiz, Guinet, & Fondrevelle, 2015; Bourlakis et al., 2014; Chardine-Baumann & Botta-Genoulaz, 2014; Fallahpour et al., 2017; Firoozi et al., 2014; Fritz, Schöggl, & Baumgartner, 2017; Govindan et al., 2013; Lim, Tseng, Tan, & Bui, 2017; Motevali Haghighi et al., 2016; Nadine, Kafa, 2013)	13
Flexibility	(Ageron et al., 2012; Amrina & Yusof, 2011; Chardine-Baumann & Botta-Genoulaz, 2014; Faisal et al., 2017; Izadikhah & Farzipoor Saen, 2016; Jellali & Benaissa, 2015; Lim et al., 2017; Motevali Haghighi et al., 2016; Nadine, Kafa, 2013; Vimal, Vinodh, & Muralidharan, 2015)	10

Delivery	(Ageron et al., 2012; Amrina & Yusof, 2011; Azadnia et al., 2015; Faisal et al., 2017; Govindan et al., 2013; Izadikhah & Farzipoor Saen, 2016)	6
Responsiveness	(Boukherroub et al., 2015; Bourlakis et al., 2014; Fritz et al., 2017; Nadine, Kafa, 2013; Vimal et al., 2015)	5
new investments	(Erol, Sencer, & Sari, 2011; MATOS & HALL, 2007; Singh, Murty, Gupta, & Dikshit, 2012; Uysal, 2012; Ziout et al., 2013)	5
Total sales/Total sales	(Gopal & Thakkar, 2015; Selvanathan, 2015; Uysal, 2012; Ziout, Azab, Altarazi, & ElMaraghy, 2013)	4
Innovations	(Erol et al., 2011; Jellali & Benaissa, 2015; Lim et al., 2017; Reefke & Trocchi, 2013)	4
Reliability	(Chardine-Baumann & Botta-Genoulaz, 2014; Govindan et al., 2013 Tajbakhsh & Hassini, 2015b)	3
Transport cost	(Azadi et al., 2015; Fahimnia & Jabbarzadeh, 2016; Tajbakhsh & Hassini, 2015a, 2015b)	3

8 metrics were identified in the social dimension, which are presented in Table 10. As seen in the Table, metrics such as “health & safety”, “work conditions/labor practices” and “employee training” have the highest frequency among the social metrics.

Table 10. Social sustainability metrics used in the literature review

Social metrics		Author	No. of articles
	Health and safety	(Ahi & Searcy, 2015b, 2015a; Amrina & Yusof, 2011; Azadi, Jafarian, Farzipoor Saen, & Mirhedayatian, 2015; Azadnia, Saman, & Wong, 2015; Boukherroub, Ruiz, Guinet, & Fondrevelle, 2015; Büyüközkan & Berkol, 2011; Dou & Sarkis, 2010; Faisal, Al-Esmael, & Sharif, 2017; Fallahpour, Udoncy Olugu, Nurmaya Musa, Yew Wong, & Noori, 2017; Garbie, 2014; Gopal & Thakkar, 2015; Govindan, Khodaverdi, & Jafarian, 2013; Hussain & Al-Aomar, 2017; Izadikhah & Farzipoor Saen, 2016; Jellali & Benaissa, 2015; Motevali Haghighi, Torabi, & Ghasemi, 2016)	16
	Work conditions/ labor practices	(Boukherroub et al., 2015;Chardine-Baumann & Botta-Genoulaz, 2014; Garbie, 2014; Husgafvel et al., 2015; Kumar & Garg, 2017; Lim, Tseng, Tan, & Bui, 2017; Reefke & Trocchi, 2013; Fritz et al., 2017)	8
	Employee training	(Amrina & Yusof, 2011; Azadnia et al., 2015; Barros & Azevedo, 2016; Erol, Sencer, & Sari, 2011; Gopal & Thakkar, 2015; Uysal, 2012; Yu & Tseng, 2014)	7

Employment practices	(Bai & Sarkis, 2010; Dou & Sarkis, 2010; Erol et al., 2011; Govindan et al., 2013; Izadikhah & Farzipoor Saen, 2016; Ziout, Azab, Altarazi, & ElMaraghy, 2013)	6
Participation stakeholders/ Stakeholder engagement	(Bai & Sarkis, 2010; Dou & Sarkis, 2010; Erol et al., 2011; Fritz et al., 2017; Jellali & Benaissa, 2015)	5
Human rights	(Chardine-Baumann & Botta-Genoulaz, 2014; Fahimnia & Jabbarzadeh, 2016; Fritz et al., 2017; Garbie, 2014)	4
Wages/ Salary	(Boukherroub et al., 2015; Fallahpour et al., 2017; Harik, El Hachem, Medini, & Bernard, 2015; Kumar & Garg, 2017)	4
Employee development	(Dou & Sarkis, 2010; Harik et al., 2015; Nadine, Kafa, 2013; Vimal, Vinodh, & Muralidharan, 2015)	4

6. Findings

In this part, the findings obtained of the present paper are expressed and also the results are compared with other findings from the researchers.

6.1. Discussion on the analysis results of the reviewed papers

6.1.1. Industry

Most studies were conducted in the various manufacturing industries with 34 papers. It is significant to note that only 4 papers in the transportation industry and 3 papers in the chemical industry were found in the SSCM research. The oil and gas industries, especially the petrochemical industry are among environmental pollutants industries. It has a variety of extremely hazardous pollutants. In other industries, such as transportation industry, energy industry and chemical industry have been ignored by researchers despite existence of hazardous waste and emission of pollutants. These findings show that there is still a shortage of studies in sensitive and polluting industries. Brandenburg et al., (2014) and Rajeev et al., (2017) confirm these results.

6.1.2. Year of publication

The distribution of papers per year indicates that studies in SSCM have been significantly increased in recent years. During the period from 2000 to 2006, the number of published articles in this area is very low, but since 2007 onwards, there is increasing trend in SSCM research and it has had a dramatic development. These findings are in line with Brandenburg and Rebs (2015) and Seuring and Müller (2008) results. There is a significant increase of studies in SSCM that may be due to “economic”, “social”, and “environmental” concerns of researchers and practitioners.

6.1.3. Research methodology

The results indicate that the “Model” methodology have been more used in SSCM research in recent years, followed by the “Survey” method and “Literature review” method. Hassini et al., (2012) expressed that analytical models were more used in studies in SSCM and Rajeev et al., (2017) expressed that mathematical modeling-related studies are more conducted in developing economics. They also stated that conceptual and empirical studies conducted in developed countries are

the basis for the studies of researchers in developing economies.

The evolution of research methodology indicates that conceptual/theoretical studies have not been conducted during 2000-2006, while case study and survey studies have been conducted during these years. The results also indicate that conceptual/theoretical studies were conducted after case study and survey studies. Then, the modeling approach (mathematical/ analytical modeling) has been used to optimize the topics relevant to sustainable SCM. The evolution of methodologies indicates that the modeling approach has been less done during 2000-2007, and after these years, the use of modeling approach is on the rise. Rajeev et al., (2017) confirm these results. On the other hand, literature review studies have been on the rise since 2012. These results are in line with Rajeev et al., (2017) findings.

6.1.4. Model type

The results indicate that analytical models have the highest frequency among other models, followed by mathematical models, hybrid models, heuristic models and simulation. The Findings obtained by Hassini et al., (2012) confirm the results of this investigation regarding the type of model. Also Brandenburg et al., (2014) found that the most of the investigated papers focused on analytical models, followed by mathematical models. The results obtained by Brandenburg et al., (2014) are in line with our results in this study. Paula Barbosa- ovoa *et al.*, (2017) found that optimization based methods are the most common methods employed in SSCM research.

Evolution of models indicates that the analytical models have been conducted since 2001 and the use of these models is on the rise. A total of 22 papers were focused on analytical models in 2017 and 2018. The mathematical models have been conducted from 2006 onwards and use of the mathematical models is on the rise and also the heuristic models have been employed by researchers in the field of SSCM research from 2010 onwards. The hybrid models have been received less attention by the researchers but the number of articles with hybrid models has been on the rise from 2014 onwards. The results obtained of Brandenburg et al., (2014) indicate that there was only one paper that focused on hybrid model.

6.1.5. Model technique

The results indicate that modeling research is dominated by MCDM techniques in SSCM, followed by multi-objective programming techniques, systemic techniques and artificial intelligence techniques. Scholars are more inclined to use MCDM techniques among the analytical models. MCDM techniques have been broadly applied in the order allocation process and supplier selection (Azadnia et al., 2015; Ghadimi et al., 2017). Mathematical programming and MCDM have mostly been selected in SSCM research (Panigrahi, Bahinipati, & Jain, 2018).

6.1.6. Solution approaches

AHP/FAHP, LCA and LP/MILP are the most common solutions employed in SSCM research, followed by fuzzy logic, DEA. Solution approaches such as genetic algorithm (GA), mixed integer nonlinear programming (MINLP), Goal programming (GP), nonlinear programming, Discrete event simulation technique and also system dynamics have been rarely employed in different studies in SSCM.

The results show that the "Queuing models" among the mathematical models, "Neural networks, "Bayesian networks", "Case-based reasoning", "Petri net" among the heuristic models (artificial intelligence technique), "Spread sheet", and "Business games" among the simulation models, "Simulated annealing", "Differential evolution", "Particle swarm optimization", "Ant colony optimization", "Greedy randomized adaptive search procedure" among the heuristic models (Meta-heuristic technique) according to modeling approaches described by Brandenburg et al., 2014, have not been used by researchers in SSCM research. Researchers are not inclined to use simulation and meta-heuristic methods, in the other hand they are more inclined to use analytical and mathematical methods. Zhu et al., (2018) stated that the meta-heuristics method is rarely used in sustainable food supply chain.

6.1.7. Sustainability metrics

The results indicate that various metrics such as "energy consumption" (11 times), "Waste minimization/Waste management" (8 times), "recycling" (7 times) have the highest frequency among environmental metrics. "Cost" (19 times), "quality" (13 times) and "flexibility" (10 times) are the most common metrics used among the economic metrics. The social metrics with high frequency include: "Health & safety" (16 times), "Work conditions/Labor practices" (8 times) and "Employee training" (7 times). The findings indicate that the number of environmental metrics is higher than the economic and social metrics. There are many environmental indicators and therefore, there is no deficiency of indices (Hassini et al., 2012). Ahi & Searcy (2015) stated that environmental topics have been received more attention in recent years. Their findings indicate that 30.6% of the metrics were related to topics of environmental, followed by economic metrics (17%) and social metrics (12.1%). They also stated that metrics like "quality", "air emissions", "greenhouse gas emissions", "energy use" and "energy consumption" were repeatedly used in SSCM and GSCM. Paula Barbosa- ovoa *et al.*, 2017) stated that cost metric is the most common used metric in SSCM and also CO2 emissions metric have been used in many articles. Zhu *et al* (2018) found that main environmental topics include "GHG emissions", "energy consumption", "ecological issues "and "natural resources consumption". Also main economic topics include "profitability", "efficiency", "pricing on quality", "consumer preferences", "cost optimization" and "revenue management".

6.2. Identified research gaps

1. Given the more significance of conceptual/theoretical studies and case studies, it can be expressed that there is a shortage in this field. A few articles used qualitative case studies (Dubey et al., 2017). Therefore a need for more case studies is felt by researchers. More empirical research is required to develop knowledge in the area of SSCM, which this type of research validates to the proposed framework (Hassini et al., 2012). Research in the field of sustainability in the supply chain should move towards the implementation of conceptual framework and testing theories (Panigrahi et al., 2018).
2. Researchers should take more attention on sensitive and polluting industries like petrochemical industry, transportation industry, energy industry, chemical industry and oil and gas industries due to existence of hazardous waste and emission of pollutants. Therefore further research is expected in these industries.

3. The AHP technique is criticized due to it deals with unbalance scale of judgment and its inability to sufficiently handle the intrinsic uncertainty and ranking in this method is imprecise (Cheng et al., 1999; Hepu Deng 1999). Therefore, researchers must use other methods to solving complicated problems. Solution approaches such as goal programming, genetic algorithm, mixed integer nonlinear programming, nonlinear programming, discrete event simulation technique and also system dynamics for advanced modeling have been rarely conducted in SSCM research. There are other methods that researchers have not used in modeling in SSCM. Methods that have not been used in SSCM are detailed in the findings section. The results show that the meta-heuristic technique (genetic algorithm) has been only used in one article and other meta-heuristic methods have not been utilized in this area ("simulated annealing", "particle swarm optimization", "ant colony optimization" and "differential evolution"). Also the simulation methods (discrete event technique and system dynamics) have been only applied in one article each.
4. Analysis of variance technique (ANOVA) is reported only in three study, and advanced data analysis techniques such as multiple regression analysis and multivariate analysis of variance (MANOVA) were not used to investigate relationship between variables by researchers. Nonlinear regression is much more precise than linear regression in predicting of the dependent variables and it is able to use quantitative and qualitative data in the model.
5. There is no comprehensive study among scholars in the field of performance measurement in SSCM that specifies what metrics should be evaluated and measured in the sustainable supply chains. However, there are significant studies in SSCM, but studies on how to measure the sustainability performance of SC are very limited. It is important to note that there is a significant gap in performance measurement in SSCM, On the other hand comprehensive literature review in this field with special focus on sustainability metrics has been less done.

5.3. Suggestions for future research and limitations

1. A complete and comprehensive study to identify a set of metrics of sustainability has not been conducted. There is a requirement for study in this area in the supply chains according to the type of industry and activity of companies and organizations. Therefore, researchers should try to obtain a set of sustainability metrics that organizations and companies use to measure their supply chain performance, so that this set of metrics is a reference for organizations and practitioners who want to measure supply chain performance in regarding to sustainability. As a result, one of the suggestions for future research is to identify the metrics used by companies and organizations for performance measurement of sustainability and also, the metrics used by researchers in SSCM research. In addition, due to the

significance of measuring sustainability performance with reliable and appropriate metrics in SC, It is suggested that studies be specially conducted to identify and categorize of qualitative and quantitative metrics for measuring sustainability performance.

2. Studies in the field of SSCM research are required in the Automobile/Automotive industry in Iran and also polluting industries worldwide. Sustainability in supply chains in Iran is still at its early stage (Badri Ahmadi et al., 2017; Ghadimi et al., 2017). On the other hand, industries such as the petrochemical industry, transportation industry, energy industry and chemical industry should be more considered by researchers because of adverse environmental effects. Therefore, this is a viewpoint for future research.
3. The results show that researchers have more used solutions such as AHP, LCA and MILP/LP. It is suggested that researchers use modeling methods such as genetic algorithm, goal programming, nonlinear programming, discrete event simulation technique and also system dynamics to solving complicated problems in the sustainable supply chains. It is suggested that researchers use other meta-heuristic methods and also other simulation techniques in modeling in sustainable supply chain.
4. This study has been restricted to papers published in English language. Some of the papers published in other journals might be missed.

6. Conclusion

This study reviews 242 papers published in the field of SSCM from 2000 to 2019 and analyzes the content of the selected papers, and also this review specifically focuses on sustainability metrics and modeling approaches. Structural dimensions and analytic categories were selected to analyze articles published in literature with deductive approach, and then selected papers were classified based on the analytic categories. The significant findings were extracted by categorizing papers based on dimensions of structural and analytic categories. The potential opportunities and research gaps in SSCM were identified through analysis and discussion on the results and findings. Proposed potential opportunities and identified research gaps for future research will lead to the knowledge development in SSCM. The evolution of research methodologies indicates that modeling approach in the field of SSCM is on the rise and many researchers have employed this approach.

Several potential opportunities were identified in this field, including:

- Expanding sustainability issues into polluting and sensitive industries.
- The need to solving problems in SSCM with solutions such as “genetic algorithm”, “goal programming”, “nonlinear programming”, “system dynamics”, “dynamic programming” and “neural networks”.
- The use of meta-heuristic methods like “Simulated annealing”, “Differential evolution”, “Particle swarm optimization” and “Ant colony optimization”.
- The use of reliable quantitative and qualitative metrics to measure performance of sustainability in SC.

- The need to identify a set of metrics of sustainability according to the type of industry and activity of companies and organizations.
- The use of advanced data analysis technique to investigate the relationships between variables.

The findings of this research prepare a basis for the modeling expansion and development in SSCM. This research will contribute to create awareness for decision-makers, researchers, and practitioners regarding the sustainability metrics, modeling in sustainability, etc.

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