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Low carbon supply chain: a state-of-the-art literature review

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Abstract

Purpose – The purpose of this paper is to review the relevant literature on low carbon supply chain management (LCSCM) and classify it on contextual base. It also aims at identifying key decision-making issues in LCSCM. This paper also highlights some of the future challenges and scope of research in this domain.

Design/methodology/approach – A content analysis is carried out by systematically collecting the literature from major academic sources over a period of 18 years (2000-2017), identifying structural dimensions and classifying it on contextual base.

Findings – There is an increasing trend of research on LCSCM, but this research is still in a nascent stage. All supply chain functions such as supplier selection, inventory planning, network design and logistic decisions have been redefined by integrating emissions-related issues.

Research limitations/implications – Limitation of this study is inherent in its unit of analysis. Only peer-reviewed journal articles published in English language have been considered in this study.

Practical implications – Findings of prior studies on low carbon inventory control, transportation planning, facility allocation, location selection and supply chain coordination have been highlighted in this study. This will help supply chain practitioners in decision making.

Originality/value – Though there are an increasing number of studies about carbon emission-related issues in supply chain management, the present literature lacks to provide a review of the overarching publications. This paper addresses this gap by providing a comprehensive review of literature on emissions-related issues in supply chain management.

Keywords Sustainable production, Supply chain management, Supply chains, Green operations, Low carbon supply chains

Paper type Literature review

1. Introduction

As a result of increasing thrust on the abatement of greenhouse gases (GHG) emissions many changes have been reported in the literature in the way the supply chains traditionally function. These changes have been triggered by the growing pressure from multiple stakeholders such as government bodies, non-government organizations and industries. Although environmental performance of the organizations has been monitored since late nineteenth century, the focus has shifted from individual organizations to supply chains since the advent of supply chain management in the 1990s. At the same time green supply chain management (GSCM) has also gained interest among the researchers and practitioners (Srivastava, 2007). However, the scope of GSCM is very broad and it also includes pollution control, natural resource conservation and waste management. Of late companies have focused largely on GHG emission reduction. A consistent increase in anthropogenic GHG emission has been attributed to the climate change and global warming (IPCC, 2014). A majority of such anthropogenic GHG emissions is a result of an increase in industrialization, population and hence supply chains. Therefore, control of GHG emission from the supply chains may not only address the climate change issues but may also satisfy the legislative requirement. As a result, emission reduction from its supply chains is a strategic imperative for any organization (Jabbour *et al.*, 2015). Accordingly, the concept of low carbon supply chain management (LCSCM) is gaining attention of academia and industry. The literature is well enriched with studies on LCSCM and is, thus, suitable for

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conducting a review. The LCSCM research has two perspectives: one deals with the functional and operational aspects of supply chain management such as sourcing, production and planning, distribution, network design and supply chain coordination; and the other deals with the accounting and conceptualization of carbon footprint (CF). Sourcing-related studies have mainly dealt with the issues pertaining to supplier selection by integrating their carbon performances with economic performances (Shaw *et al.*, 2012; Kuo *et al.*, 2015). Production and planning-related studies have primarily integrated emission issues into the classical lot size, inventory ordering policy and inventory routing problem (Diabat and Al-Salem, 2015; Hammami *et al.*, 2015; Alhaj *et al.*, 2016). In the transportation-related studies, researchers (Hoen *et al.*, 2014; Rudi *et al.*, 2016; Glock and Kim, 2015) have investigated the effectiveness of demand consolidation, transportation planning, and impact of transport mode selection and reduction of trip interval for reducing carbon emission. Similarly, studies on supply chain network design have included emission issues in location selection, eco-efficient network design, resource allocation and inventory routing planning (Pishvaee *et al.*, 2012; Kostin *et al.*, 2015). Recently, measurement of product carbon footprint (PCF) has also gained popularity among researchers. Sundarkani *et al.* (2010) and Benjaafar *et al.* (2013) have explained the concept of CF in supply chain management. Later, many researchers (Svanes and Aronsson, 2013; Roibas *et al.*, 2016; Agyemang *et al.*, 2016) have applied life cycle analysis (LCA) to measure PCF. Based on the available literature, we define LCSCM as a strategy that integrates CO_2 or CO_2 equivalent or GHG emissions either as a constraint or as an objective in supply chain design and planning. The major activities of LCSCM include supplier selection, inventory planning, transportation management, network design and coordination strategy. The ultimate objective of LCSCM is to reduce overall supply chain carbon emissions without compromising the economic interest of the firm at large. Hence, there are trade-offs between economic and environmental objectives in all supply chain functions.

Many authors (Srivastava, 2007; Seuring and Müller, 2008; Carter and Rogers, 2008; Brandenburg *et al.*, 2014) have contributed to the literature on sustainable supply chain management. Table I describes such related literature reviews. The focus areas of these reviews were wider and mostly covered green and sustainability issues of supply chain management. For example, Srivastava (2007) exhaustively reviewed GSCM, but he focused mainly on remanufacturing issues. Seuring and Müller (2008) reviewed conceptualization of sustainable supply chain management. A few researchers have focused on emission issues. For instance, Pandey *et al.* (2011) reviewed the current method of CF estimation; Jensen (2012) addressed the standardization and consistency of the current method of PCF; Edwards *et al.* (2011) presented the auditing and methodological issues on CO_2 emission; Gaussin *et al.* (2013) reviewed environmental footprint measurement; and Subramanian and Gunasekaran (2015) conducted a review on cleaner supply chain practices. However, no comprehensive review was found in the literature that exclusively reviewed emissions-related issues of supply chain management. Thus, it may be said that the present literature lacks to provide a comprehensive review on LCSCM.

Managing a supply chain in itself is a very complex process. This complexity further increases when two or more conflicting objectives are involved in the decisions-making process. Integration of emissions issues with normal supply chain considerations is an example of such increased complexity. Thus, there is a need to account all overarching complex problem contexts of LCSCM. Although, a significant number of studies have been conducted on LCSCM, review papers pertaining to carbon emission issues in supply chain management are limited (Plambeck, 2012). Earlier studies have only considered CF issues on vehicle routing problem (Lin *et al.*, 2014), CF measurement issues (Pandey *et al.*, 2011; Edwards *et al.*, 2011; Jensen, 2012; Gaussin *et al.*, 2013) and cleaner technology (Subramanian and Gunasekaran, 2015). Therefore, this paper aims at addressing this limitation by providing an exhaustive review of the literature on LCSCM. While doing so, we identified

Authors name	Main theme of review	Number of papers reviewed	Year covered
Gold *et al.* (2010)	To test the role of sustainable supply chain management for inter-organizational resources building to gain inter-firm competitive advantages	70	1994-2007
Seuring (2013)	To provide a review of quantitative modeling of sustainable supply chain management	36	Till 2010
Lin *et al.* (2014)	This study provides an exhaustive literature review of different variants of green vehicle routing problem	283	Till 2013
Pandey *et al.* (2011)	To account several methods of carbon footprint accounting in the literature	na	–
Gupta and Desai (2011)	Classification of sustainable supply chain management literature considering organizational perspectives	na	–
Carter and Rogers (2008)	Integration of several facets of sustainability, i.e. economic, environmental and social, with supply chain management for development of the theoretical propositions	na	–
Seuring and Müller (2008)	To build conceptual framework with different dimensions of the sustainable supply chain management	191	1994-2007
Srivastava (2007)	To provide an exhaustive literature review on green supply chain management and classified the whole literature in contextual and methodological dimensions	227	1990-2007
Brandenburg *et al.* (2014)	To provide a literature review on several modeling aspects of sustainable supply chain management considering only quantitative models	134	1994-2012
Jensen (2012)	This study provides an exhaustive review of product carbon footprint issues, measurement, and reduction strategies	115	2006-2010
Gaussin *et al.* (2013)	This study provides an explorative study on methodology and standardization of manufacturing product carbon footprint	na	–

Note: NA: number of papers reviewed not mentioned in the paper

Table I. Related past literature reviews

the key strategic and operational issues on LCSCM and classified the entire literature on contextual basis. Finally, we provide a wide array of suggestions and research questions for conducting future research in this area.

The rest of this paper is organized as follows: Section 2 addresses the research methodology including scope and boundary selection, data collection method and detailed content analysis. Section 3 provides the results and discussion of this literature review. Section 4 provides the future directions and research implications of this study. The paper ends with conclusion in Section 5.

2. Research methodology

The primary objective of this research was to review the existing literature on LCSCM to identify the key issues and directions for future research. To achieve these objectives, a qualitative analysis of the relevant literature is probably the most appropriate methodology. Fink (1998) noted, "A literature review is a systematic explicit and reproducible method of identifying, evaluating, and synthesizing the existing body of completed and recorded work produced by researchers, scholars and practitioners." In their literature review, Booth *et al.* (2011) have noted that the review process will be more focused if the scope of research is limited. Thus, it contains explicit and specific information. Further, a filtered concept, categories and theoretical framework can be developed through qualitative content analysis (Graneheim and Lundman, 2004). Therefore, a qualitative content analysis was carried out to provide a "state-of-the-art" literature review. The taxonomy of the "state-of-the-art review" is justified as Booth *et al.* (2011)

stated that a "state-of-the-art literature review" addresses the current state of knowledge, may also offer new perspectives or even extend the future area of research.

To provide a detailed understanding of the current status of research on LCSCM, we investigated the following research questions in our review process:

- What are the problem contexts being addressed in the literature on LCSCM?
- What will be the future challenges and research directions in LCSCM?

The classification of literature is done only on contextual base. In order to answer the research questions, research papers were collected from several sources. Upon carefully reviewing the contents, the entire literature has been classified as per the problem contexts. The scope of this literature review is explained below.

2.1 Scope and delimitation criteria

It is almost impossible in any literature review to cover all sources of information, or all the information relevant to the researcher's interests. Therefore, it is important to limit the scope before conducting the review. The delimiting criteria for this paper are as follows:

- This review included only peer-reviewed academic journals published in English language. Journals published in other languages, trade journals and conference proceedings were excluded from the review.
- This review focused only on those papers which addressed carbon emission issues in supply chain management. Papers, which addressed environmental science- and technology-related issues of carbon emission were also omitted from this study.
- As the awareness of emissions-related issue on supply chain management has increased after the year 2000, the papers published during 2000 to July 2017 were included in this review.

2.2 Content analysis

For conducting a content analysis, one needs prior research frameworks and methodologies. Therefore, we followed the methodology proposed by Mayring (2003) and further adopted by Seuring and Müller (2008) and Shukla and Jharkharia (2013). Based on this, the detailed methodology is as follows.

2.2.1 Material collection. The first step in conducting a content analysis is to select the unit of analysis. Only peer-reviewed academic journals were chosen for the unit of analysis of this study because these journals are a strong medium used by researchers for communicating their thoughts, ideas and findings. This paper followed Seuring and Müller (2008) for material collection methodology. Articles were searched by using key words "Low carbon" and "supply chain", and "Carbon emission" and "supply chain" in the Scopus database. By using the identified keywords journal articles were also searched on other major academic publishers such as Elsevier (www.sciencedirect.com), Emerald (www.emeraldinsight.com), Springer (www.springerlink.com), Wiley (www.wiley.com) and EBSCO (www.ebsco.com). Thereafter, the content of these papers were critically analyzed by studying their abstract and introduction. Finally, 181 papers were found to be relevant within the scope and boundary of the research. Thus, these papers were selected for further review. As earlier stated this review paper included only those articles which addressed emission issues in various stages of supply chain management such as sourcing, supplier selection, production and planning, inventory control, transportation and distribution, network design, contract design and supply chain coordination and collaboration. Articles related to the life cycle assessment of PCF and conceptual issues of supply chain CF were also included in this paper. However, papers related to the CF of a particular manufacturing process at the production level alone were excluded from this review.

2.2.2 Descriptive analysis. In this review, we provide descriptive analysis in terms of year of publications and frequency analysis of all identified journal publications.

2.2.3 Category selection. All theory-driven structural dimensions and analytical categories were first described in this content analysis. Under each structural dimension, several distinct theoretical concepts were defined. By analyzing all distinct theoretical concepts, sub-categories and categories were developed. A revised loop was used for continuous revision of dimensions whenever there was an overlap among categories. Figure 1 shows the detailed category selection and material evaluation.

For example, Cooper *et al.* (1997) conceptually defined supply chain management as a business process and structure. A business process includes planning, procurement and product management, whereas supply chain structure includes inter-organizational collaboration and design of a logistic network. Thus, broad dimensions such as low carbon operations, low carbon supply chain design and carbon management were identified upon reviewing the SCM literature (Cooper *et al.*, 1997; Lambert *et al.*, 1998; Lambert and Cooper, 2000). Under the broad dimension low carbon supply chain operations, we identified theoretical concepts such as lot size, economic ordering quantity (EOQ), newsvendor model, transport modes selection, routing decisions, freight scheduling, location selection, inventory allocation, facility selection, etc. Trough analyzing the identified theoretical concepts, sub-dimensions of low carbon supply chain operations such as supplier selection, inventory management and transportation were identified. Thus, classification of the entire literature which is depicted in Figure 2 has been carried out.

2.2.4 Content evaluation. We evaluated the collected research articles to determine the relevant contextual issues and research trends and to draw conclusions. In the subsequent sections, the detailed issues of each category are described as a result of analysis of the collected materials.

Figure 1 provides the detailed description of the category selection and material evaluation of the content analysis. Structural dimensions and analytical categories can be developed either inductively or deductively or in both ways. It is better to use both inductive and deductive approaches for identification of structural dimensions (Shukla and Jharkharia, 2013). Therefore, in this paper both inductive and deductive approaches were used and broad dimensions, based on the supply chain management theory, were identified. These included low carbon operations, low carbon supply chain design and carbon management. Under each structural dimension, several theoretical concepts were defined through inductive approaches. To avoid errors, one needs to iteratively follow steps 3 and 4 as defined in Figure 1. The attributes and categories in this process of analysis were also

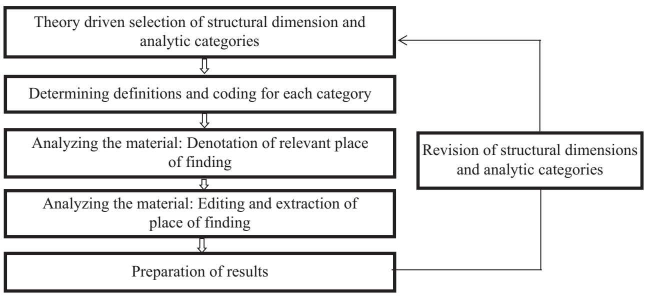

Figure 1.
Research process of structuring content analysis

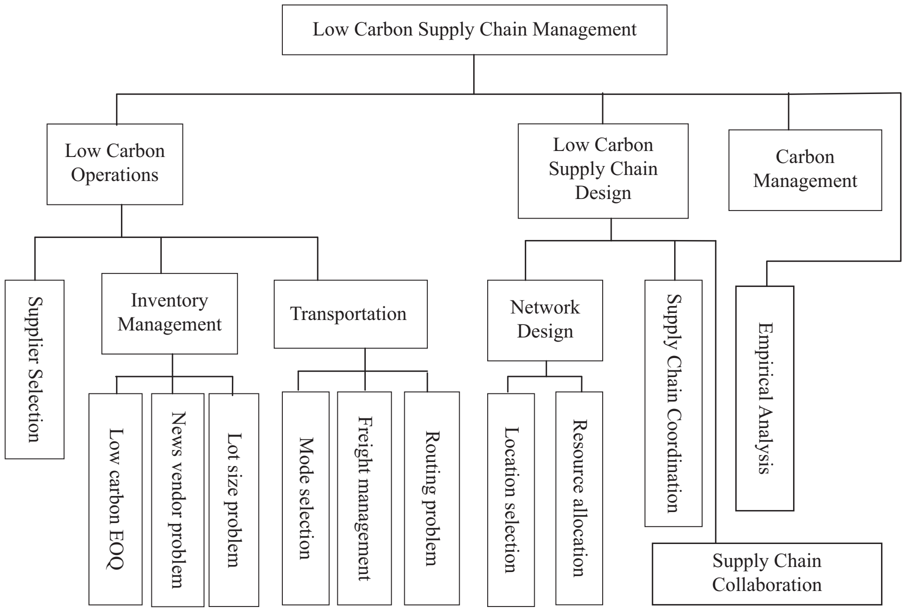

Figure 2. Content-wise classification of literature

revised as suggested by Mayring (2003). Shukla and Jharkharia (2013) justified that the categorical classification of the literature is the true representation and synthesis of the literature.

2.3 Rigor of research methodology

In content analysis, trustworthiness is one of the main challenges. This indicates whether the research is valid and relevant, and whether the procedures being followed are genuine or not. There are several measures of trustworthiness in the literature. These include credibility, validity, reliability and reproducibility. Graneheim and Lundman (2004) proposed that credibility and reliability are appropriate measures for trustworthiness. In this review paper, a right and focused procedure for relevant data collection method has been followed. In addition to the authors, one more independent research assistant was also deployed by the authors to carry out this research on the lines as defined and used by the authors. It was observed that there was no significant difference in the research outcomes of these two sets of literature review. Therefore, it may be said that this research meets the requirements of a credible, reproducible and rigorous research.

3. Results and discussion

In this section, the outcomes of the literature review, in terms of descriptive analysis and contextual classification, are provided as below.

3.1 Descriptive analysis

A detailed descriptive analysis of reviewed papers is provided by classifying these on the basis of the year of publication (Figure 3) and journals of publication (Table II). The aim of providing descriptive analysis is to portray the trend of research and major contributing journals. It may be inferred from Figure 2 that only 5 percent of reviewed papers included in this study were published before 2009. The reason for the less number of papers during this period may be attributed to the fact that the issue of carbon emissions might not have received enough attention of practitioners and academicians by this time; meanwhile, sustainability and GSCM have got tremendous attention. It is also observed from Figure 2 that there is a sharp increase in research on LCSCM after 2010. This sudden change may be attributed to the regularity pressure on the organizations for emission reduction after the Kyoto Protocol (signed 1997, effective 2005).

Table II provides a detailed list of journal-wise publication of articles in this field. In this table, only those journals have been included that have at least two relevant publications. It is

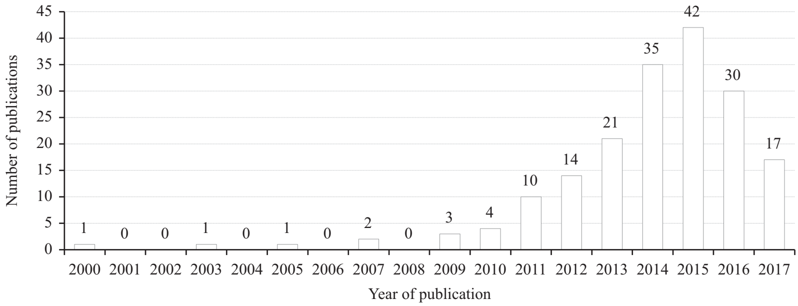

Figure 3.
Year-wise distribution of all publications

Table II.
Journal-wise publication of articles

Journal name	Number of papers
International Journal of Production Economics	25
Journal of Cleaner Production	23
International Journal of Production Research	9
European Journal of Operations Research	8
Production Planning & Control	5
Resource, Conservation and Recycling	4
Transportation Research Part D: Transport and Environment	4
Computers and Industrial Engineering	4
Flexible Services and Manufacturing Journal	3
Supply Chain Management: An International Journal	3
Applied Energy	3
Applied Mathematical Modeling	3
Journal of Industrial Ecology	3
Journal of Industrial Engineering and Management	3
EURO Journal on Transportation and Logistics	3
International Journal of Physical Distribution & Logistics Management	3
Transportation Research Part E: Logistics and Transportation Review	3
International Journal of Environmental Science and Technology	2
Computers & Chemical Engineering	2
Expert System with Application	2
Journal of Environmental Management	2
Management Research Review	2
Omega	2
Annals of Operations Research	2
Industrial Management & Data Systems	2
International Journal of Logistics Research and Applications	2
International Journal of Life Cycle Assessment	2
Sustainability	2
International Journal of Logistic Management	2
Others	48

observed from the table that the LCSCM is an interdisciplinary domain of research where the journals from environmental science (*Journal of Cleaner Production*, *Resource, Conservation and Recycling*, and *International Journal of Environmental Science and Technology*, etc.), operations and supply chain management (*International Journal of Production Economics*, *International Journal of Production Research*, *Supply Chain Management: An International Journal* and *International Journal of Physical Distribution & Logistics Management*, etc.), and decision science (*European Journal of Operations Research*, *Expert System with Application*, and *Annals of Operations Research*, etc.) have been the major contributors.

The focus of operations management journals is mainly on incorporating emissions-related issues in the traditional operational functions and strategies such as supplier selection, inventory management, transportation and supply chain network design. Similarly, the focus of environmental and policy related journals is mainly on LCA, impact assessment and CF measurement. *International Journal of Production Economics* primarily focused on incorporating emission-related issues on inventory control planning and resource allocation problem. Likewise, *European Journal of Operational Research* primarily focused on pricing and coordination issues of supply chain considering the different emissions trading schemes. Additionally, the *Journal of Cleaner Production* mainly focused on LCA, impact assessment, CF measurement and emissions reduction strategies; similarly, the primary attention of *Resource, Conservation and Recycling* is industrial ecology; and *Applied Energy* mainly concentrates on energy conservation.

3.2 Classification by context

To get a comprehensive perspective of the literature, the existing literature is classified on contextual basis. Such a classification often simplifies the complex relationship among the different dimensions of the topic under review. We, thus, depict the structured classification of LCSCM in Figure 2. A classification is primarily carried out to depict a clear picture of the literature. Further, it also presents the close relationship among various criteria. In this classification, all the dimensions are not exclusive to each other and there is some inherent overlap among criteria. For example, there is often an overlap of inventory allocation problem, location selection and inventory routing problem with network design problem. Additionally, this classification does not address these hybrid complex relationships. We, thus, include the papers into a single dimension on the basis of their broader perspective. In the subsequent sub-sections, we discuss detailed contextual issues of LCSCM.

3.2.1 Supplier selection for low carbon emissions. In general, the objective of supplier selection is to develop an efficient supplier network for uninterrupted supply of raw materials with the desired specification. However, these days the focus has shifted in line with the new emission constraints. Hence, it is no longer effective to focus only on the focal company's carbon reductions. Thus, supplier selection on the basis of their emissions performance criteria gets special attention in the literature (Shaw *et al.*, 2012; Kumar *et al.*, 2014; Hsu, Kuo and Chiou, 2014; Kuo *et al.*, 2015). Further, the profitability of the focal firm, quality of products and services and customer satisfaction also significantly depend on effective selection of suppliers (Shaw *et al.*, 2012). The supplier selection problem is a multi-criteria decision-making problem. Both environmental and other commercial criteria are modeled for low carbon supplier selection. For example, important environmental criteria are GHG emission (Shaw *et al.*, 2012; Hu *et al.*, 2015; Shaw, Shankar and Yadav, 2016); CF (Kumar *et al.*, 2014); supplier carbon management including carbon governance, carbon policies, carbon reduction targets, training, carbon accounting and inventory, capability to low carbon design, management information system of carbon emission, carbon risk assessment, carbon disclosure reports (Hsu, Kuo and Chiou, 2014; Kuo *et al.*, 2015). The other commercial criteria are cost, quality, delivery lead time, reliability and on time delivery performances.

Rad *et al.* (2013) found that the outsourcing decisions of companies have significantly reduced carbon emissions. Beer and Lemmer (2011), Tidy *et al.* (2016) and Cerutti *et al.* (2016) analyzed carbon emission issue in food procurement. Hsu, Kuo, Shyu and Chen (2014) considered energy efficiency of products, eco-labeling, carbon accounting, energy reduction strategy, carbon governance and transport efficiency as criteria for selecting suppliers for the hotel industry. Interestingly, Rosen *et al.* (2000) applied transaction cost economics theory for supplier development in the computer industry. Therefore, by incorporating carbon criteria in the supplier selection process, an organization puts pressure on suppliers to monitor their carbon performances. As a result, suppliers need to be more responsive toward development of standard guidelines, management systems and strategies for improving their carbon performances. Based on the above discussions on the issue of supplier selection for low carbon emissions our finding (F) is as follows.

F1: Low carbon supplier selection is primarily a multi-criteria decision-making problem where several environmental criteria such as suppliers' carbon policies, reduction target, CF measurement and disclosure are incorporated with some other commercial criteria.

3.2.2 Inventory management. The objectives of conventional inventory management are to decide optimal ordering quantity, maintain stock level and allocate resources with minimization of total inventory cost (inventory ordering cost and holding cost). These objectives have been reformulated in line with the growing concerns for carbon emission reduction (Bazan *et al.*, 2016). For example, the traditional EOQ model (Hua *et al.*, 2011; Diabat and Al-Salem, 2015; Hammami *et al.*, 2015; Gurtu *et al.*, 2015; Alhaj *et al.*, 2016); multi echelon inventory control model (Bouchery *et al.*, 2017; Ghosh *et al.*, 2017); and capacity expansion decisions (Song *et al.*, 2017) have been reformulated with a new optimization model where inventory allocation, storage and distribution have been decided based on minimization of total carbon emissions and total cost. Arıkan and Jammernegg (2014) reformulated the traditional news vendor problem with dual sourcing options such as offshore and onshore. Sarkar *et al.* (2015) minimized total carbon emission due to transportation and total cost considering fixed and variable emission cost by a mathematical optimization method. Arıkan *et al.* (2014) addressed uncertainty issues of lead time and carbon emissions, and Purohit *et al.* (2016) extended lot sizing problem considering non-stationary stochastic demand and carbon cap and trade policy. While, Sarkar *et al.* (2016) found that emissions cost is sensitive to the total inventory cost. Thus, there is a trade-off between environmental and economic objectives. Similarly, Ni and Shu (2015) considered the lead-time issue in addition to the carbon emission issue in the inventory control model. They reported that the greater the lead time, the lower the emissions. Thus, there must be an optimal ordering quantity that can simultaneously minimize not only the total carbon emissions but also the total cost (Bozorgi *et al.*, 2014). Based on the above discussions our finding is as follows.

F2: Optimal inventory ordering quantity differs with the inclusion of carbon emissions cost into the inventory control model, and the total cost will depend on the "cap and trade policy," carbon tax and carbon price.

3.2.3 Transportation. Transportation is the major source of secondary carbon emissions (Piecyk and McKinnon, 2010). Such carbon emissions can significantly be reduced by effective management of transport mode selection (Hoen *et al.*, 2014; Bouchery *et al.*, 2016), freight size (Rudi *et al.*, 2016), routing decision (Validi *et al.*, 2014; Glock and Kim, 2015; Kumar *et al.*, 2016; Suzuki, 2016; Qiu *et al.*, 2017), transport consolidation (Brown and Guiffrida, 2014; Loon *et al.*, 2015), location selection (Lam *et al.*, 2010; Rao *et al.*, 2015; Musavi and Bozorgi-Amiri, 2017), logistics outsourcing (Ameknassi *et al.*, 2016; Li *et al.*, 2017) and energy conservation (Müller *et al.*, 2014). Traditionally, transport mode selection depends on both lead time and transportation cost. Higher the lead time, higher the inventory required.

Therefore, low cost transportation mode will be selected. However, lesser the lead time, faster modes of transportation required. Therefore, an expensive transportation mode will be selected (Hoen *et al.*, 2014). However, nowadays, in addition to these criteria (cost and lead time), carbon emissions are also considered as an important criterion while deciding transport modes (Chen and Wang, 2016). For example, air transport mode is considered to be the costliest and is highly polluting, but least in lead time compared to other rail and sea transport modes. For rail and sea transport modes, total cost is lesser, but lead time is very high and emissions are also lesser (Hoen *et al.*, 2013). Furthermore, total carbon emissions increase with lead time variability. This is because organizations need to purchase products from other sources that require a faster air freight transportation mode to meet unexpected demands.

Carbon emissions also depend on logistics parameters such as distance, load factor, freight size (full truck load, FTL, or less than truck load, LTL), product-specific characteristics (weight and volume) and transhipment schedule (Rudi *et al.*, 2016). If the logistic service provider adopts an FTL strategy, there will be fewer trips. Hence, carbon emissions will also get reduced. However, the risk of stock-out and lead-time variability will also be increased. Similarly, logistics service providers can charge less for demand consolidation and can charge comparatively higher for non-consolidation (Berling and Eng-Larsson, 2016). Interestingly, Farmery *et al.* (2015) found that CF for seafood imported in Australia compared to that of the domestic supply chain is similar or less, despite higher transportation distances.

Similarly, carbon emissions also depend on last mile delivery options such as cross dock, milk run delivery and customer pick-up (Brown and Guiffrida, 2014; Loon *et al.*, 2015). Loon *et al.* (2015) found that carbon emissions were higher for online shopping than for traditional brick and motor shopping. Similarly, Danloup *et al.* (2015) found that collaborative last mile delivery among logistic service providers at the customer ends significantly reduced carbon emissions. In the case of global supply chains, transportation collaboration within the same territory is always beneficial (Sadegheih *et al.*, 2011; Le and Lee, 2013; Gurtu *et al.*, 2017). Carbon emissions can also be reduced by creating a logistic transport ecosystem (Boschian *et al.*, 2013). In another study, Cachon (2014) analyzed the impact of store density of retail supply chains on cost and carbon emission levels. Radio frequency identification based logistic monitoring also reduces uncertainty and carbon emission (Kang *et al.*, 2013). In addition, carbon emissions can be significantly reduced by the selection of transport modes and the use of heterogeneous vehicles. Zhu *et al.* (2014) developed standard measures for logistic carbon emissions and also addressed the allocation problem of CF. Therefore, there is a trade-off decision between carbon emissions and operational performances. Based on the above discussions our finding is as follows.

F3: Demand consolidation, switching transportation modes, collaborative distribution and FTL strategy will lead to a reduction in total GHG emissions. However, at the same time, these practices also increase total transportation cost.

3.2.4 Network design. The literature on network designs covers a wide array of issues such as facility location selection, location allocation and resources routing decisions. The objective of the SCM network design is to minimize total supply chain cost (production cost, transportation cost and fixed operating cost of facilities). However, the objective of low carbon SCM network design is to decide facility locations, facilities and allocating resources on the basis of minimization of total cost and carbon emissions (Osmani and Zhang, 2014; Altmann, 2015; Brandenburg, 2015; Shaw, Irfan, Shankar and Yadav, 2016; Kuo *et al.*, 2017). Total supply chain carbon emissions are calculated by taking account of emissions resulting from the production process, transportation and inventory storage. In particular, emissions caused by the production process are calculated from the energy consumed in the production process and by multiplying with a conversion factor; emissions due to transportation are accounted for by the fuel consumption of vehicles by multiplying with a conversion factor; and emission due to inventory storage at facilities are accounted for by multiplying energy consumption of facilities by a conversion factor (Pishvaee *et al.*, 2012; Soysal *et al.*, 2014; Wanke *et al.*, 2015; Zakeri *et al.*, 2015). Therefore, a traditional cost-efficient network optimization design has been reformulated into an eco-efficient network design. Different carbon constraints such as carbon caps and carbon credits have been integrated with conventional SCM constraints such as demand, supply, capacity and inventory balance constraints. Similarly, the objective function has also been reformulated with inclusion of minimization of total carbon emissions (Huppes and Ishikawa, 2005; Neto *et al.*, 2009; Kalenoja *et al.*, 2011; Sadegheih *et al.*, 2011; Wang *et al.*, 2013; Caputo *et al.*, 2014; Choudhary *et al.*, 2015; Carrano *et al.*, 2015; Gao and You, 2015; Colicchia *et al.*, 2016). In addition, Nouira *et al.* (2016) examined impact of emissions sensitive demand on facility selection. The emission issue has also been integrated into reverse logistics and a closed loop supply chain network design (Kannan *et al.*, 2012; Mohajeri and Fallah, 2014; Gao and Ryan, 2014; Garg *et al.*, 2015; Das and Posinasetti, 2015; Tao *et al.*, 2015). On the contrary, supply chain responsiveness is also an important criterion to be considered while deciding the network design. Therefore, there are trade-offs among the supply chain economic, carbon emissions and supply chain responsiveness criteria (Mohajeri and Fallah, 2016; Martí *et al.*, 2015; Tognetti *et al.*, 2015). Similarly, Kwon *et al.* (2015) analyzed a collaborative industrial ecosystem for CO_2 emission reduction in magnesium supply chains. Thus, a low carbon SCM network design is primarily an optimization model which is mainly formulated by the MILP method. The objectives of a low carbon network design are to decide the SCM network structure and resource allocation plan in such a way that the total supply chain cost and carbon emissions will be simultaneously minimized (Ortiz-Gutiérrez *et al.*, 2013; Paksoy and Ozceylan, 2014; Altmann, 2015; Boonsothonsatit *et al.*, 2015; Hasan *et al.*, 2015). Based on the above discussions, our finding is as follows.

F4: There is a Pareto-optimal solution for supply chain configuration that can reduce total supply chain cost at the same time transportation emissions. Thus, eco-efficient network design can improve emissions reduction at large.

3.2.5 Supply chain coordination. Supply chain coordination is a mechanism through which interdependent firms decide their pricing strategy. The primary objective is to optimize total supply chain profit. Such coordination mechanisms are revenue sharing, quantity discount and wholesale price (Zhou *et al.*, 2016; Yang *et al.*, 2017). In the case of low carbon supply chain coordination, the demand and profit function of a buyer, supplier and total supply chain have been reformulated with a new carbon emission constraint (Choi, 2013; Yang *et al.*, 2014; Du *et al.*, 2017). The objective of low carbon supply chain coordination is to maximize the total supply chain, retailer and manufacturer profit under these strict carbon emission constraints (Ji *et al.*, 2017). The major decision variables in the contract design are optimal wholesale price, retail price and ordering quantity (Jaber *et al.*, 2013; Chen and Hao, 2015; Huang *et al.*, 2016; Qi *et al.*, 2017). Different trading schemes such as carbon cap, cap and trade, carbon tax and carbon offset have been included in supply chain coordination strategies (Chen and Hao, 2015; Xu *et al.*, 2016; Ding *et al.*, 2016; Bai *et al.*, 2017; Toptal and Çetinkaya, 2017). Du *et al.* (2015) included consumer preferences for the low carbon product and emission sensitivity in the demand function. It is also found that consumer environmental awareness has an impact on manufacturers' and retailers' eco-performance (Liu *et al.*, 2012). Tseng and Hung (2014) incorporated social cost pertaining to CO_2 emissions in their supply chain design decision-making model. Further, a low carbon contract design may also be applied to the firm's investment decisions (Lukas and Welling, 2014; Jiang and Chen, 2016). Based on the above discussions our finding is as follows.

F5: With increasing preferences of low carbon products among the consumers, traditional supply chain coordination strategies such as revenue sharing, quantity discount and wholesale price have been reformulated, and decisions variables such as wholesale price, retail price and ordering quantity have also been redefined.

3.2.6 Collaboration. The literature suggests that the collaboration among supply chain members is not just limited to enhance the operational effectiveness of a supply chain it goes beyond that. Nowadays organizations have adopted different collaborative strategies to reduce overall supply chain emissions. For example, collaborative product design and production planning to reduce PCF (Trappey *et al.*, 2012), product configuration to reduce energy and material consumption (Jaegler and Burlat, 2012), multi-level supplier coordination optimization considering with the contract negotiation cost and total carbon emission cost (Huang *et al.*, 2016), collaborative game theoretic analysis to reduce environmental risk and carbon emission (Zhao *et al.*, 2012), collaborative decision regarding the demand consolidation during transportation and inventory replenishment (Treitl *et al.*, 2014; Tinoco *et al.*, 2017), and collaborative decision to last mile delivery either centralize distribution center or decentralize distribution center. Theiben and Spinler (2014) have emphasized on collaborative relationship among the supply chain partners, thereafter, providing six steps of successful collaboration to reduce carbon emissions. Thus, carbon emissions can be reduced by adopting different collaborative strategic decision of supply chain (Giurco and Petrie, 2007). Based on the above discussions our finding is as follows.

F6: Collaboration with suppliers, collaborative product design, collaborative transportation and inventory allocation can reduce overall GHG emissions.

3.2.7 Carbon management. Wiedmann and Minx (2008) defined CF as "The carbon footprint is a measure of the exclusive total amount of carbon dioxide emissions that is directly and indirectly caused by an activity or is accumulated over the life stages of a product." Sundarkani *et al.* (2010) and Benjaafar *et al.* (2013) proposed illustrative conceptual frameworks for integrating CF into supply chain modeling. In contrast, Mckinnon (2010) and Edwards *et al.* (2011) emphasized on accounting issues of CF. ISO 14067, DEFRA 2010, PAS 2050 and Greenhouse Protocol are some standard guidelines to account for carbon emissions (Ranganathan *et al.*, 2004; Yamin, 2012). In addition, a few conceptual frameworks, theoretical models, measurement methods and benchmarking of supply chain CF have also been developed. One can find these conceptual models in Sundarkani *et al.* (2010), Rizet *et al.* (2012), Hitchcock (2012), Dasaklis and Pappis (2013), Koh *et al.* (2013), Kuo (2013), Cordero (2013), Acquaye *et al.* (2014), Velazquez-Martinez *et al.* (2014), Farmery *et al.* (2014), Frizelle and Casali (2014), Court *et al.* (2015), Ingrao *et al.* (2015), Montoya-Torres *et al.* (2015) and Nakajima *et al.* (2015). Despite such standard guidelines, there is a lack of specific standard guidelines for product, corporate and national level CF accounting. Generally, LCA and hybrid Input-Output (IO)-based LCA are applied for product level CF measurement (Lee, 2011; Lee and Cheong, 2011; Elia *et al.*, 2012; Jensen, 2012; Pelletier *et al.*, 2013; Handler *et al.*, 2014; Lake *et al.*, 2015; Savino *et al.*, 2015; Wiedemann *et al.*, 2015). IO analysis is applied for national and corporate level CF measurement (Huang *et al.*, 2009; Munasinghe *et al.*, 2016). Further, common methodological issues in LCA are life cycle inventory accounting and environmental impact assessment (Jolliet *et al.*, 2003; Weisser, 2007; Bojarski *et al.*, 2009; Bevilacqua *et al.*, 2011; Vázquez-Rowe *et al.*, 2013; Godard *et al.*, 2013; Klein *et al.*, 2016). However, environmental impact assessment is beyond our scope of analysis because this is a technological aspect of environmental management.

The common methodological steps of life cycle inventory accounting are organizational boundary selection, scope identification, functional unit selection and final CF accounting

(Lee, 2012; Svanes and Aronsson, 2013; Aivazidou *et al.*, 2013; Murphy *et al.*, 2014; Miguel *et al.*, 2015; Agyemang *et al.*, 2016; Roibas *et al.*, 2016; Chen and Chen, 2017). Organization boundary is generally selected using equity approach and stakeholder analysis. Similarly, carbon emission scopes are classified into Scope-I (direct CO_2 emissions that are owned by a company), Scope-II (indirect greenhouse emissions) and Scope-III (other indirect GHG emissions) (Ranganathan *et al.*, 2004). Generally, Scope-I and Scope-II are considered for CF accounting. Functional unit is the standard operational unit for accounting CF. Because organizations measure emissions at the aggregate level, it is a challenging task to allocate aggregate CF data into individual product levels. This is because there is a lack of standard methodology for allocating CF in the product level (Zhu *et al.*, 2014). Moreover, structural decomposition analysis and structural path analysis are primarily applied to identify the hotspot area of carbon emission (Acquaye *et al.*, 2011; Pelton and Smith, 2015). Based on the above discussions our finding is as follows.

F7: LCA and IO analysis are primarily used to account PCF. Scopes identification, organizational boundary selection and allocation of aggregated carbon inventory data are primary challenges for LCA.

3.2.8 Empirical analysis on LCSCM. Some empirical research studies on LCSCM have been conducted to find the effectiveness of LCSCM. Giovanni and Vinzi (2014a) worked on Italian firms to determine the effectiveness of the Emission Trading Scheme (ETS) on a firm's internal and external environmental performances. They found that environmental collaboration was not effective with the ETS registered firms. This is because ETS registered firms have only focused on their environmental management performances (Giovanni and Vinzi, 2014a, b). Similarly, Zhu and Geng (2013) worked on drivers and barriers of Chinese energy saving and emission reduction goals. Saka and Oshika (2014) studied the impact of carbon emission disclosure on a firm's value. In particular, they investigated the uncertainty of firms' corporate value with respect to disclosure of carbon emissions. Nishitani *et al.* (2016) examined whether LCSCM reduces carbon emission or not; Gattiker *et al.* (2012) studied comparative CF of traditional hard text books and electronic e-books; Luthra *et al.* (2015) have studied the critical success factors of environmental sustainability; and Chen (2017) studied the relationship between inventory leanness, structural strategies such as outsourcing and product diversification and carbon intensity. Few case studies have also been reported in the literature. For example, Jabbour *et al.* (2015) studied critical success factor for eco-innovation by using the case study research method; Theiben *et al.* (2014) applied the case study method for reducing carbon emission by operational activity; Plambeck (2012) analyzed the impact of GHG emission on profitability using the case study method; Liljestrand *et al.* (2015) applied case study research to transport portfolio framework to reduce CF; Wu and Feng (2014) applied a questionnaire-based in-depth interview in Singapore for identifying non-value activities in production management. In addition, Long and Young (2016) conducted exploratory research on assessment of efficacy of GHG emission management by using grounded theory method. The results of above research about the effectiveness of LCSCM have been inconclusive. Hence, our finding is as follows.

F8: Very limited empirical studies have been conducted on LCSCM. The literature mainly covers the effectiveness of several emission reduction policies; disclosure of emission data; drivers, barriers and critical success factors of environmental management; and relationship between operational capabilities and emissions.

Based on the review of literature, the findings may now be summarized. Though every aspect of supply chain management has an impact on emission reduction the literature has suggested some important aspects for the same. For example, transportation (Rudi *et al.*, 2016), carbon constraint resource allocation (Altmann, 2015), location selection considering emission reduction objective (Musavi and Bozorgi-Amiri, 2017), suppliers' emission performance evaluation (Hsu, Kuo and Chiou, 2014; Kuo *et al.*, 2015), emission constraint lot sizing and ordering policy (Hua *et al.*, 2011), designing supply chain coordination contract considering ETSs (Du *et al.*, 2017), LCA of a product (Koh *et al.*, 2013; Acquaye *et al.*, 2014), etc., are some of the most relevant aspects of LCSCM. The role of lead players in the supply chain and the suppliers in reducing the carbon emission has been highlighted by Plambeck (2012) in his study of Walmart. It was found that Walmart has significantly reduced the emission level from its extended supply chains by imposing emission reduction target on its suppliers. Piecyk and McKinnon (2010) have noted that transportation is the major sources of GHG emissions from a supply chain. Therefore, pooling of supply chains for last mile delivery (Plambeck, 2012), demand consolidation (Brown and Guiffrida, 2014), full truckload strategy (Rudi *et al.*, 2016) and modes selection (Hoen *et al.*, 2014) are some of the measures to significantly reduce the carbon emission level. Though transportation is one of the most important cause of carbon emission in supply chains, the decisions on transportation are dependent on several other operational aspects of supply chains such as inventory lot sizing, supply chains demand, inventory ordering policy, inventory routing planning, etc. Supply chain configuration design is another strategic supply chain decision (Zakeri *et al.*, 2015), which may help in containing the carbon emission. It is very important to design supply chain network such as plants, warehouses and distribution centers in eco-efficient manner for gaining long-term benefits (Altmann, 2015). The frequency of transportation is largely a function of lot size of inventory (Hua *et al.*, 2011). Therefore, after the network design, inventory control models also have an impact on LCSCM. Supply chain coordination contracts have been found to optimally minimize both, the cost and emission from supply chain operations (Du *et al.*, 2015, 2017).

In compliance with the legislative requirements, accounting of CF from the operations is nowadays getting mandatory (Pandey *et al.*, 2011). The LCA is the most widely used methodology to account PCF (Acquaye *et al.*, 2014; Lake *et al.*, 2015). Thus, CF measurement is an integral part of LCSCM. There are other issues such as organizational boundary selection, aggregating and disaggregating emissions data, scope identification, etc., which need to be standardized in the literature. Though all the aspects of supply chain management have their direct or indirect roles in reducing the carbon emission transportation, network design and inventory planning are the key issues which are instrumental in reducing GHG emission from a supply chain.

4. Future research challenges and directions

It is a challenge for managers and researchers to decide whether the adoption of low carbon supply chain strategies improves a firm's economic and operational performances. Although few empirical studies (Giovanni and Vinzi, 2014a; Nishitani *et al.*, 2016) have been reported in the literature, the measuring construct for low carbon supply chain practices is still in the underdeveloped stage. Therefore, there is a need of developing a comprehensive construct for measuring the effectiveness of LCSCM. Additionally, the literature has failed to define the theoretical relationship of LCSCM with other management theories such as resource-based view, transaction cost economics, social exchange theory, modernization theory, etc. Compared to sustainable supply chain management, the theoretical foundation of LCSCM is in the nascent stage. Therefore, conceptual framework-oriented qualitative research is needed in this field. However, this could be a challenge for researchers to reconnect economic, social and organizational theories with LCSCM. Thus, future academicians may address following research questions on LCSCM:

RQ1. What are the antecedents, measuring construct and outcome of the LCSCM practices?

RQ2. How can organizational theories be related to LCSM practices?

In recent times, organizations have faced tremendous pressure from multiple stakeholders to reduce their overall emission level. Therefore, to integrate emission issues into supply chain decision-making models will be a challenge for the next-generation supply chain managers. Further, organizations need to analyze the carbon emission issue beyond their boundary. Thus, it is increasingly important for a parent organization to monitor its suppliers' carbon performance. However, this alone may not be effective. It is necessary to develop a long-term sustainable supplier network for gaining long-term sustainability. Thus, future academicians may address following research question on selection of suppliers:

RQ3. How to create a long-term sustainable suppliers network?

The integration of carbon emission issue with the traditional economic order quantity model has led to a reduction of emission levels but at the same time it has also increased the total cost of inventory (Hua *et al.*, 2011). Therefore, research is needed for optimal trade-offs among various environmental, economic and operational aspects of inventory control model. Demand consolidation with FTL strategy is found to reduce the transportation emissions (Danloup *et al.*, 2015). However, these practices require a close coordination among supply chain partners. Thus, in future, there should be more research on collaborative transportation planning for reduction in emission levels. However, uncertainty in demand and lead time will be a challenge for logistics managers. It could be resolved through incorporating stochastic control processes into the transportation planning model. Further, the last mile delivery option has incurred a huge amount of transportation emissions (Glock and Kim, 2015). However, the literature has failed to address optimal last mile delivery strategies for emission reduction. Thus, following research question on sustainable transportation may be addressed:

RQ4. How to develop a collaborative and sustainable transportation planning, which aims at optimizing the supply chain efficiency and carbon emission levels?

In recent years, increasing numbers of study that consider emission issue in facility location selection and resource routing planning have been conducted. However, these studies consider only environmental and economic aspects. In contrast, Martí *et al.* (2015) stated that customer responsiveness is also an important priority for an organization. Thus, in future, more eco-efficient multi-objective robust formulation should be made. It will be a challenge for managers to formulate this complex network design problem. In recent years, carbon ETSs have been integrated with the supply chain contracts design. However, consumer willingness to buy low carbon products has got little attention in the literature. Therefore, in the near future, more research should be carried out on carbon-constraint pricing in supply chain coordination strategy. Thus, following research question may address in future:

RQ5. How to trade-off among the operational, economic and environmental performance?

The main objective of LCSCM is to integrate the emission issue into supply chain management. Therefore, it is increasingly important to develop a comprehensive and standardized measurement model for supply chain CF. Although only some initial (Sundarkani *et al.*, 2010; Benjaafar *et al.*, 2013) conceptual models have been developed, there is a need for supply chain function-specific conceptual CF models in the literature. Another important aspect of LCSCM is CF measurement. Velazquez-Martinez *et al.* (2014) identified that the major difficulties for CF measurement are to define organization boundary, scope identification and allocation of aggregated carbon data at individual product levels. Thus, academicians and managers may address following research question on carbon management:

RQ6. How to define organizational scopes and boundaries for measuring PCF?

4.1 Research implications

In the recent years, integration of CF in supply chain decision-making process has got tremendous attention of academicians and practitioners. However, the present literature lacks to provide a comprehensive frame of reference on LCSCM. Based on our literature review, a mapping of various solution techniques and context-wise classification of the literature is provided in Table III. Thus, the major contribution of this study is to provide a comprehensive review of the literature on LCSCM. As an outcome of this review, some newly found problem contexts are also highlighted. Further, we highlighted some of the newly developed problem contexts on LCSCM as a result of our literature review. Thus, future researchers will have a complete frame of reference that will guide them to identify what are the key issues to consider for their research design. Apart from the theoretical contributions, this study has a lot of practical implications. We highlighted some of the practical findings of prior studies on emission constrained inventory control, transportation planning, facility location selection and supply chain coordination that will help supply chain practitioners in their decisions-making process. The issues related to the measurement of the CF, solutions tools and techniques, and the problem associated with boundary and scope identification have also been covered in this paper. This may guide the practitioners in measurement and analysis of supply chain CF.

5. Conclusion

This paper provides a comprehensive review of research on the emission issue in supply chain management. The literature indicates that due to an increased thrust on emission reduction a different kind of inevitable changes are now taking place in the domain of supply chain management. These changes are largely observed in supplier selection, inventory management policy, transportation planning, facility selection and contract design. This paper provides an exhaustive review of these changing supply chain practices. Because focal firms have integrated more carbon management criteria in line with the economic criteria in their supplier performance evaluation strategy in recent times, suppliers have to develop standard guidelines and management systems for improving their carbon performance to sustain themselves in this competitive environment. This will lead to a reduction of emissions at large. It is also observed from the literature that a change in the operational practices of supply chain management can lead to a reduction of emissions. By changing the inventory management policy, emissions can be reduced. This will, however, incur an increase in total cost. Similarly, demand consolidation, collaborative transportation planning and full truckload strategy will significantly reduce transportation emissions. However, these need close cooperation among supply chain partners. However, reaching an acceptable tradeoff among many of these conflicting criteria still remains a challenge for future managers and hence an issue of future research. In the future, smart logistic planning will be appropriate for this changing logistics requirement. It is also highlighted in this review that emissions can be reduced by effectively selecting facilities and their location. However, uncertainty of demand could be a challenge for the development of eco-efficient supply chain network design. Therefore, in future, stochastic mathematical modeling will be more appropriate for facility location decisions.

It is imperative to account for supply chain CF to find an effective strategy against emission. LCA has dominantly been used for PCF measurement. However, selection of organizational boundary for supply chains, standardized methodology and accuracy of data will be among the challenges for a reliable LCA. It would be a good idea if the interdisciplinary research community works on these topics of interest. The present study may also be extended in many ways by providing theoretical propositions or by drawing a conceptual framework through a systematic literature review.

Table III. Mapping of solution techniques and context-wise classification of the literature

	Context-wise classification												
		Inventory management		Transportation management			Network design		Carbon management				
Methodology	Low carbon supplier selection	Lot sizing problem	News vender problem	Mode Selection	Routing decision	Freight management	Facility location selection	Resource allocation	Carbon footprint	Hot spot identification	Supply chain coordination	Collaboration	Survey-based empirical research
Fuzzy ANP & TOPSIS	Kuo *et al.* (2015)												
ANP	Hsu, Kuo, Shyu and Chen (2014)												
DANP	Theiben and Spinler (2014)												
VIKOR	Hsu, Kuo, Shyu and Chen (2014) and Hsu, Kuo and Chiou (2014)												
DEA	Kumar *et al.* (2014)												
Algebraic equation		Sarkar *et al.* (2015), Bouchery *et al.* (2017), Bozorgi *et al.* (2014), Hua *et al.* (2011), Hammami *et al.* (2015), Sarkar *et al.* (2016) and Song *et al.* (2017)	Arıkan and Jammernegg (2014) and Jiang and Chen (2016)	Chen and Wang (2016) and Hoen *et al.* (2013, 2014)		Li *et al.* (2017) and Zhu *et al.* (2014)		Martí *et al.* (2015)	Frizelle and Casali (2014)		Berling and Eng-Larsson (2016), Chen and Hao (2015), Ding *et al.* (2016), Lukas and Welling (2014), Qi *et al.* (2017), Toptal and Çetinkaya (2017), Xu *et al.* (2016) and Zhou *et al.* (2016)	Tinoco *et al.* (2017)	
Non-linear function		Diabat and Al-Salem (2015) and Gurtu *et al.* (2017)				Rudi *et al.* (2016)					Choi (2013)		
Simulation					Danloup *et al.* (2015)	Arıkan *et al.* (2014)			Piecyk and McKinnon (2010)			Jaegler and Burlat (2012)	

(*continued*)

	Context-wise classification												
		Inventory management		Transportation management			Network design		Carbon management				
Methodology	Low carbon supplier selection	Lot sizing problem	News vender problem	Mode Selection	Routing decision	Freight management	Facility location selection	Resource allocation	Carbon footprint	Hot spot identification	Supply chain coordination	Collaboration	Survey-based empirical research
Mixed Integer Linear Programming (MILP)	Shaw, Irfan, Shankar and Yadav (2016) and Shaw *et al.* (2012)	Alhaj *et al.* (2016), Ni and Shu (2015) and Purohit *et al.* (2016)			Musavi and Bozorgi-Amiri (2017), Pishvaee *et al.* (2012), Qiu *et al.* (2017), Sadegheih *et al.* (2011) and Suzuki (2016)		Brandenburg (2015) and Nouira *et al.* (2016)	Altmann (2015), Das and Posinasetti (2015), Gao and You (2015), Gao and Ryan (2014), Kannan *et al.* (2012), Kostin *et al.* (2015), Paksoy and Ozceylan (2014), Shaw, Shankar and Yadav (2016), Tognetti *et al.* (2015) and Zakeri *et al.* (2015)					
Mixed Integer Non-Linear Programming (MINLP)					Glock and Kim (2015)		Wanke *et al.* (2015)	Garg *et al.* (2015) and Paksoy and Ozceylan (2014)					
Multi-objective Linear Programming (MOLP)					Kumar *et al.* (2016) and Validi *et al.* (2014)	Ameknassi *et al.* (2016)		Kuo *et al.* (2017), Neto *et al.* (2009), Pishvaee *et al.* (2012) and Soysal *et al.* (2014),					
Network equilibrium								Tao *et al.* (2015) and Wang *et al.* (2013)					
Convex optimization		Ghosh *et al.* (2017) and Ni and Shu (2015)											
Life Cycle Analysis (LCA]									Acquaye *et al.* (2014), Agyemang *et al.* (2016, Aivazidou *et al.* (2013), Carrano *et al.*	Acquaye *et al.* (2011) and Pelton and Smith (2015)		Loon *et al.* (2015)	

(*continued*)

Table III.

Table III.

Methodology	Low carbon supplier selection	Inventory management: Lot sizing problem	Inventory management: News vender problem	Transportation management: Mode Selection	Transportation management: Routing decision	Transportation management: Freight management	Context-wise classification – Network design: Facility location selection	Context-wise classification – Network design: Resource allocation	Carbon management: Carbon footprint	Carbon management: Hot spot identification	Supply chain coordination	Collaboration	Survey-based empirical research
									(2015), Chen and Chen (2017), Dasaklis and Pappis (2013), Elia *et al.* (2012), Farmery *et al.* (2015), Farmery *et al.* (2014), Giurco and Petrie (2007), Godard *et al.* (2013), Handler *et al.* (2014), Ingrao *et al.* (2015), Klein *et al.* (2016), Kuo (2013), Lee (2011), Lee (2012), Lee and Cheong (2011), McKinnon (2010), Murphy *et al.* (2014), Nakajima *et al.* (2015), Pelletier *et al.* (2013), Roibas *et al.* (2016), Rosen *et al.* (2000), Svanes and Aronsson (2013), Vázquez-Rowe *et al.* (2013), Velazquez-Martinez (2014), Weisser (2007) and Wiedemann *et al.* (2015)				
Input-Output method									Court *et al.* (2015), Huang *et al.* (2009), Koh *et al.* (2013) and Lake *et al.* (2015)				

(*continued*)

Table III.

Methodology	Low carbon supplier selection	Inventory management: Lot sizing problem	Inventory management: News vender problem	Transportation management: Mode Selection	Transportation management: Routing decision	Transportation management: Freight management	Context-wise classification Network design: Facility location selection	Context-wise classification Network design: Resource allocation	Carbon management: Carbon footprint	Carbon management: Hot spot identification	Supply chain coordination	Collaboration	Survey-based empirical research
Decisions support system				Liljestrand *et al.* (2015)			Boonsothonsatit *et al.* (2015)	Mohajeri and Fallah (2016)				Trappey *et al.* (2012)	
Game theory											Du *et al.* (2015, 2017), Ji *et al.* (2017), Liu *et al.* (2012) and Yang *et al.* (2014, 2017)	Huang *et al.* (2016) and Zhao *et al.* (2012)	
P-median							Lam *et al.* (2010), Rao *et al.* (2015) and Suzuki (2016)						
Others	Beer and Lemmer (2011), Cerutti *et al.* (2016) and Tidy *et al.* (2016)	Bazan *et al.* (2016)			Boschian *et al.* (2013), Brown and Guiffrida (2014) and Cachon (2014)				Jabbour *et al.* (2015), Kalenoja *et al.* (2011), Kwon *et al.* (2015), Long and Young (2016), Plambeck (2012), Rizet *et al.* (2012), Savino *et al.* (2015) and Sundarkani *et al.* (2010)		Tseng and Hung (2014)	Giurco and Petrie (2007), Theiben *et al.* (2014) and Treitl *et al.* (2014)	Chen (2017), Giovanni and Vinzi (2014a, b), Luthra *et al.* (2015), Nishitani *et al.* (2016), Saka and Oshika (2014) and Zhu and Geng (2013)

Note: The numbers in the table indicate the serial number of the corresponding article in the list of references

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