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Review

Green supply chain management: A review and bibliometric analysis

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ABSTRACT

The emergent field of green supply chain management has been rapidly evolving with a geometric growth in the number of academic publications in this field. A number of literature reviews have been published focusing on specific aspects of green supply chain management such as performance measurement, supplier selection/evaluation, analytical modeling efforts, and some others with broader areas of focus. This paper presents a thorough bibliometric and network analysis that provides insights not previously fully grasped or evaluated by other reviews on this topic. The analysis begins by identifying over 1000 published studies, which are then distilled down to works of proven influence and those authored by influential investigators. Using rigorous bibliometric tools, established and emergent research clusters are identified for topological analysis, identification of key research topics, interrelations, and collaboration patterns. This systematic mapping of the field helps graphically illustrate the publications evolution over time and identify areas of current research interests and potential directions for future research. The findings provide a robust roadmap for further investigation in this field.

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1. Introduction

Supply chain and operations management has matured from a field that myopically addressed only operational and economic matters to one that comprehensively considers the broader environmental and social issues that face organizations of today. The successful integration of economic, environmental and social sustainability goals has been at the forethought of leading supply chain and operations management. This emergent field has been growing for at least 20 years and is well into its third decade of investigation. Corresponding to a global trend, the concept of green and sustainable supply chain management has received more attention in the past decade and garnered emerging clusters of research in this area.

A number of literature reviews on green and sustainable supply chain management have been completed in the past few years. Some of these reviews have been general and comprehensively covered entire field (Seuring and Müller, 2008; Srivastava, 2007), whilst others have focused on specific aspects such as performance measurement (Taticchi et al., 2013), supplier selection in green supply chains (Igarashi et al., 2013) or analytical models for green supply chain management (Brandenburg et al., 2014; Govindan et al., in press). These reviews have identified various topical issues covered within the emergent research literature. They have been relatively straightforward in their analyses, providing summary aggregate statistics of the number of papers and topical areas (Brandenburg et al., 2014). Each study has provided insight into the field, but additional analysis of this literature using rigorous bibliometric tools can provide further insights not previously fully grasped or evaluated.

Network analysis through bibliometric tools can prove powerful for identifying established and emerging topical areas. It can also help identify the clusters of research and researchers showing how the various areas of thought may have emerged based on author and institutional characteristics. Identifying the more influential researchers within the clusters sets the stage for determining additional emergent study fields through capturing of more recent topics covered by these researchers. This paper presents a comprehensive evaluation of the field, focusing on forward green supply chain practices, starting with a pool of over 1000 published studies and filtering this pool to more influential works and investigators. Using rigorous bibliometric tools, a comprehensive network analysis (e.g. citation and co-citation analyses) is completed and five major clusters of research are identified. These algorithmically identified clusters set the stage for topical classification of the published models and further investigation of the evolution of these clusters over years. From these results additional insights are also gained on the current research interests and potential directions for future research.

The remainder of the paper begins with an overview of green supply chain management in Section 2 explaining how the field has been defined and reviewed in the past. Section 3 introduces the structured methodology used to identify and further refine the literature that will be reviewed and evaluated in this study. Some general observations are also made in Section 3 before presenting a detailed analysis using BibExcel and Gephi bibliometric network analysis tools in Sections 4 and 5. An evaluation of the results with a critical analysis is presented in Section 5. Section 6 summarizes the results, presents some limitations of this study, and discusses opportunities for future research.

2. Green supply chain management definition

The concepts of supply chain management and environmental management as strategic organizational practices to gain competitive advantage have been receiving increased attention especially during the period of the late 1980s and early 1990s. However, the relative importance of these strategic practices can be easily traced back to the early periods of the environmental management movement of the late 1960s (Sarkis et al., 2011). It was not until formalization of the field in the mid 1990s that investigations started to become more established (Seuring and Müller, 2008). Since these early beginnings, as we shall see in our literature review, there has been a geometric growth (upwardly increasing, nonlinear growth) in academic publications in this field. The topic has never been more important, both from a practitioner and from a research perspective. Recent practical evidence is provided from the latest United Nations Global Compact sustainability survey of major companies. The survey emphasized that managing the sustainability of supply chains is one of four key issues for diffusing corporate sustainability (United Nations, 2013b). Not only are environmental sustainability (greening) issues a concern, but burgeoning issues related to social sustainability have been gaining in importance (Sarkis et al., 2010; Seuring and Müller, 2008).

A consensus definition for green and sustainable supply chains does not exist. In fact, a review paper focusing purely on definitions for green and sustainable supply chains found a total of 22 definitions for green and 12 definitions for sustainable supply chain management (Ahi and Searcy, 2013). This issue alone makes a literature review on this topic a non-trivial exercise due to the many definitions that do exist. Part of this difficulty is the definition of a supply chain and where the boundaries are to be drawn (Sarkis, 2012). Whether terms such as logistics, reverse logistics, purchasing, and procurement are to be considered synonyms for supply chain management is another point of confusion. Similarly, whether definitional boundaries are affected by the inclusion of upstream and downstream partners in the supply chain is another concern in determining the search terms. To help bound the scope of our research, we focus our review on forward supply chains, leaving reverse logistics and closed-loop supply chains outside the scope of this study.

Comprehensive reviews of the green and sustainable supply chain management studies have been recently completed (Benjaafar et al., 2013; Brandenburg et al., 2014; Seuring, 2013b; Tang and Zhou, 2012; Varsei et al., 2014). Their focus has been on showing the growth of the field, identifying the research gaps, and specific areas of research interest. The linkage of the literature across authors, topics, and fields has been completed through content analysis and descriptive statistics. A more thorough network analysis is missing in these reviews. A network analysis is valuable for mapping the scope and structure of the discipline, identifying the most authoritative papers, and discovering key clusters of research. Without a thorough network analysis, determining these factors is less precise and more subjective. The proposed network analysis in this paper provides the opportunity to objectively identify the clusters of research streams within the green supply chain management literature, graphically illustrate the evolution of the field over time, and identify the areas of current research interests, and potential directions for future research. This paper complements the published reviews on the

topic and provides a more detailed and robust roadmap for further investigation in this field.

3. Research methodology and initial data statistics

Literature reviews aim to map and evaluate the body of literature to identify potential research gaps and highlight the boundaries of knowledge (Tranfield et al., 2003). Structured literature reviews are typically completed through an iterative cycle of defining appropriate search keywords, searching the literature, and completing the analysis (Saunders et al., 2009). Rowley and Slack (2004) recommend a structured methodology for scanning resources, designing the mind map to structure the literature review, writing the study and building the bibliography. In a similar approach, we use a five-step methodology for data collection and comprehensive evaluation of the field aiming to identify the most influential studies, determine the topical areas of research and provide insights for current research interests and directions for future research in the field.

3.1. Defining the appropriate search terms

The keywords used for data collection include "Supply Chain", "Green", "Environmental", "Sustainability", "Sustainable" and "Ecological". Four combinations of these keywords were used including (1) Green AND Supply Chain, (2) Environmental AND Sustainable AND Supply Chain, (3) Environmental AND Sustainability AND Supply Chain and (4) Ecological AND Supply Chain. Green supply chain can be defined mainly from two perspectives of operations and design. We ensured that both aspects are completely covered by the keywords chosen. For example green supply chain manufacturing/production, operations, purchasing, sourcing, performance measurement, product development, and product design are all covered by "Green Supply Chain". Since green supply chain management has emerged from environmentally sustainable development, other possible sustainability-related keywords, instead of "Green", were also used in our search attempts. Notice that reverse logistics and closed-loop supply chains were not included in our work to help further bound our efforts to those papers focusing on sustainability oriented supply chains.

3.2. Initial search results

Using the "title, abstract, keywords" search in Scopus database,[3] we collected and stored "journal" articles (conference papers, books and chapters of books excluded) for the defined search terms. The initial search attempts resulted in a total of 1586 articles. The breakdown of search results for the four sets of keywords is shown in Table 1. The search results were stored in RIS format to include all the essential paper information such as paper title, authors' names and affiliations, abstract, keywords and references.

[3] Managed by Elsevier publishing, Scopus is the largest abstract and citation database of peer-reviewed research literature in the fields of science, technology, medicine, social sciences, and arts and humanities. It covers over 20,000 peer-reviewed journals including those published by Elsevier, Emerald, Informs, Taylor and Francis, Springer and Interscience. The Scopus coverage details including access to tens of millions of peer reviewed journal articles can be found at http://www.info.sciverse.com/scopus/scopus-in-detail/facts. The Scopus database is more comprehensive than Web-of-Science database which would include only ISI indexed journals, limited to 12,000 titles only (Yong-Hak, 2013). Since we are focusing on peer-reviewed journals, we found that the Scopus database would capture the most reputable international journals, some of which may be relatively new, but influential. Scopus has been used and recommended as a good source of supply chain peer reviewed articles (Chicksand et al., 2012). One limitation of Scopus is the limited access to pre-1996 peer reviewed journal articles.

Table 1
The initial search results.

Search keywords	Search results (no. of papers)
Green AND "Supply Chain"	536
Environmental AND Sustainable AND "Supply Chain"	495
Environmental AND Sustainability AND "Supply Chain"	388
Ecological AND "Supply Chain"	167
Total	1586

Table 2
The search results after refinement.

Search keyword	Search results (no. of papers)
Green AND "Supply Chain"	381
Environmental AND Sustainable AND "Supply Chain"	293
Environmental AND Sustainability AND "Supply Chain"	82
Ecological AND "Supply Chain"	128
Total	884

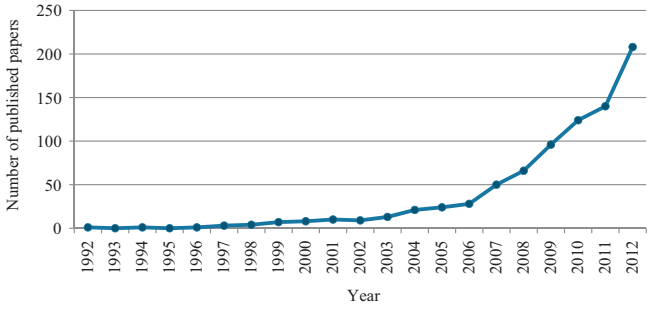

Fig. 1. Publishing trend in the area of green supply chain management.

3.3. Refinement of the search results

From 1586 papers in Table 1, many papers appear in more than one category. Eliminating these duplications leaves 1066 unique papers. Amongst these papers are short non-refereed papers and those published in commercial magazines which may not be regarded as scientific contributions. Further refinement to eliminate these non-refereed articles, commercial magazine papers and those with unknown author names resulted in 884 journal articles, published during a 21-year period, between 1992 and 2013. Given that the beginning of the debate on green supply chain management is traced to the 1990s (Seuring and Müller, 2008; Srivastava, 2007), it is no surprise that the oldest papers in our search attempts date back to 1992. Table 2 shows the number of articles after refinement for each of the four search categories. To create the corresponding refinements in the RIS file, the RIS data was imported to Endnote bibliography software, the elimination of papers was completed in Endnote and the format was reconverted to RIS. The resulting RIS file is used for further data analysis.

3.4. Initial data statistics

Fig. 1 shows the trend in quantity of articles published. While the field is still in its early growth and expansion period, these results show that a geometric growth in publications is occurring. The initial statistics show that 396 journals have contributed to the publication

Table 3
The top 10 publishing journals contributing to the area of green supply chain management.

Source	Publication year																		
	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Total
Journal of Cleaner Production							3	2	2	2	3	3	11	5	5	5	6	12	59
International Journal of Production Economics						1					2	1	5	1	1	4	17		32
International Journal of Production Research												6		3	3	1	9	3	25
Business Strategy and the Environment	1	1		1					1	2	1	1	4	1	3	3	2		21
Supply Chain Management: An International Journal			2	1						1			2	2		1	7	2	18
Environmental Science and Technology								2	1	1		1	1	3	3	3	2		17
Computer Aided Chemical Engineering											1		1		1		10		13
Ecological Economics								1				2		2	2	2	3	1	13
International Journal of Physical Distribution and Logistics Management												1		1	6	1	3	1	13
International Journal of Life Cycle Assessment										1		1	1	2	4	2	1		12
Journal of Industrial Ecology						1					1	1		4	1	2	2		12
Sustainability														1	3	4	4		12
Total	1	1	2	2		2	3	5	4	7	8	17	25	25	32	28	66	19	247

of 884 papers. It was found that 10 journals have published 247 of these identified articles, representing approximately 28% of all papers published. Table 3 shows the journals in which these papers appeared. There are also additional journal statistics that are not shown in this table. For example, the *Journal of Cleaner Production* and *International Journal of Production Economics*, which appear on top of this list, have the highest self-citation rates within this sample. Alternatively, data on citation between journals shows that these two journals, especially the *Journal of Cleaner Production*, are also the most cited by other journals.

3.5. Data analysis

Given the nature of a citation analysis study, we adopt an inductive approach for the purpose of data analysis (Seuring and Müller, 2008). The literature classification portion of this study is completed before the actual data analysis by using a deductive approach. Data analysis is conducted in two parts including a "bibliometric analysis" and a "network analysis", presented in Sections 4 and 5, respectively. Bibliometric analysis using BibExcel provides additional data statistics including author, affiliation and keyword statistics. BibExcel is chosen due to its flexibility to work with large datasets and the compatibility with different computer applications including Excel, Pajek and Gephi (Persson et al., 2009). BibExcel is also used to prepare the input data for a detailed network analysis. The network analysis part uses Gephi to perform a citation analysis and topical content-based classification of the existing literature of green supply chain management. Gephi is chosen over the existing network analysis software such as Pajek (Batagelj and Mrvar, 2011) and VOSviewer (van Eck and Waltman, 2013) due to its capability to work efficiently with large datasets and providing a range of innovative visualization, analysis and investigation options.

4. Bibliometric analysis

Several software packages have been used in the past for bibliometric analysis, each with different capabilities and limitations. Some of the most popular tools include Publish or Perish,[4] HistCite,[5] and BibExcel.[6] BibExcel was chosen for this study due to its high degree of flexibility in modifying and/or adjusting the input data imported from various databases including Scopus and Web of Science, and the ability to provide comprehensive data analysis for use in a range of network analysis tools including Gephi, VOSviewer and Pajek (Persson et al., 2009). For example, HistCite only accepts data from Web-of-Science and Publish or Perish only from Google Scholar and Microsoft Academic Search. Furthermore, none of these tools provide sufficiently detailed network analysis data in their output. Whilst a powerful tool for analyzing bibliographic data (or any data of a textual nature formatted in a similar manner), one drawback of BibExcel is its relatively complex operating environment requiring several training hours. We use BibExcel to perform some initial bibliometric and statistical analysis and to prepare the input data for additional network analysis in Gephi.

Table 4
The top 10 contributing authors and number of published articles.

Author	Number of published articles
Sarkis, J.	26
Zhu, Q.	17
Klassen, R.D.	9
Koh, S.C.L.	9
Lai, K.H.	9
Lenzen, M.	9
Seuring, S.	9
Vachon, S.	7
Chan, H. K.	6
Guillén-Gosálbez, G.	6

The data source used as input into BibExcel is in RIS format (Scopus output) containing the bibliographic information of the articles. Our analysis is focused on the following pieces of information: authors, title, journal, publication year, keywords, affiliations, and references. These analyses require reformatting of the RIS file into a number of different formats and hence producing several file types. An OUT-file needs to be first created to enable data analysis in Bibexcel. Interested readers can refer to Paloviita (2009) and Persson et al. (2009) for more

[4] http://www.harzing.com/pop.htm.

[5] http://interest.science.thomsonreuters.com/forms/HistCite.

[6] http://www8.umu.se/inforsk/Bibexcel.

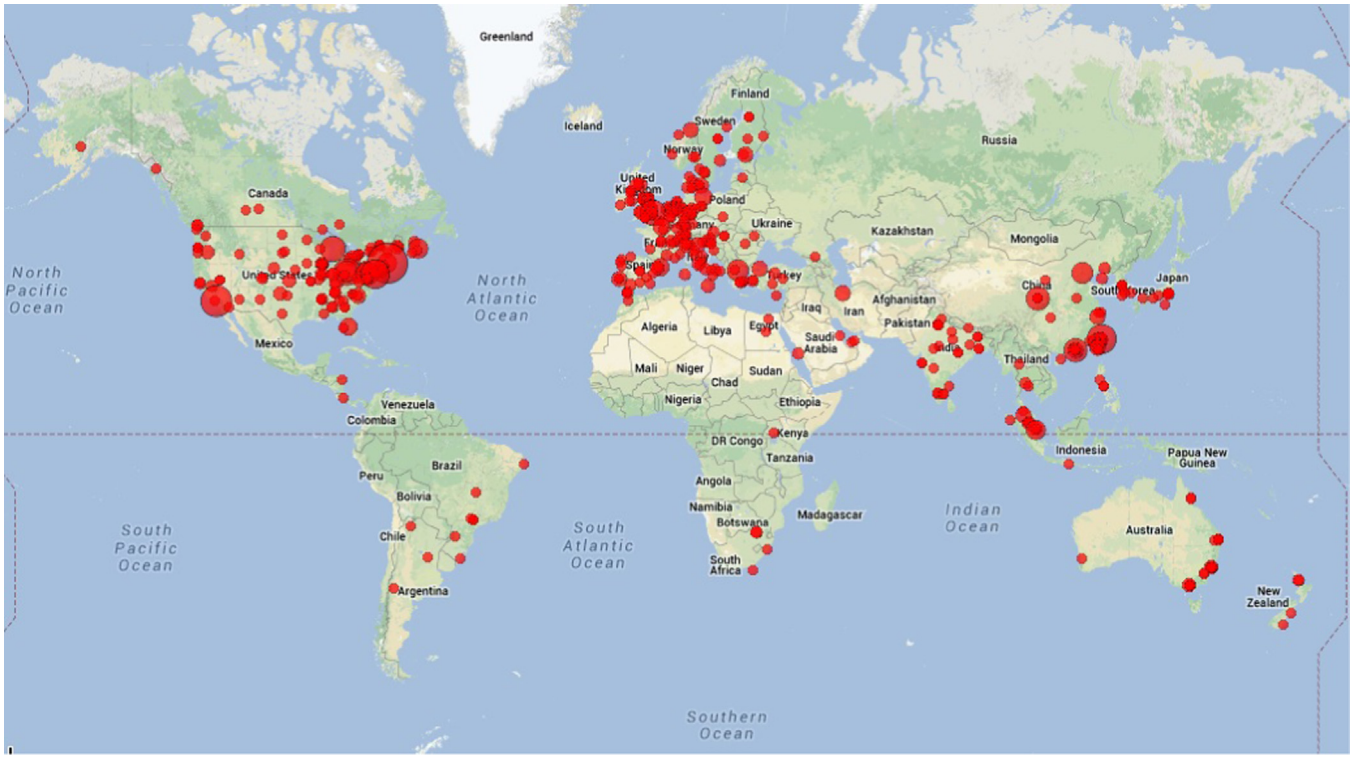

Fig. 2. (Color online) Geographical locations of all contributing organizations.

detailed procedure and applications of Bibexcel in bibliometric and statistical analysis. The following sections provide the author, affiliation and keyword statistics drawn from our Bibexcel analysis.

4.1. Author influence

BibExcel can be used to analyze the frequency of occurrence of a text in different fields of the bibliographic data. The author field was extracted from the data file and frequency of appearance of all authors was recorded. Table 4 outlines the top ten contributing authors and the quantity of papers they authored or co-authored.

As can be seen in this data Sarkis and Zhu seem to dominate the list. It should be noted that Sarkis and Zhu have coauthored with each other a large number of these papers. Vachon and Klassen were also co-author of a number of their papers. While the majority of these researchers have backgrounds in operations research/management and supply chain management, two fall outside this category: Lenzen, with a background of physics focuses on general sustainability research and Guillen-Gosalbez with an environmental engineering field focus. More than half of these leading scholars tend to publish using analytical formal modeling techniques. Sarkis and Zhu have published both analytical formal models, such as multi-criteria decision making tools, and broad based empirical case studies. The proliferation of their work may be explained by the flexibility of methodologies and theories they have used. Other scholars tend to utilize more descriptive case studies and empirical approaches. Seuring, for example, utilizes case studies and literature analyses in his works. Overall, the breadth of methodologies and disciplines even amongst the more prolific scholars exemplifies the interdisciplinary nature of green and sustainable supply chain research.

4.2. Affiliation statistics

The affiliations of the authors were extracted from the RIS file in BibExcel. For each affiliation, the city where the organization is located was extracted for this analysis. Using the coordination of these cities in gpsvisualizer.com, Fig. 2 shows the geographical locations of organizations contributing to green supply chain literature. The size of the red circles is proportional to the contribution degree of each organization. Greater density of contributing organizations can be found in the Eastern United States and the Western Europe. Overall, the geographical dispersion of these organizations indicates that green supply chain research and practice has attracted organizations and research centers from around the globe.

Table 5
Contribution of organizations based on their geographical regions.

Geographical region	No. of papers	Percentage contribution (%)
Europe	651	39.41
Northern Europe	329	19.92
East Asia	214	12.95
Western Europe	185	11.20
Southern Europe	137	8.29
North America	479	28.99
United States	414	25.06
Northeast United States	128	7.75
Midwest United States	117	7.08
Western United States	90	5.45
Southern United States	79	4.78
Canada	72	4.36
Asia	373	22.57
South Asia	61	3.69
Southeast Asia	56	3.39
Middle East	42	2.54
Oceania	72	4.36
South America	20	1.21
Rest of the World	37	2.24
No affiliation in Scopus records	20	1.21

Table 6
The top 20 contributing organizations.

Organization	Location	No. of papers
Clark University	United States	37
Dalian University of Technology	China	21
Hong Kong Polytechnic University	Hong Kong	20
Aristotle University of Thessaloniki	Greece	15
University of Western Ontario	Canada	9
Oslo School of Management	Norway	6
Universiti Teknologi Malaysia	Malaysia	6
Copernicus Institute for Sustainable Development and Innovation	Netherlands	6
Kansas State University	United States	5
National University of Singapore	Singapore	5
China National Chemical Information Center	China	5
The University of Sydney	Australia	5
Thammasat University	Thailand	4
University of Leeds	United Kingdom	4
University of Moncton	Canada	4
University of Cantabria	Spain	4
The Ohio State University	United States	4
University of Santiago de Compostela	Spain	4
Nanyang Technological University	Singapore	4
Dokuz Eylul University	Turkey	4

Table 7
The most frequently used words in paper titles.

Word	Frequency	Word	Frequency
Supply chain	352	Energy	50
Green	249	Food	44
Sustainable/Sustainability	227	Carbon	40
Management	160	Logistics	38
Environmental	151	Case study	37
Performance	63	Model	35
Development	56	Manufacturing	34
Production	52	Social	24
Assessment	55	Water	25
Life-cycle	50	Closed-loop	23

A greater provincial breakdown of these contributions can also be given for different geographical regions of USA, Europe and Asia. The United States' divisions are obtained from US Census Bureau (2013) and data from United Nations (2013a) is used for drawing the European and Asian regions. We add Canada and Oceania to these categories and include the other regions in a final category of "rest of the world" due to their smaller aggregate contributions. Table 5 shows the contribution of each region to the literature of green supply chain management (note that papers with authors from different organizations may have been assigned to multiple regions).

The top performing organizations (based on the number of papers contributed), their geographic location and the quantity of papers contributed are shown in Table 6. Comparing this list with the top 10 contributing authors in Table 4, we observe that Clark University, Dalian University of Technology, Hong Kong Polytechnic University, University of Western Ontario, The University of Sydney, and University of Kassel are represented respectively by the more prolific authors Sarkis, Zhu, Lai, Klassen, Lenzen, and Seuring. Thus, it may only take the work of one or two researchers for an organization to be ranked as a top performer.

4.3. Keyword statistics

A similar analysis is conducted to identify the most frequently used words/phrases in the paper title and the list of keywords. The top 20 keywords used in the paper titles are summarized in Table 7. Similarly, Table 8 shows the most popular keywords from the list of keywords. This is from a pool of 2421 keywords drawn from 884 papers. A comparison between the two tables indicates that in most cases there is a consistency in the use of keywords in the title and the list of keywords. For example, the top keywords in both tables include a combination of supply chain, green, sustainability, environmental management and life-cycle. Obviously, the four most popular words in Table 7 occur because they were the search keywords chosen in this study. The "life-cycle" keyword is the most interesting to appear since there is an implication that much of the green supply chain research has a life cycle perspective to it.

Table 8
The most popular keywords.

Word	Frequency	Word	Frequency
Supply chain management	142	Environment	20
Sustainability	135	Environmental performance	19
Green Supply Chain Management	69	Industrial ecology	16
Supply chain	84	Recycling	16
Sustainable development	62	Environmental sustainability	15
Green supply chain	61	Carbon footprint	15
Environmental management	56	Environmental issues	14
Life-cycle assessment	53	China	13
Reverse logistics	34	Remanufacturing	12
Corporate social responsibility	20	Optimization	12

5. Network analysis of publications

A network analysis and graphical investigation is now completed for the selected sample. Different tools are available for this purpose, the most popular of which include Pajek, VOSviewer, HistCite Graph Maker, and Gephi. Gephi was chosen for this study due to its visualization flexibility (editable and user-friendly environment), advanced filtering capabilities, ability to work with different data formats, and several built-in network analysis toolboxes. For example, HistCite graph maker is restricted to Web-of-Science data outputs and Pajek works with files in ".Net" format only. VOSviewer does not have the limitation of Pajek in

making manual amendments in network illustrations, but then it only offers limited network analysis toolboxes.

"Gephi" is an open source software package that uses a 3D render engine to develop illustrations of large networks in real-time and assist in speeding up the exploration process (Gephi, 2013). The flexible and multi-task architecture allows innovative approaches to work with complex datasets and produce insightful visual aids. Gephi provides easy and broad access to network data and assist in specializing, filtering, navigating, manipulating and clustering of data (Bastian et al., 2009). For Gephi to be able to map and visualize the citations among papers, a graph dataset is needed to be generated in which published papers are shown as nodes and citations are represented by the arcs/edges between the nodes. The bibliographic data obtained from Scopus (in RIS format) cannot be directly used for this purpose. The file needs to be reformatted to represent a graph dataset. BibExcel is used as a mediator to prepare this dataset. Gephi accepts a number of graph data formats including ".NET" which is what BibExcel is able to generate. In this format, each paper has different information fields and data can be extracted from each filed, as required, for Gephi analysis. The list of references of each paper, which was initially extracted from Scopus bibliographic data, is included in one of these fields. This bibliographic data field is used for citation analysis.

5.1. Citation analysis

A citation analysis is used to examine the degree of connectivity between pairs of nodes/papers in the created 884-node network. The initial citation analysis in Gephi revealed that 455 papers out of 884 have cited each other. About 25% of these papers have been cited only once. The top 10 papers based on the number of local citations are shown in Table 9. "Local citation" refers to the number of times a paper has been cited by other papers within the 884-paper network, and "global citation" is the overall Scopus citations for the paper. The noticeable gap between local citation and global citation values in Table 9 indicates that green supply chain management has also received attention from researchers in other disciplines (i.e. they have also been cited by papers not appearing in our search results). It can also be seen that the order of papers based upon local citation does not necessarily match the global citation order. For example Seuring and Müller (2008) is ranked 6th based on the number of local citations, but has the highest global citation count. This result is interesting since the citation references for Seuring and Müller (2008) seem to be more popular outside the realm of green supply chains. A major reason is that Suering and Müller present a structured methodology for literature reviews and the methodological approach is highly cited, not just for content.

Zhu, Sarkis, Vachon, Klassen and Seuring who have co-authored seven out of 10 highly-cited papers (Table 9) are also represented in the list of top authors in terms of quantity of papers contributed (Table 4). Thus, not only are they prolific, but also influential in the papers they publish. It is also likely that self-citation has increased the number of local citations for each. Interestingly, most of these highly-cited papers have been authored by non-European authors, while from Table 5 we saw that Europe has contributed the greatest number of works. It should however be noted that as a general rule, the highly cited papers have had sufficient time to establish citations. This is evidenced by the fact that all these highly-cited papers are at-least five years old and that some of the more recent papers which have not yet been cited by others in the network are not even included in our citation analysis. One approach to capture the immediate impact of more recently published papers is to use an "average citation" or "citation per year" measure (i.e. local citation divided by the number of years from publication). Interestingly, we found that 9 out of 10 highly cited papers are also amongst the top ten papers using an average citation measure. Seuring and Müller (2008) and Zhu and Sarkis (2004) hold the highest average citations, about 14 citations per annum. Bai and Sarkis (2010) with about eight citations per annum is the only paper that is not appearing in Table 9, perhaps due to its more recent publication date.

Table 9
The top 10 papers: citation measure.

Author (year)	Local citation[a]	Global citation[b]
Zhu and Sarkis (2004)	67	309
Sarkis (2003)	62	311
Vachon and Klassen (2006)	57	186
Rao (2002)	49	154
Linton et al. (2007)	43	222
Seuring and Müller (2008)	38	372
Hervani et al. (2005)	37	194
Seuring (2004)	34	80
Vachon and Klassen (2008)	31	153
Zhu et al. (2005)	28	168

[a] Local citation: citation within the 884 papers.
[b] Global citation: actual Scopus citation.

Table 10
The top 10 papers: PageRank measure.

Author (year)	PageRank	Local citation	Global citation
Rao (2002)	0.0245	49	154
Green et al. (1996)	0.0219	20	94
Zhu and Sarkis (2004)	0.0206	67	309
Green et al. (1998)	0.0192	23	95
Sarkis (2003)	0.0181	62	311
Vachon and Klassen (2006)	0.0138	57	186
Azapagic and Clift (1999)	0.0094	6	154
Seuring (2004)	0.0092	34	80
Linton et al. (2007)	0.0089	43	222
Seuring and Müller (2008)	0.0089	38	372

5.2. PageRank analysis

Different methods have been used in the past to measure the significance of a paper. The most common method is to count the number of citations (Cronin and Ding, 2011) which was presented in Section 5.1. Ding et al. (2009) argue that in addition to *popularity* of a paper measured by the number of citations, *prestige* is another important indicator which is the number of times a paper is cited by highly cited papers. A highly-cited paper may not necessarily be a prestigious paper, although in some cases there might be a strong positive correlation between the two measures. PageRank is used as a measure for both popularity and prestige.

PageRank was introduced by Brin and Page (1998) to prioritize web pages when a keyword search is performed in the Google search engine. This initial application of PageRank to determine the relationship between webpages can be extended to explore the relationship between papers in a citation network. Assume paper A has been cited by papers $T_1, \ldots, T_n$. Define parameter d as a damping factor, set between 0 and 1, to represent the fraction of random walks that continue to propagate along the citations. Also, $C(T_i)$ is defined as the number of citations going out of paper T_i (i.e. the number of times T_i has cited other papers). The PageRank of paper A ($PR(A)$) in a network of N papers is calculated as follows:

$$PR(A) = \frac{(1-d)}{N} + d\left(\frac{PR(T_1)}{C(T_1)} + \ldots + \frac{PR(T_n)}{C(T_n)}\right)$$

Note that if $C(T_i) = 0$, then $PR(T_i)$ will be divided to the number of papers instead of $C(T_i)$. The PageRanks form a probability distribution

over papers and hence the sum of all papers' PageRanks will be equal to one. The formula calculates PageRank using an iterative algorithm and corresponds to the principal eigenvector of the normalized citation matrix of the papers. In the original Google PageRank algorithm of Brin and Page (1998), the parameter d was set equal to 0.85 using the anecdotal observation that an individual surfing the web will typically follow of the order of 6 hyperlinks, corresponding to a leakage probability of $1/6 \cong 0.15 = (1-d)$, before becoming bored with this line of search and begin a new search. In the context of citation analysis, Chen et al. (2007) showed that entries in the reference list of a typical paper are collected following somewhat shorter paths of average length of two, making $d=0.5$ a more appropriate choice for PageRank analysis in citation networks.

Table 10 shows the top papers using a PageRank measure. Comparing the top ten papers based on citation and PageRank (Table 9 versus Table 10), we see that three of the highly-cited papers are not among the top ten high-PageRank papers. These include Hervani et al. (2005), Vachon and Klassen (2008) and Zhu et al. (2005). In return, Green et al. (1996, 1998) and Azapagic and Clift (1999) appear in the top 10 papers with highest PageRank, but they are not high-cited papers. Given that PageRank is greatly influenced by the citations from other high-cited papers, the later-published papers (especially after 2005) have obviously had a limited chance to be cited by other high-cited papers (simply because they have not been around long enough to establish citation). Notice that the top ten highly cited papers in Table 9 were published prior 2008 (majority prior 2005) and the prestigious papers from this period could only reference earlier works. This observation is further supported by the fact that the average publication date is much earlier in the top ten papers using a PageRank measure (Table 10) than those using a citation measure (Table 9). As the field matures and stabilizes in terms of output, PageRank will likely give a better picture of overall prestige of publications.

5.3. Co-citation analysis

The co-citation map visualization is a form of exploratory data analysis (EDA) that relies on graph theory to explore the data structure (Pampel, 2004). A co-citation map consists of a set of nodes representing journal articles and a set of edges representing the co-occurrence of nodes/articles in the reference list of papers of that map (Leydesdorff, 2011). Publications are co-cited if they appear together in the reference lists of other documents. Therefore, papers A and B are co-cited if both papers A and B are cited by paper C. It has been shown that papers that are more often cited together by other papers are more likely to be related and hence belong to a similar subject area (Hjørland, 2013). We use this concept to map and classify the literature of green supply chain management.

The generated ".NET" file in BibExcel can be directly opened in Gephi for co-citation analysis. Even though a ".NET" file format only contains limited features related to the network's topology, it suffices for the purposes of this study's analysis. The initial co-citation mapping with Gephi revealed that there are 235 articles out of a total of 884 that have been co-cited by other papers within this sample. When opening the ".NET" file in Gephi for the first time, the positioning of the nodes in the citation map is randomly generated by the software. This default layout has no discernible pattern, which is not surprising due to the random nature of the positioning. The nodes have identical sizes, but different x and y coordinates. Gephi however offers a variety of algorithms for creating different layouts. Force Atlas is a force-driven algorithm and the most recommended layout by the developers in terms of simplicity and readability. The network is arranged in a way that linked edges attract and linked nodes repulse each other. It also allows for the manual adjustment of the repulsion strength, gravity, speed, node size and other characteristics (Bastian et al., 2009). With this algorithm, the most connected nodes move to the center of the network while the more isolated (less connected) nodes move to the borders. Fig. 3 illustrates the Force Atlas layout of the proposed 235-node citation map.

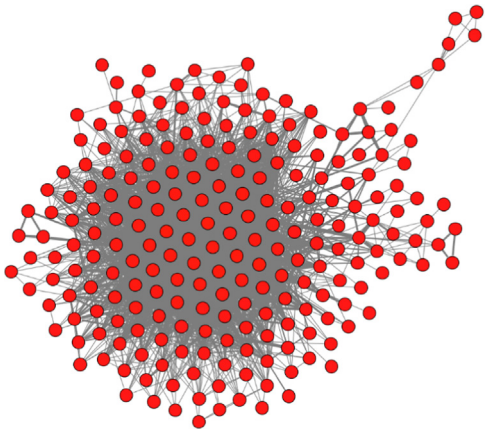

Fig. 3. The Force Atlas layout of the 235-node network.

5.3.1. Data clustering: topical literature classification

The nodes of a network can be divided into clusters or modules where the density of edges is greater between the nodes of the same cluster compared to those of different clusters (Clauset et al., 2004; Leydesdorff, 2011; Radicchi et al., 2004). Where nodes represent articles in a literature network, a cluster can be seen as a group of well-connected articles in a research area with limited connection to papers in another cluster or research area. Data clustering can be used as a classification tool for grouping of a set of given articles (Radicchi et al., 2004). Clustering allows for the topological analysis of networks, identifying topics, interrelations, and collaboration patterns. Modularity has received increasing attention from scholars turning it into a critical research field in social network analysis (Blondel et al., 2008).

The default modularity tool in Gephi is based on the Louvain algorithm, an iterative optimization model that aims to determine the optimal number of partitions that maximize the modularity index (Blondel et al., 2008). The modularity index of a partition is a scalar value between -1 and $+1$ that measures the density of links inside communities versus the links between communities. According to Blondel et al. (2008), for a weighted network (i.e. networks with weighted links, such as the number of communications between two mobile phone users), the modularity index can be formulated as

$$Q = \frac{1}{2m}\sum_{ij}\left[A_{ij} - \frac{k_i k_j}{2m}\right]\delta(c_i, c_j),$$

where A_{ij} represents the weight of the edge between nodes i and j, k_i is the sum of the weights of the edges attached to node i ($k_i = \sum_j A_{ij}$), c_i is the community to which vertex i is assigned, $\delta(u, v)$ is equal to 1 if $u = v$ and 0 otherwise, and finally $m = (1/2)\sum_{ij} A_{ij}$.

Applying this algorithm to the filtered 235-node network resulted in the creation of five major clusters. The number of papers in each cluster varies from 20 in cluster 5 to 69 articles in cluster 1, the largest module. Gephi allows the use of different layouts for presentation of the resulting modules. Fig. 4 shows a layered configuration of the five clusters where the papers of each cluster are included in one separate orbit/circle. The modularity index in Fig. 4 is equal to 0.167 indicating the significant interrelationships between clusters. This result is evident by comparing Fig. 4b with a, with and without the edges/arcs displayed.

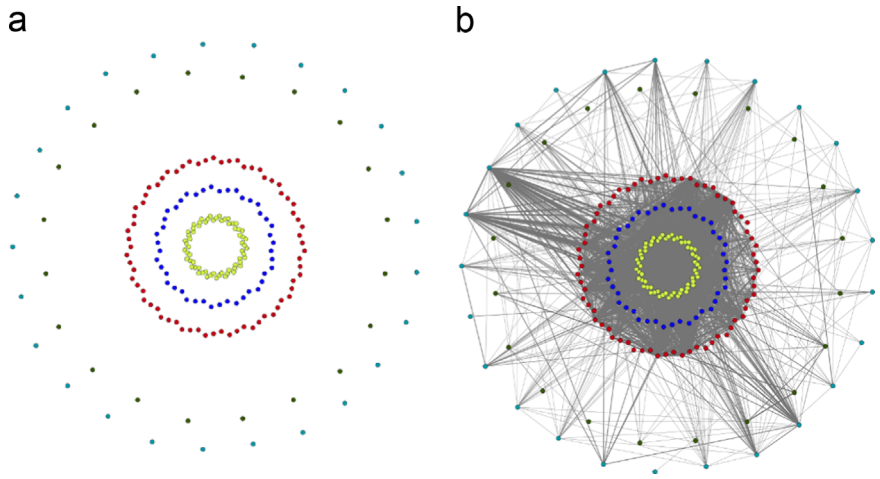

Fig. 4. The layered configuration of the seven clusters: (a) the layered configuration of the nodes in seven clusters and (b) the layered configuration with arcs between nodes.

Table 11
The lead papers of each cluster: co-citation PageRank measure.

Cluster 1	Cluster 2	Cluster 3
Seuring and Müller (2008)	Zhu et al. (2008a)	Zhu et al. (2008b)
Yu et al. (2010)	Zhu et al. (2007)	Vachon (2007)
Seuring (2004)	Zhu et al. (2011)	Kainuma and Tawara (2006)
Wiedmann (2009)	Zhu and Sarkis (2007)	Bai and Sarkis (2010)
Wiedmann et al. (2011)	Zhu and Sarkis (2004)	Holt and Ghobadian (2009)
Preuss (2005)	Zhu and Sarkis (2006)	Lu et al. (2007)
Veleva et al. (2003)	Zhu et al. (2005)	Vachon and Mao (2008)
Wolf and Seuring (2010)	Walker et al. (2008)	Ciliberti et al. (2008)
Stoughton and Votta (2003)	Zhu and Cote (2004)	Testa and Iraldo (2010)
Wu and Pagell (2011)	Vachon and Klassen (2006)	Kuo et al. (2010)
Cluster 4	**Cluster 5**	
Tsoulfas and Pappis (2006)	Bojarski et al. (2009)	
Chien and Shih (2007)	Mele et al. (2011)	
Hsu and Hu (2008)	Grossmann and Guillén-Gosálbez (2010)	
Olugu et al. (2010)	Guillén-Gosálbez and Grossmann (2010)	
Arimura et al. (2011)	Fiksel (2010)	
Georgiadis and Besiou (2008)	Chaabane et al. (2012)	
Curkovic and Sroufe (2011)	Corsano et al. (2011)	
Olugu et al. (2011)	Giarola et al. (2011)	
Simpson (2010)	Guillén-Gosálbez and Grossmann (2009)	
Georgiadis and Besiou (2010)	Barari et al. (2012)	

Given that papers that are more often co-cited are more likely to present similar subject areas (Hjørland, 2013) and that papers within a cluster have strong co-citation relationship (Clauset et al., 2004; Leydesdorff, 2011; Radicchi et al., 2004), careful analysis of papers of one cluster can define the area of research focus of that cluster. Due to the high number of papers in each cluster, we completed this content analysis for the lead papers of each cluster. The lead papers of each cluster were identified based on their co-citation PageRank.[7] It was also found that most of the papers with high citation also possess a high co-citation PageRank (true in 9 out of 10 instances). The lead papers of each cluster are shown in Table 11. The next step was to carefully evaluate the contents and research areas of the lead papers to be able to determine the area of research focus of each cluster (i.e. characterizing or labeling of clusters). The cluster labeling process was completed by the two senior scholars. Table 12 summarizes the areas of research focus for each of the five clusters.

[7] For co-citation networks, the PageRank algorithm gives higher weights to papers that are (1) co-cited with different papers and (2) co-cited with highly co-cited papers. "Co-citation PageRank" has been shown to be an effective measure for determining the top papers in a given co-citation cluster (Ding et al., 2009; Yan and Ding, 2011).

The topical literature classification summarized in Table 12 shows that green supply chain management investigations have tended to focus on theoretical, conceptual and empirical studies (clusters 1–3) to show the feasibility of jointly improving environmental and economic performance of supply chains. Such results do not inevitably occur without design, planning, and support (area of research in clusters 4 and 5). Our five-cluster classification shows that normative, prescriptive, and quantitative modeling efforts have received significantly less attention. This is consistent with observations of some of the recent reviews (Seuring, 2013a; Seuring and Müller, 2008; Srivastava, 2007). Therefore, the primary insight that can be gained from this classification is the opportunity for additional research in formal modeling of green supply chain management which from a practical point of view can help steward and convince supply chain participants of the benefits of greening their supply chains. In fact, more recently some of the scholars have focused on closing this modeling gap (Abdallah et al., 2012; Chaabane et al., 2012; Fahimnia et al., 2013a, 2013b, in press-b), but not all of these efforts have been captured in our five-cluster topical classification due to their relatively recent publication and hence inability to establish citation.

Although clusters 1 and 2 overlap with theory development, cluster 1 focuses on initial conceptual and theory development, which may be

Table 12
The five major research clusters and their areas of research focus.

Cluster	No. of papers	Area of research focus
1	69	Theory development – Sensemaking Conceptual development of the field
2	63	Testing hypothesis/theories/factors Broad-based empirical studies
3	44	Measuring and evaluation of sustainability Further understanding of the trends in the field
4	25	Barriers in practical applications Design and planning strategies
5	20	Prescriptive mathematical modeling and optimization Solving practical problems Identifying the problem areas

Table 13
The joint author–cluster analysis.

Author	No. of papers contributed to each cluster				
	1	2	3	4	5
Sarkis, J.		11	2	1	
Zhu, Q.		9	1		
Lai, K.H.		4	1		
Seuring, S.	8	1			
Lenzen, M.	4				
Klassen, R.D.	1	5			
Koh, S.C.L.					
Vachon, S.		3	2		
Guillén-Gosálbez, G.					4
Chan, H.K.		2	1		

more exploratory in nature. This first cluster will be dependent on making sense of the field. The second cluster focuses on taking more established theories and confirming and advancing them through more rigorous testing, typically empirically oriented testing. The most popular clusters are the first two, characterized by older articles (by publication date). The field matures through these early stages in helping to describe and evaluate the field, an inevitable requirement for the development of prescriptive measures and normative models. With this strong foundational knowledge and descriptive background we have available today, it is expected that the latter clusters will continue to grow for the next decade.

The contribution of top-10 authors to the evolution of clusters is shown in Table 13. This joint author–cluster analysis shows that only one author, Guillén-Gosálbez, not an operations/supply chain management researcher, has been contributing to the last cluster. Most of the other prolific authors are spread over a variety of clusters. For example, Sarkis has a spread over three clusters showing larger breadth in his work. Zhu and Lai, who have co-authored several papers with Sarkis, seem to also have a similar pattern of contributing to cluster 2 and 3 papers. This may be due to the similarities in the empirical methodologies used, in addition to overlapping theories. But, there are also authors who contribute solely to one cluster such as Lenzen completely in cluster 1, although he has overlaps with operations and supply chain management works of Klassen and Seuring.

5.3.2. *Dynamic co-citation analysis*

To help understanding the evolution of green supply chain research over time, we also complete a dynamic co-citation analysis for the papers of all clusters. Table 14 shows the number of papers published in each cluster since 1996. As could be expected, the earlier

Table 14
The number of published papers at each cluster (1996–2012).

Year	No. of published articles				
	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5
1996		1			
1997		1			
1998	1	2			
1999		2			
2000	1	3			
2001	1	2	1	1	
2002	1	2	1		
2003	6	2			
2004	3	3			
2005	3	4	2		
2006	3	4	2	2	
2007	10	9	3	1	
2008	10	11	7	3	
2009	8	6	7	5	4
2010	10	3	8	10	3
2011	10	7	6	3	7
2012	2	1	7		6
Total	69	63	44	25	20

publications had more focus on theory development, conceptual analysis and empirical studies (clusters 1 and 2). It was only after 2005 when the focus shifted to assessing sustainability measures and further sensemaking of the field (cluster 3). However, the theoretical and conceptual developments have continued to grow until more recently when more focus has been placed on modeling efforts and practical applications. What is very clear from Table 14 is the growing interest in green supply chain management research evidenced by the increasing quantity of published models, especially after 2005.

This evolution is also graphically shown in Fig. 5. The size of a node for each layout represents the PageRank of the article and hence the larger the size of a node, the more highly-cited and prestigious the corresponding paper. Reinforcing our former findings, the top papers using a PageRank measure, denoted by the larger nodes in Fig. 5, are co-authored by Zhu and Sarkis. The evolution of topics and methodologies is very strong as cluster 5 continues to grow and clusters 1 and 2 stabilize. It can be expected that the prescriptive/normative papers in cluster 5 will continue to grow at an increased pace as can be seen by an initial step increase in 2009.

6. Conclusions and directions for future research

This paper presented a structured review of green supply chain management literature. There have been hundreds of papers published in this area, many of them in the past decade. Although a few literature reviews on green and sustainable supply chain management have been published, a thorough bibliometric and network analysis to analytically and objectively identify influential works and authors and emergent research clusters has not been completed. This initial effort shows an evolution of the influential articles and contributes to the field by further mapping the relationships amongst the higher impact works.

Our findings see that there is a relative concentration of the more influential works amongst a handful of scholars. Yet, as the field continues to mature, many additional authors have joined this sub-discipline of supply chain management expanding the work in a variety of areas. Many of the more influential papers seemed to have occurred in the middle of the last decade. This result is not surprising since it was around this period that the rigor of the research started to increase. The recently published works, within the last 3–4 years, have not had a chance to gain as much traction since citations have yet to accrue,

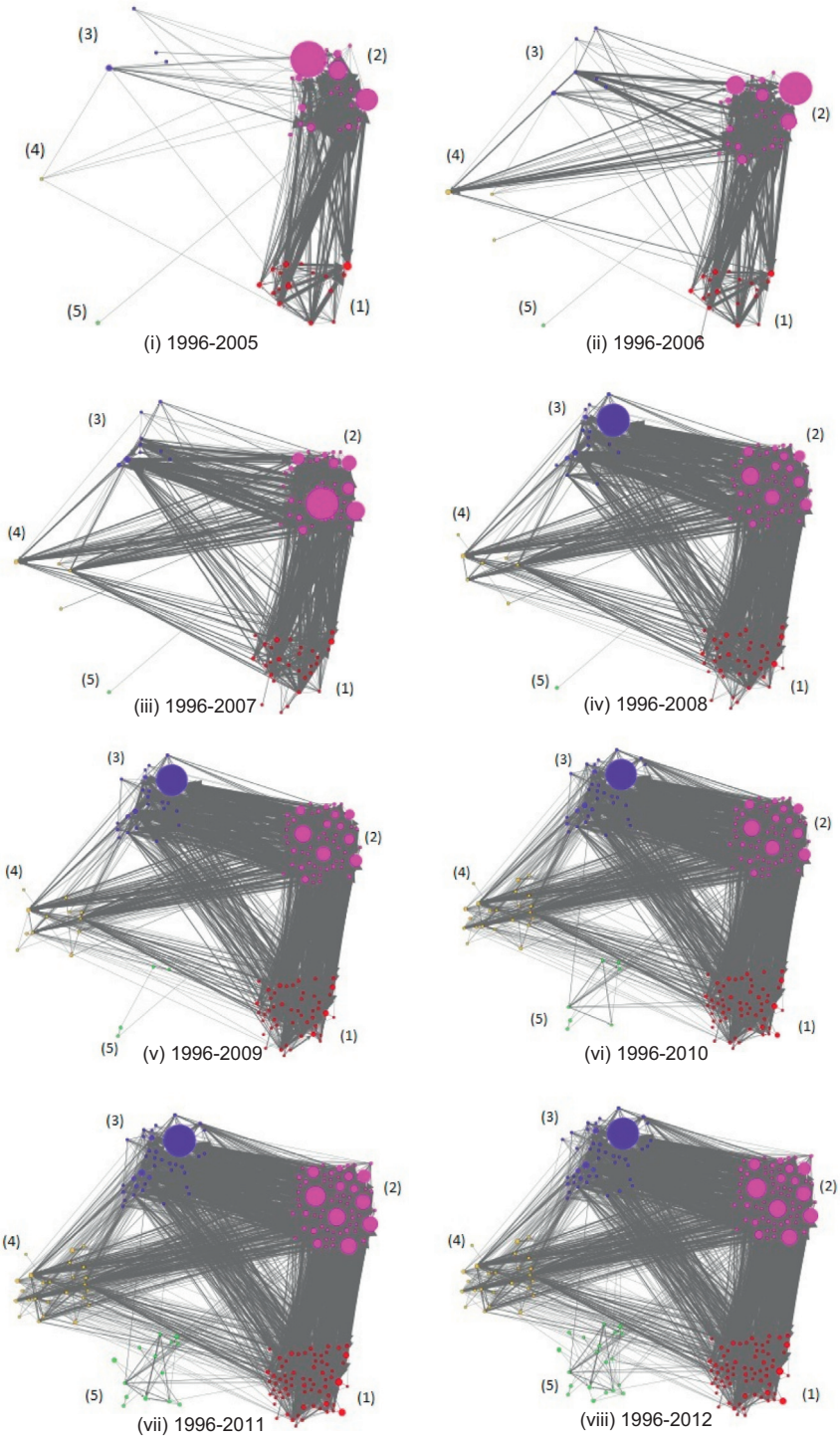

Fig. 5. The evolution of research areas/clusters over time.

given that management and business research typically requires a longer time to build citations.[8]

The geographic dispersion of the works did show that Europe, though with few highly influential publications, seemed to have the greatest number of works, with North America not far behind. The diffusion of the work into Asia is also starting to occur. We observed, using an objective clustering approach, that conceptual and empirical studies have set the foundation and represent the most influential works. Our topical literature classification shows that prescriptive, normative, quantitative modeling has started to take on greater importance. We see this as the most fruitful direction of research, especially through practical real data usage and modeling, for the next few years.

For those seeking to do research in the area, and for pedagogical purposes, the identified "core" articles may prove a good starting

[8] For example, based on the 2012 Journal Citation Reports of the Web of Knowledge listing (http://admin-apps.webofknowledge.com/JCR/), the Aggregate Cited Half-Life for Business journals is >10 years, while for the Applied Physics discipline it is 5.8 years. This shows that diffusion of publication citations is slower in Business fields, especially when compared to basic sciences such as physics and chemistry (interested readers can refer to the study of Larsen and Ins (2010)).

point. We identified some of the more recent works that can be utilized to identify potentially influential works. Awareness of the various scholars who are influential in this field is important since they may set the stage for future developments. Carefully monitoring their and their co-authors' works can provide some guidelines for further research. For example, recent works of some leading scholars have focused on sustainability and sub-supplier management, behavioral/individual issues in sustainable supply chains, and barriers and enablers evaluation of sustainable supply chain implementation.

We can also identify some weaknesses in these results and the field overall. First, the small number of scholars and repetition in the studies, although influential, may provide a stagnant view of the sustainable supply chain management discipline. We hope this is not the case and trust additional and diverse researchers will be contributing and influencing the field in innovative and interesting directions. The lack of non-Western, non-Asian researchers is problematic. Sustainable and green supply chain management is necessarily globalized. Broadening the number and location of countries where green supply chain management is investigated is required. Without the voices of less developed countries amongst the researchers portends a major weakness and belies a multiculturally and globally relevant viewpoint.

Not only is there a relative lack of diversity in the authorship and location of the work, the lack of cross-sector efforts limits the "transdisciplinarity" of this field – see a discussion on transdisciplinarity in sustainability research by Creasey (2007). That is, the field is dominated by teams of academic scholars. Practitioners, whether they are industry or policymaker partners, are almost completely absent within these research teams. Perhaps, this explains why much of the research to date has been conceptual and theoretical. The issue of usefulness of such investigations in practical and policy environments is brought into question. Future research needs to utilize actual data from industry practices instead of merely relying on subjective opinions of respondents. Integrating real industry data and practitioner groups into academic investigations will likely benefit both practical and theoretical advancement. This may occur more frequently as practical and normative modeling continues to develop in the green supply chain management field.

Overall, the sustainable and green supply chain management field is growing and maturing. Significant room still exists for development given the small number of influential articles and that there are only 235 papers relatively connected. This number should be expected to increase given the solid foundation provided by the existing research, a foundation that did not exist a decade ago. In particular, opportunities abound for additional research in formal modeling of green supply chain management with practical applications. This has been a research focus in some of the more recently published works (Abdallah et al., 2012; Chaabane et al., 2012; Diabat et al., 2013; Fahimnia et al., in press-a; Pinto-Varela et al., in press).

Part of this research requirement also means an expansion to what we completed in this study. Clearly, there are limitations in how we structured and presented the results of this study. Expanding the keywords to include logistics, transportation, shipping, alliances, interorganizational efforts, partnering, and a wide variety of other keywords could result in a more exhaustive review of the field. For example, green logistics and green purchasing were early precursors to the green and sustainable supply chain field. The topic of reverse logistics was also not as prominent. Additional future research expansion in this direction would identify numerous other contributions and potentially shift the core research areas further. The inclusion of additional keywords will however result in a larger pool of papers which will then require innovative bibliometric and network analysis tools and approaches. Most of the existing tools have difficulty working with very large datasets. There are also opportunities for additional content analysis of specific and influential manuscripts to further identify gaps and research directions. Additional longitudinal analysis of the field will help determine if our forecast of evolution to more prescriptive and normative models continues.

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