Logist. Res. (2012) 4:39–47
DOI 10.1007/s12159-012-0071-3

REVIEW ARTICLE

Green supply chain research: past, present, and future

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Received: 8 October 2011 / Accepted: 4 February 2012 / Published online: 18 February 2012

Abstract In the past several decades, great strides have been made to incorporate the ethical and environmental responsibilities into the core culture of today's business world. With the increased attention paid to such responsibilities, a growing number of firms have explored "greening" (environmental-friendly) initiatives as their competitive strategic weapons. This paper traces the evolution of green supply chain research, synthesizes the past and current research efforts to develop a viable green supply chain strategy, and then proposes promising future research themes related to this strategy.

Keywords Green supply chain management · Sustainability · Corporate social responsibility (CSR)

1 Introduction

Realizing that sustainability can drive the improvement of the company's bottom line through cost savings, improved market share, and stronger brand images, a growing number of firms have begun to take "greening" (environmental-friendly) initiatives as their strategic weapons. Following this industry trend, the interest of academia on sustainability has also begun to increase substantially in the late 1990s. This growing interest sparked a series of new lines of research dealing with various supply chain activities that have important environmental implications. These activities include sourcing that involves acquiring, storing, handling, and recovering virgin or recycled materials. In sourcing, for example, the failure to reduce the obsolescence and waste of maintenance, repair, and operating (MRO) supplies or scrap materials can contribute to environmental problems. In manufacturing, for example, the irresponsible disposal of defective products or unwanted manufacturing by-products can adversely impact the environment. Likewise, logistics reliance on transportation modes such as trucks and airplanes using fossil burning fuels and the subsequent emission of CO_2 can pollute the living environment such as air, water, and ground. One of the first attempts to consider the environmental implications of supply chain activities includes: [5, 12, 18]. To elaborate, Sarkis [12] identified potential research agenda by linking environmentally conscious manufacturing to supply chain management. Min and Galle [5] examined the impact of environmentalism on purchasing practices and identified a variety of environmental factors influencing the supplier selection decision through the empirical study. Based on the in-depth case study of furniture companies, Walton et al. [18] discovered that environmentally friendly supply chain practices could help the company lower cost and better serve its customers.

Following suit, a series of studies dealing with the environmental implications of supply chain practices were conducted, and the body of literature on green supply chain management has grown dramatically over the last two decades [1, 10, 14, 15]. Despite this explosive growth of green supply chain research, there are still numerous

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opportunities for further studies and scientific investigations. To identify these opportunities while avoiding the duplications of past research efforts, the main objectives of this paper are to: (1) classify the past literature on green supply chain management (GSCM) through the structured taxonomy; (2) develop a frame of references; (3) chronicle the evolution of the GSCM research for the last 15 years; (4) identify the emerging trends of GSCM research; and (5) point the direction of future research.

2 Research framework

Despite the relative youth of GSCM research, its body of literature is abundant. Given this rich GSCM literature, it is important for us to examine, evaluate, and integrate prior studies related to the topic of GSCM. Without the effort to synthesize prior GSCM research, we may end up duplicating what has already been studied, fail to develop a new theory built upon the previous efforts of others, and experience difficulty in identifying emerging research agenda that were often overlooked in the past. This effort begins with the retrieval of past research works on GSCM through the on-line literature search, a summary of research outcomes, critiques of prior research works, identification of key research themes and popular research streams, and integration of past research efforts. To elaborate, we first defined GSCM in the broadest possible sense so that we could conduct thorough literature searches and determine how GSCM literature was evolved from the theoretical underpinnings of other related social science, economics, business, and engineering fields. To avoid confusion created by a lack of consensus on GSCM terminology and the introduction of rivaling concepts such as sustainable supply chain management (SSCM) propagated by some circles of the academia, we would like to define GSCM as an incorporation of environment-friendly initiatives into every aspect of supply chain activities encompassing sourcing, product design and development, manufacturing, transportation, packaging, storage, retrieval, disposal, and post-sales services including end-of-product life management. Herein, the examples of environment-friendly initiatives include the company-wide environmental guidelines/policy, compliance with environmental regulations (e.g., U.S. Environmental Protection Agency rules, European Union environmental regulations) and standards (e.g., ISO 14000 environmental management standards), supplier certification and selection based on its commitment to sustainability, use of renewable energy (e.g., sunlight, wind, rain, and geothermal heat), use of biofuels, use of degradable or compostable packages, and environmental performance monitoring. To systematically locate past research works relevant to the above definition of GSCM, we utilized several literature search methods specified below.

2.1 Literature search media

Prior to locating past research works relevant to GSCM, we need to choose the target populations that will be the references of this literature review. Our target populations are primarily articles published in refereed scholarly journals that fit into the definition of GSCM made earlier. Excluded are parts of the book chapters, dissertations/theses, working papers, white papers, and proceeding papers presented in the academic conferences. We also excluded published articles that dealt with generic environmental issues, but had no direct bearing on supply chain management. In other words, our literature review primarily focuses on the prior studies addressing environmental issues associated with the business activities of sourcing, making, and delivering. To avoid the reference biases, the primary means to find the target publications includes a variety of reference-retrieval sources: on-line keyword search through Google, Google Scholar, Thomson Reuter Web of Science, and Dow Jones Factiva; the educational database search via the Academic Source Complete (ASC) and Electronic Journal Center (EJC) of Ohio Link; EBSCO Business Source Complete database; keyword search through the ABI/INFORM Research™ database and the Procite© database in which the past literature has been classified according to content- and methodology-oriented criteria; the perusal of tables of contents of the key academic journals (e.g., *Journal of Business Logistics*, *International Journal of Physical Distribution and Logistics Management*, *International Journal of Logistics: Research and Applications*, *International Journal of Logistics Management*, *International Journal of Logistics Systems and Management*, *Journal of Operations Management*, *International Journal of Production Research*, *International Journal of Operations and Production Management*, *Journal of Supply Chain Management*, *Supply Chain Management: An International Journal*) in the fields of supply chain management; and tracking articles listed in the reference sections of widely cited GSCM articles. Examples of keywords that we used include: "green supply chains," "sustainable supply chains," "closed-loop supply chains," "reverse logistics," "environmental-friendly sourcing," "green purchasing," "hazardous material transportation," "industrial ecology," and "remanufacturing." Due to the sheer size of the initial search results—ASC alone produced more than 400 entries—we perused the abstracts of only the published articles to see whether they contained any keywords related to supply chain management and then screened them one by one. To delimit the number of publications, we excluded articles that did not incorporate environmental initiatives

into any aspect of supply chain management (i.e., sourcing, making, and delivering) or the ones that failed to integrate environmental thinking with supply chain perspectives. For example, publications that discussed environmental policy, pollution control, waste management, or life cycle assessment, but had no direct ties to sourcing, making, and delivering activities were omitted from the list. In other words, content analysis was performed to examine any relationships between the concept of environmental thinking and that of supply chain management in the context of the published article. Since the term "supply chain management" was rarely used in the 1980s and earlier, we primarily focused on the articles published in 1995 and later. The complete literature search through the multiple media specified above yielded a total of more than 519 articles as of December 31, 2010.

2.2 The taxonomy of the GSCM literature

To provide an organized look at the published literature and review it in a systematic fashion, we develop the taxonomy of the GSCM literature. This taxonomy will help the researcher identify hot research fields of GSCM, neglected areas of research, and research trends. In terms of the subject areas of research, this study classified the published GSCM articles into six areas of applications. These six categories are developed by taking into account a sufficient number of published articles (at least a total of 40 hits) in the each cluster of categories and the typical breakdown of key supply chain activities (sourcing, making, and delivering):

- *Policy,* which is mainly concerned with business ethics and corporate social responsibility tied to triple bottom lines (namely the three pillars of people, planet, and profit), environmental policy guidelines addressing public community concerns, environmental audits, statutory requirements, and government regulations.
- *Synthesis,* which portrays a broad picture (e.g., literature reviews, research agenda explorations, and tutorials) of green supply chain management that cuts across the different boundaries (business activities integrating sourcing, making, and delivery processes) of supply chain management.
- *Purchasing,* which focuses on environmental issues related with supplier–buyer relationship, environmentally sound sourcing decisions, and supplier certification and selection based on environmental quality standards such as ISO 14000 guidelines (see, e.g., [5]).
- *Manufacturing,* which pays attention to remanufacturing, environmental-friendly product design and development that aims to reduce pollution and harmful waste (e.g., see, [4]).
- *Green Logistics,* which deals with environmental issues related to sustainable transportation, hazardous material handling and storage, inventory control, warehousing, packaging, and facility location-allocation decisions that aim to reduce carbon footprints (see, e.g., [8]).
- *Reverse Logistics,* which improves logistics efficiency in handling returned or recycled products and managing waste disposal and removal after the end of a product life cycle (see, e.g., [16]).

In terms of the research methodologies, the papers are categorized into the following areas:

- *Conceptual* Those expository studies that discuss the strategic importance of greening initiatives to supply chain management and summarize emerging trends and/or newer environmental quality concepts based on qualitative analyses.
- *Case study* Those intensive studies primarily focused on idiosyncratic nature of a single or several real-life examples that reflect the relevance/irrelevance of certain theories or prescriptions. Case studies as a research methodology explain, explore, or describe a phenomenon of interest. This requires a methodologically rigorous and accurate representation of actual data and multiple sources of evidence. Thus, the purposes, presentation of data, and methods for gathering data may differ among cases [2]. However, real-life contexts under special focus of the case study are not perfect representation of the population and thus can be questioned for generality and consistency [3].
- *Exploratory* Those employing descriptive data analyses based on the questionnaire survey data that intend to identify the most prevalent environmental practices and synthesize the common opinions of practitioners regarding environmental initiatives. This type of methodology that often relies on the summary statistics is less concerned about theory building or theory refinement (see, e.g., [9] for an application of an exploratory study to the logistics area).
- *Empirical* Those based on a social science research tradition that aims to develop, advance, and refine theories through hypotheses testing by employing rigorous statistical data analyses such as a structural equation model or other forms of confirmatory data analysis such as path analysis that helps find cause–effect relationships among a set of variables. This type of methodology is increasingly used to build theories in the GSCM literature (see, e.g., [13] for a methodological foundation of an empirical study).
- *Analytic* Those employing quantitative tools such as integer programming, dynamic programming, goal programming, nonlinear programming, and other

techniques such as simulation, systems dynamic modeling, or soft systems methodologies (SSM) (see, e.g., [17]).

3 The analysis of prior GSCM literature

The detailed analysis of prior GSCM literature can provide us with a glimpse of what was investigated, observed, and discovered, which areas of concern are overlooked by past studies, how those studies are typically conducted, and where those studies are published. With this in mind, we summarize the detailed analysis of the past GSCM literature published for the last 15 years.

3.1 Key publication outlets

Based on this preliminary search, the academic journals in business and in other related areas where GSCM issues are published were identified. Those are listed in Table 1. Although some specialty journals exclusively devoted to environmental issues such as *Journal of Cleaner Production* tops the list, many traditional supply chain journals such as *International Journal of Production Research*, *International Journal of Production Economics*, *European Journal of Operational Research*, and *International Journal of Physical Distribution and Logistics Management* round out the top five list. This fact implies that sustainability has been deeply ingrained in the supply chain discipline and has become one of the hottest and emerging topics in the supply chain field. On the other hand, there are a growing number of specialty journals exclusively dedicated to environmental issues that cover GSCM issues as shown in Table 1. Examples of those journals include: *Greener Management International; Journal of Environmental Management; Resources, Conservation and Recycling; Corporate Social Responsibility and Environmental Management; Journal of Industrial Ecology;* and *Corporate Environmental Strategy*.

3.2 The research classification

According to the taxonomy developed earlier, the extant literature on GSCM was categorized with respect to its focused research area and methodology as recapitulated in Table 2.

In terms of the research area, reverse logistics turns out to be the most popular theme with a total count of 198 papers out of 519 GSCM papers. A subject of the environmental policy is the second most popular theme with a total of 82 papers.

In terms of the research methodology, the analytic papers representing the hard core of the traditional operations management paradigm or that of industrial engineering case study takes up the overwhelming majority with a total count of 171 papers, and the case studies comprise the second largest with a total of 143 papers. Though perceived to be less rigorous than analytic or empirical studies due to its expository nature, conceptual papers seem to be almost on a par with case studies with a total of 117 papers.

Figure 1 shows the trend in the number of published GSCM articles by the year of publication. Reflecting the growing strategic importance and popularity, the number of GSCM papers has steadily increased over the last 15 years. Especially, we have witnessed a surge in the number of GSCM publications in 2010, signaling the explosive growth of this line of research. After a slight decline in 2002, 2003, 2004, 2006, and 2009, the number of GSCM publications nicely rebounded in 2008 and 2010 and actually peaked in 2010 with a total of 78 publications.

Figure 2 shows the number of GSCM publications by the research methodology. Overall, an analytic method is the most favored research methodology, which was followed by case study and conceptual methods. In particular, the number of analytical papers surged from the year 2007 onward, whereas case studies tapered off. Especially, we have witnessed a dramatic rise in the number of analytical papers in 2010. A rapid growth of analytical papers is due in part to the increased popularity of reverse logistics modeling.

Figure 3 shows the numbers of papers by the research areas published each year. The papers dealing with the reverse logistics issues show the most visible growth, the year 2006 onward in particular. The popularity of reverse logistics studies reflects the increased public appeal and acceptance of reuse, recycling, and reduction of the amount of virgin materials used. Also, thriving e-tailing businesses increased the chance of returned products, which created more challenging reverse logistics problems. These problems became a popular subject of GSCM research as revealed by the content analysis of the reverse logistics literature [10]. In addition, green logistics seemed to bring more attention to GSCM researchers in 2010. This upward pattern reflects the company's increased efforts to reduce greenhouse gas emissions associated with manufacturing, product use, and recycling. For example, Apple began to estimate its total carbon footprints associated with its manufacturing, transportation, use, and recycling using the comprehensive lifecycle analysis in 2010. On the other hand, after peaking in 2008, the GSCM research dealing with policy and strategic issues has begun to decline for the last several years. This pattern reflected the fact that an increased government involvement in mitigating negative

Table 1 A list of popular publication outlets for GSCM research

Journal name	Number of GSCM articles published	Popularity ranking
Journal of Cleaner Production	134	1
International Journal of Production Research	49	2
International Journal of Production Economics	36	3
European Journal of Operational Research	32	4
International Journal of Physical Distribution and Logistics Management	19	5
Computers and Industrial Engineering	18	6
International Journal of Logistics Systems and Management	18	6
Supply Chain Management: An International Journal	18	6
Journal of Operations Management	14	9
Business Strategy & the Environment	14	9
International Journal of Logistics: Research and Applications	13	11
Greener Management International	12	12
Omega	10	13
International Journal of Operations and Production Management	9	14
Journal of Business Logistics	7	15
Journal of Supply Chain Management (including the International Journal of Purchasing and Materials Management)	7	15
Production and Operations Management	6	17
Journal of Environmental Management	6	17
Transportation Research E: Logistics and Transportation Review	6	17
International Journal of Logistics Management	5	20
Journal of Manufacturing Technology Management	5	20
Interfaces	4	22
Resources, Conservation and Recycling	4	22
Academy of Management Journal	4	22
Corporate Social Responsibility and Environmental Management	4	22
Journal of Purchasing and Supply Management (including the European Journal of Purchasing and Supply Management)	4	22
Journal of Business Ethics	3	27
California Management Review	3	27
British Journal of Management	3	29
Corporate Environmental Strategy	3	29
International Journal of Services and Operations Management	3	29
OR Spektrum	3	29
Journal of Industrial Ecology	2	33
Technovation	2	33
Advanced Robotics	2	33
Benchmarking: An International Journal	2	33
Clean Technologies and Environmental Policy	2	33
Environmental Quality Management	2	33
European Management Journal	2	33
Industrial Management and Data Systems	2	33
International Journal of Quality and Reliability Management	2	33
Journal of Business Research	2	33
Journal of Management Studies	2	33
Management Science	2	33
Transportation Journal	2	33
Academy of Management Perspectives	1	46
Agricultural Systems	1	46
Business Ethics: A European Review	1	46
Decision Sciences	1	46
Ecological Economics	1	46
Eco-Management and Auditing	1	46
European Journal of Innovation Management	1	46
Global Journal of Flexible Systems Management	1	46
Growth and Change	1	46
International Journal of Computer Integrated Manufacturing	1	46
International Journal of Environmental Science and Technology	1	46
International Journal of Environmental Technology and Management	1	46
International Journal of Organizational Innovation	1	46
International Journal of Productivity and Performance Management	1	46
International Journal of Retail and Distribution Management	1	46
International Journal of Technology Management	1	46
Journal of Economics and Management Strategy	1	46
Journal of Business Approach	1	46
Journal of Business Strategy	1	46
Journal of Corporate Citizenship	1	46
Journal of Economics and Management Strategy	1	46
Journal of Environmental Economics and Management	1	46

Table 1 continued

Journal name	Number of GSCM articles published	Popularity ranking
Journal of Environmental Planning and Management	1	46
Journal of Intelligent Manufacturing	1	46
Journal of International Consumer Marketing	1	46
Journal of International Entrepreneurship	1	46
Journal of Manufacturing Systems	1	46
Journal of Quality Management	1	46
Journal of Technology Management and Innovation	1	46
Knowledge-Based Systems	1	46
Logistics Information Management	1	46
Logistics Research	1	46
Management Decision	1	46
Management of Environmental Quality: An International Journal	1	46
Management Research News	1	46
Management Research Review	1	46
Manufacturing and Service Operations Management	1	46
Mathematical and Computer Modeling	1	46
Production and Inventory Management Journal	1	46
Robotics and Computer Integrated Manufacturing	1	46
Supply Chain Forum: International Journal	1	46
The Review of Economics and Statistics	1	46

The journal outlets listed in this table are not exhaustive

externalities created by environmental degradation has lost its steam in the recent past. In other words, even though a growing number of government entities across the world introduced business incentives (e.g., low-interest loans, subsidies, tax benefits) for the company's greening initiatives, there is a growing concern over the impact of tougher environmental regulations on economy in times of ongoing world-wide financial crises. For instance, in the U.S., the Obama Administration recently has taken unprecedented actions to build a foundation for clean energy economy, tackle the issue of climate change (e.g., global warming), and develop a blueprint for the sustainable environmental future. This type of government actions might have inspired more research focusing on the environmental policy in the past, but lost their clouts for the last several years due to prolonged economic downturns.

4 A summary of the research findings, trends, and future research implications

Base on our analysis of the past GSCM literature, the following points are noteworthy:

1. With an exception of *Journal of Cleaner Production*, the main stream business journals (e.g., operations management and supply chain management) still play a prominent role as a viable forum or as a popular publication outlet for the GSCM research activities despite the emergence of specialty journals exclusively dedicated to environmental issues.
2. The research activities dealing with sustainable transportation and warehousing, the life cycle assessment of logistics activities from the environmental perspective, and environmentally conscious sourcing (purchasing) are scant relative to those studies focusing on manufacturing (e.g., green production/design, remanufacturing) and reverse logistics. As such, more future research efforts should be directed toward the impact analyses of transportation (e.g., alternative fuel) and warehousing activities (e.g., recycling of pallets and packages) as well as sourcing practices (e.g., supplier selection and competitive bidding), which encouraged many tiers of suppliers to comply with environmental regulations and rules.
3. Despite the increased government involvement in environmental protection and pollution control in the recent past, the GSCM studies that focus on policy issues are declining as evidenced by its dwindling number of publications for the last 3 years (from a

Table 2 The breakdown by the research area and methodology

	Conceptual	Case study	Exploratory	Empirical	Analytic	Total
Policy	21	19	9	24	9	82
Synthesis	29	17	2	7	8	63
Purchasing	12	29	7	16	15	79
Manufacturing	8	24	3	5	14	54
Green logistics	12	9	2	3	17	43
Reverse logistics	35	45	6	4	108	198
Total	117	143	29	59	171	519

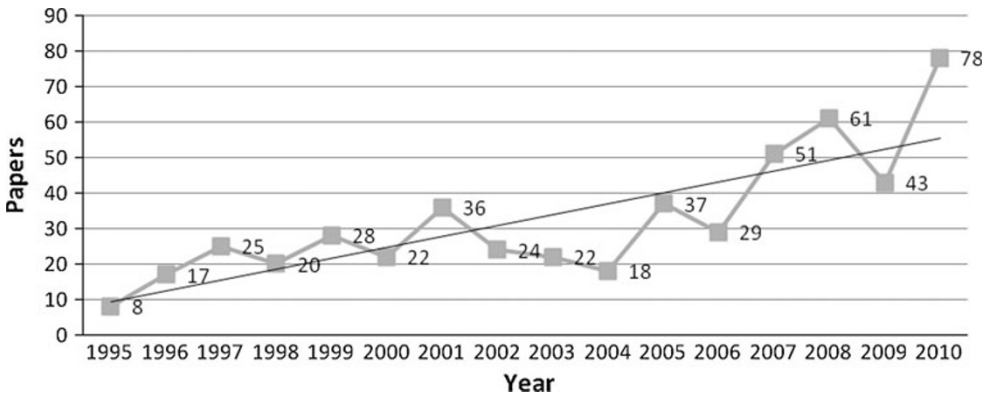

Fig. 1 The number of papers published each year

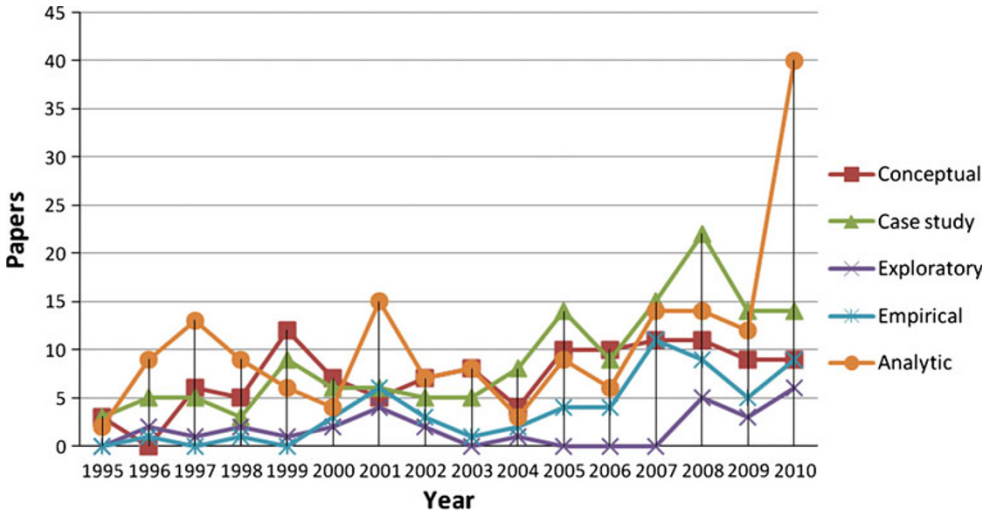

Fig. 2 The number of papers by the methodologies

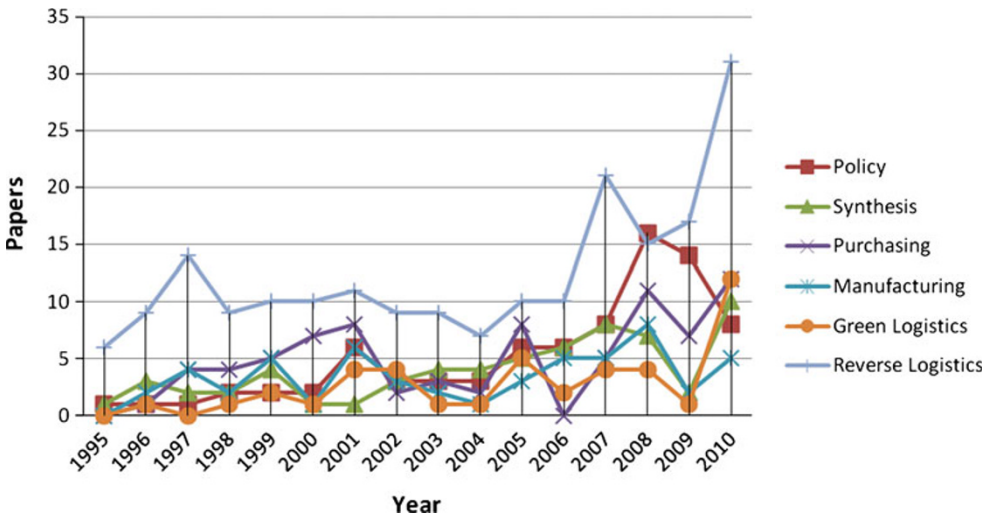

Fig. 3 The number of papers by the research areas

peak of 16 papers in 2008 to 8 papers in 2010, resulting in 50% drop for a 3 year span).

4. The presence of the large percentage (27.94% of total GSCM publications) of policy and synthesis papers that intersects the number of different disciplines suggests that GSCM research is interdisciplinary by nature. However, the analysis of the past literature reveals that the use of research tools that reflect its interdisciplinary nature are still lacking. As such, there is a growing need for the use of hybrid research

methodologies (e.g., a mixture of both case study and analytic methods) that combine the merits of different research tools and address interdependent environmental issues encompassing the entire spectrum (from the upstream to downstream) of supply chain issues.

5. It is apparent that the case study method is still the popular research methodology for GSCM due in part to the increased difficulty in collecting empirical or secondary data. There is no doubt that this pattern will continue in the future given the increased recognition of this type of a research method as the legitimate research tool given the practical importance of environmental initiatives and the company's interest in best-in-class environmental practices. However, in the GSCM research field, it should be noted that a relatively large number of GSCM case studies were concentrated in the reverse logistics, purchasing, and manufacturing areas. These studies do not necessarily meet the rigor or orthodox norm of case research methods needed in the supply chain field in the sense that most existing case studies in those areas (especially manufacturing area) did not go beyond the summaries of anecdotal stories heard from practitioners.
6. The analytics method, usually adopted as a way to handle routine operational problems involving the collection, sorting, consolidation, transfer, routing, and disposal of returned or recycled products have become the dominant method of choice for the reverse logistics studies, as evidenced by the presence of 108 analytical papers out of the total of 198 reverse logistics studies (accounts for 54.55% of the reverse logistics research). The popularity of analytical methods that relied on mathematical programming, simulation, and heuristics solution procedures for reverse logistics may stem from the fact that the reverse logistics problems were relatively well-defined and structured (e.g., [6, 7]). Thus, it is easier for the model builder to develop systematic decision-aid tools such as mathematical models and solution algorithms. However, as environmental issues cut across different functional areas of the supply chain and encompasses the different level of decision-making hierarchy (from operational to strategic), there is a growing need for a more fluid, open research methodology such as soft operations research (O.R.) tools that can effectively deal with ill-defined, less structured environmental issues facing practicing managers and policy makers.
7. The empirical methodology, despite being recognized as a hallmark of rigorous supply chain research, constitutes a mere 11.37% (59 out of 519 papers). This indicates that much of the GSCM research methodologies are largely expository, exploratory, and descriptive in their nature. In particular, it should be noted that the use of the empirical research methodology for manufacturing, green logistics, and reverse logistics is very rare, as evidenced by a mere five empirical studies of manufacturing, four in reverse logistics, and only three in green logistics, whereas there exists 24 empirical studies dealing with environmental policy issues. A majority of the empirical studies on environmental policy were primarily interested in examining whether the adoption of greening initiatives or policy guidelines has a positive impact on the financial performance or the competitiveness of the firm adopting company-wide environmental policy or vice versa.
8. Logistics is the most dominant theme of GSCM research, representing 46.44% of the total publications. Yet the past GSCM literature pertaining to logistics was heavily tilted toward reverse logistics, whereas a green logistics aspect was somewhat overlooked. In particular, research dealing with hazardous material transportation and storage is lacking despite its growing importance to supply chain security in the aftermath of September 11.

5 Conclusions

The world population has grown almost exponentially over the last century. As of 2011, it reached the seven billion mark, representing more than 430% jump from an estimate of 1.6 billion people at the beginning of twentieth century [11]. As the world population continues to grow tremendously, resources in our planet earth are further strained. Without finding systematic ways to sustain our resources and surrounding environments, the quality of our lives will deteriorate rapidly and may reach the point of no return. One of such ways includes the environment-friendly management of supply chain activities from the beginning to the end, which is dubbed GSCM. For the last 15 years, we have seen a wealth of articles addressing GSCM-related issues. In an effort to gain valuable insights into the evolution of GSCM research and grow this line of research further, this paper describes the past development and current state of GSCM research, synthesizes the focused areas of GSCM research, captures the emerging perspectives of GSCM research, and points the directions for future research opportunities. As the GSCM research is beginning to mature as a subfield of mainstream supply chain studies, we should not lose sight of major drivers of GSCM: the incorporation of eco-efficiency into value chains, links among sourcing, making, and delivering activities, and externalities influencing those activities.

Regardless of research focus and methodology, the continued investigation of these drivers should help the GSCM research field mature and refresh.

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