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Energy-related performance measures employed in sustainable supply chains: A bibliometric analysis

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A B S T R A C T

The purpose of this paper is to identify and analyze the metrics that have been used to address energy-related issues in green supply chain management (GSCM) and sustainable supply chain management (SSCM). The metrics were identified based on a structured content analysis of 115 peer-reviewed articles published in the Scopus database. A total of 113 unique energy-related metrics were identified. Only three metrics were used more than 10 times: "energy use" (24 times), "energy consumption" (21), and "energy efficiency" (11). The majority of the metrics were used only once (73 metrics) or twice (29). The results highlight a lack of agreement on how energy-related issues should be measured in GSCM and SSCM. To better understand the use of energy-related metrics in GSCM and SSCM highlighted in the literature, the metrics were analyzed using 13 key characteristics of SSCM. Approximately, two-thirds (65%) of the metrics focused exclusively on the environmental focus of SSCM. Thirty-nine (35%) metrics simultaneously addressed two or more key characteristics of SSCM. This paper presents an original contribution through one of the first in-depth analyses of metrics used to measure energy-related issues in the GSCM and SSCM areas. The analysis provides the basis for several recommendations on measuring energy-related issues, including sets of original standardized metrics, in supply chains going forward.

Keywords: Energy; Sustainable supply chain management (SSCM); Green supply chain management (GSCM); Metrics; Indicators; Performance measures

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1. Introduction

Research focused on the integration of sustainability into supply chain management (SCM) is in its emergent stages (Ashby et al., 2012; Ahi and Searcy, 2013). As highlighted by Handfield and Bechtel (2004), the SCM concept extends over multiple interdisciplinary fields, including operations research, business, economics, organizational science, and industrial psychology. Given its broad scope, SCM also covers a wide range of technologies, such as those related to energy generation, that affect its study within these fields (Boone et al., 2007).

Energy has been identified as a vital requirement in every sector (e.g., manufacturing, transportation, retail, etc.), and the growing demand for energy has become a major issue in the last few decades (Tsoutsos et al., 2005; Kotcioglu, 2011; Roldán et al., 2014). Energy has thus become a core issue in SCM. Renewable energy issues, in particular, have been prominently considered in recent publications (Halldorsson et al., 2009; Bagliani et al., 2010; Cucchiella and D'Adamo, 2013; Montoya et al., 2016). Given the widespread economic, environmental, and social impacts of energy, it has become closely associated with the concept of sustainability.

Over the last decade, awareness has been growing on the need to consider sustainability issues in the context of SCM (Carter and Rogers, 2008; Seuring and Muller, 2008). Economic, environmental, and social impacts are commonly referred to as the "triple bottom line" (TBL) of sustainability (Elkington, 1998) and have contributed to a further broadening of the SCM concept. Increasingly, SCM is viewed as constituting a leading edge of business sustainability in practice as it provides a reasonable prospect and opportunity for organizations to assimilate the TBL performance objectives (as a minimum) into decision making processes across the entire value chain of a product or service (Meixell and Luoma, 2015).

Given its key role in both sustainability and SCM, energy-related issues provide an important leverage point for their joint implementation. Better consideration of energy issues in supply chains could potentially provide a clearer path to improved local, regional, and global sustainability (Cucchiella and D'Adamo, 2013; Halldorsson and Svanberg, 2013). These points underline the need for a greater emphasis in both academic and practitioner-oriented work on studying the role of energy-related issues in the management of sustainable of supply chains.

This paper addresses the core research question of "*How should energy-related issues be measured in sustainable supply chains?*" The question is addressed through a multi-stage process. First, an in-depth study of energy-related issues in green and sustainable supply chains is presented. A database of existing energy-related metrics published in the literature is thoroughly analyzed. The database was developed based on a systematic research literature review of 115 relevant articles from the Scopus database. Second, original sets of standardized metrics for measuring energy-related issues in sustainable supply chains are presented. The development of the standardized metrics was informed by the analysis of the database of existing metrics. These standardized metrics will provide a strong basis for future work by both academics and practitioners.

The remainder of the paper is organized as follows. Section 2 presents a review of background material most relevant to the analyses conducted. The research methodology is provided subsequently in Section 3. Detailed analyses of the results, along with accompanying discussions, are provided in Section 4. Research recommendations are presented in Section 5. The conclusion, including research implications, contributions, and suggested future research directions, is provided in Section 6.

2. Background

2.1. *Sustainable supply chains*

Efforts to incorporate sustainability issues into SCM have been carried out under a variety of umbrellas. Two of the most prominent terms used to stress such integration are green supply chain management (GSCM) and sustainable supply chain management (SSCM) (Ashby et al., 2012; Ahi and Searcy, 2013). While the GSCM concept primarily focuses on how SCM can be viewed in the context of the environment (Gurtu et al., 2015; Mangla et al., 2015), the SSCM concept extends its scope to cover economic, social, and potentially other viable issues (e.g., resilience, efficiency) alongside environmental considerations (Shi et al., 2012; Ahi and Searcy, 2013). SSCM therefore expands the basic concept of SCM by widening performance to contemplate the key characteristics of sustainability. Given the broad definitions of both SCM (e.g., Stock and Boyer, 2009) and sustainability (e.g., Dahlsrud, 2008), it is unsurprising that a number of different factors have been used to characterize SSCM. This is reflected in the many different definitions of SSCM in the literature. As a set of representative examples, ten key definitions of SSCM are presented in Table 1.

As shown in Table 1, different definitions of SSCM emphasize different characteristics of both sustainability and SCM. In recognition of this point, Ahi and Searcy (2013) conducted a structured review of 12 definitions of SSCM and 22 definitions of GSCM. The analysis revealed that there were 13 key characteristics of SSCM (Ahi and Searcy, 2013, p. 337–338):

1. Economic focus, which includes "language related to the economic dimension of sustainability", such as economic, profit, etc.
2. Environmental focus, which includes "language related to the environmental dimension of sustainability", such as environment, ecological, etc.

Table 1 – Representative definitions of SSCM.[a]

SSCM definition	Source
"The strategic, transparent integration and achievement of an organization's social, environmental, and economic goals in the systemic coordination of key inter-organizational business processes for improving the long-term economic performance of the individual company and its supply chains".	Carter and Rogers (2008, p. 368)
"The management of material, information and capital flows as well as cooperation among companies along the supply chain while taking goals from all three dimensions of sustainable development, i.e., economic, environmental and social, into account which are derived from customer and stakeholder requirements".	Seuring and Muller (2008, p. 1700)
"The creation of coordinated supply chains through the voluntary integration of economic, environmental, and social considerations with key inter-organizational business systems designed to efficiently and effectively manage the material, information, and capital flows associated with the procurement, production, and distribution of products or services in order to meet stakeholder requirements and improve the profitability, competitiveness, and resilience of the organization over the short- and long-term".	Ahi and Searcy (2013, p. 339)
"Involvement of the planning and management of sourcing, procurement, conversion and logistics activities involved during pre-manufacturing, manufacturing, use and post-use stages in the life cycle in closed-loop through multiple life-cycles with seamless information sharing about all product life-cycle stages between companies by explicitly considering the social and environmental implications to achieve a shared vision".	Badurdeen et al. (2009, p. 57)
"The management of supply chain operations, resources, information, and funds in order to maximize the supply chain profitability while at the same time minimizing the environmental impacts and maximizing the social well-being".	Hassini et al. (2012, p. 70)
"The set of supply chain management policies held, actions taken, and relationships formed in response to concerns related to the natural environment and social issues with regard to the design, acquisition, production, distribution, use, reuse, and disposal of the firm's goods and services".	Haake and Seuring (2009, p. 285)
"The specific managerial actions that are taken to make the supply chain more sustainable with an end goal of creating a truly sustainable chain".	Pagell and Wu (2009, p. 38)
"The management of supply chains where all the three dimensions of sustainability, namely the economic, environmental, and social ones, are taken into account".	Ciliberti et al. (2008, p. 1580)
"Adding sustainability to existing supply chain management processes, to consider environmental, social and economic impacts of business activities".	Font et al. (2008, p. 260)
"The integration of sustainable development and supply chain management [in which] by merging these two concepts, environmental and social aspects along the supply chain have to be taken into account, thereby avoiding related problems, but also looking at more sustainable products and processes".	Seuring (2008, p. 132)

[a] Adapted from Ahi and Searcy (2013).

3. Social focus, which includes "language related to the social dimension of sustainability", such as social, community, etc.
4. Volunteer focus, which includes "reference to the voluntary nature of business sustainability", such as voluntary actions, voluntary integration, etc.
5. Resilience focus, which includes "reference to resilience, defined as 'an ability to recover from or adjust easily to misfortune or change' (Merriam-Webster, 2016)", such as resilient organizations, recovery from global risks, etc.
6. Long-term focus, which includes "reference to the long-term nature of sustainability", through terms such as end-of-life management, product life cycle, etc.
7. Stakeholder focus, which includes "explicit reference to stakeholders, including (but not limited to) customers, consumers, and suppliers", such as end-users satisfaction, customer requirements, etc.
8. Flow focus, which includes "language related to the flows of materials, services, or information", such as capital flows, distribution, etc.
9. Coordination focus, which includes "reference to coordination within the organization or between organizations", such as coordinated supply chain, cooperation, etc.
10. Relationship focus, which includes "reference to the networks of internal and external relationships", such as relationships within a firm, relationships between interdependent organizations, etc.
11. Value focus, which includes "reference to value creation, including increasing profit or market share and converting resources into usable products", such as supply chain profitability, market share creation, etc.
12. Efficiency focus, which includes "reference to efficiency, including a reduction in inputs", such as maximizing the social well-being, minimizing the environmental impacts, etc.
13. Performance focus, which includes "reference to performance, including applying performance measures, improving performance, improving competitive capacity, monitoring, and achieving goals", such as improve profitability, improve competitiveness, achieving goals etc.

The complete derivation and analysis of the 13 key characteristics of SSCM are presented in Ahi and Searcy (2013). The authors used the 13 characteristics to propose their definition of SSCM, which is summarized in Table 1. The definition of SSCM by Ahi and Searcy (2013) (i.e., arguably one of the most comprehensive definitions of SSCM offered to date), is used in this paper to guide analysis and discussion conducted. This characterization provides a meaningful basis for addressing the (potentially) conflicting issues in SSCM. This, in turn, could help pave the way toward improved overall SSCM performance.

Building on the above, a number of explicit issues have been highlighted in SSCM. As representative examples, attention has been directed toward economic concerns including

"Cost" (Hassini et al., 2012), "Process" (de Brito et al., 2008), "Quality" (Carter and Rogers, 2008), "Market Share" (Zailani et al., 2012), and "Profit" (Gold et al., 2010). Environmental concerns associated with SSCM have also been widely addressed, including issues such as "Emissions" and/or "Pollution" (Chaabane et al., 2012), "Energy" (Hassini et al., 2012), "Waste" (Curkovic and Sroufe, 2011), "Material(s)" (Hadiguna et al., 2011), "Water" (Erol et al., 2011), and "Biodiversity" (Binder et al., 2012). Social concerns have been addressed in a limited number of cases, including studies highlighting aspects of "Employment" (Yakovleva et al., 2012), "Community" (Klassen and Vereecke, 2012), "Health and Safety" (Morali and Searcy, 2012), "Stakeholder" (Meixell and Luoma, 2015), and "Welfare" (Ahi and Searcy, 2015b). Among the explicit issues highlighted, one prominent core issue that addresses multiple characteristics of SSCM is the use of energy.

2.2. *Energy in SSCM*

As highlighted earlier, energy has been identified as a vital requirement in virtually every sector. This has critical implications for SSCM. Energy is a source of power that may be generated through a number of different technologies, such as combustion, wind, or solar systems. A variety of energy carriers (e.g., coal, crude oil, natural gas, wind, sunlight, waste and biomass) are used to provide different consumable forms of energy (e.g. electricity, heat and vehicle fuel) that are ultimately used by different industries and/or households. However, a number of fundamental energy-related issues (e.g., fossil fuel vs. renewable energy) have not been adequately considered in the design and implementation of modern supply chains (Rogers et al., 2007; Christopher, 2011; Halldorsson and Kovacs, 2010). Furthermore, renewable energy has also been recently considered as one of the essential topics in the broad context of energy (Montoya et al., 2016). Renewable energy is a resource that is regenerated naturally over a certain period of time and originated either directly from the sun (e.g., thermal, photoelectric and photochemical) (Bahadori and Nwaoha, 2013), or indirectly from the sun (e.g., hydropower, wind, and photosynthetic energy stored in biomass) (Moriarty and Honnery, 2012; Shafiullah et al., 2013; Kousksou et al., 2015). It may also be derived from other sources of natural mechanisms in the environment (e.g., tidal and geothermal energy) (Kousksou et al., 2015). Renewable energy, however, may not comprise energy resources that are originated from fossil fuels, and the waste products from fossil or inorganic sources (Banos et al., 2011; Manzano-Agugliaro et al., 2013). Given the fact that focusing on renewable energy sources may encourage health equity, reduce poverty, and build societies that live within environmental boundaries (Kilkis, 2012), renewable energy usage is potentially a critical component of supply chain sustainability (Cucchiella and D'Adamo, 2013).

In light of the above, it is necessary to emphasize that approaches to GSCM and SSCM must consider issues such as shortages of natural resources, variability in fuel prices, energy availability, energy sources used in manufacturing and/or transportation, and emissions (e.g., greenhouse gas, CO_2, SO_2), among others.

2.3. *Metrics in SSCM*

Metrics are needed to ensure key energy-related issues are explicitly considered in GSCM and SSCM. Sustainability metrics are used as information to evaluate and motivate progress toward sustainability objectives (Veleva and Ellenbecker, 2001). Usually, metrics focus on quantitative measures, but they can also include narrative description of important sustainability concerns (Tanzil and Beloff, 2006). There are five basic classifications of metrics used in this paper. A quantitative metric is defined as "quantified and verifiable information used for quantitative assessment of measuring, comparing, or tracking performance of sustainability issues and objectives" while a qualitative metric is described as "information used to evaluate perceptions, attitudes, and strategies that motivate progress toward sustainability objectives covering narrative description of important sustainability issues" (Ahi and Searcy, 2015b, p. 35). An absolute metric is a measure that states operational performance in terms of what overall levels of performance would be in specific areas of interest (e.g., energy use) for an organization or supply chain as a whole. A relative metric states operational performance in terms of how performance in one area (e.g., energy use) would correlate to performance in another area (e.g., revenue or total production) (Adapted from McElroy and van Engelen, 2012, p. 62–63). Finally, a context-based metric expresses organizational performance in terms of impacts on vital capitals, relative to norms, standards or thresholds for what such impact ought to be (for specific periods of time) in order to be sustainable (e.g., total energy consumed per employee per year compared with a fair or equitable allocation of available renewable supplies) (Adapted from McElroy and van Engelen, 2012, p. 65).

A number of recent studies have highlighted the performance measures used in SSCM. By conducting a systematic literature review, Hassini et al. (2012) identified the sustainable performance measures used in sustainable supply chains. The authors argued that there is a relative dearth of efforts on developing measures required for assessing sustainability in supply chains. They highlighted that many of the identified measures used were not originally designed to be applied in a sustainable supply chain context (Hassini et al., 2012). Furthermore, Ahi and Searcy (2015a) conducted a systematic literature search and review to identify and analyze metrics used to measure performance in green and sustainable supply chains. They considered the 13 key characteristics of SSCM outlined above (Ahi and Searcy, 2013) in their structured content analysis. The authors found that a multitude of different metrics were used to measure essentially the same issues within GSCM and SSCM. Critically, their analyses highlighted a requirement for using clearly defined metrics with relatively standardized terminology, and also a tangible need for establishing a common measurement basis for the key areas of concern in GSCM and SSCM. They further emphasized a need for a collective set of scientifically-sound metrics that can address the entire supply chain, particularly, those that can connect the supply chain to the broader (i.e., local, regional and/or global) environmental, economic, and social context within which it operates.

Along the lines of these two comprehensive reviews, Tajbakhsh and Hassini (2015) also conducted a systematic literature review on performance measurement in sustainable supply chains. Their focus was on comprehensive measures that include multiple supply chain partners as well as different sustainability aspects. They employed an analytical approach based on seven sustainability dimensions (i.e., economic; environmental; social; valuable [uniting economic and environmental dimensions]; reputable [uniting economic and social dimensions]; equitable [uniting environmental and social dimensions]; and sustainable [uniting all dimensions]).

Consistent with the findings of Hassini et al. (2012) and Ahi and Searcy (2015a), the authors argued that there is a scarcity of pan-chain performance measurements and their related information and organizational structures. All three of the studies discussed also highlighted a need for aggregation measures (e.g., composite metrics), which would generate meaningful measurements for multiple players and sustainability aspects. The design and application of such metrics would necessitate a combination of quantitative and qualitative approaches to ensure reasonable and meaningful outcomes.

2.4. *Motivations for research*

As indicated above, a multitude of metrics focused on GSCM and SSCM are available (e.g., Hervani et al., 2005; Bai et al., 2012; Bjorklund et al., 2012; Hassini et al., 2012). However, no systematic analysis of the use of energy-related metrics in GSCM and SSCM has been conducted. This is an important oversight for two reasons. First, there are inconsistencies in the use of sustainability metrics (Roca and Searcy, 2012). Multiple metrics are often used to measure essentially the same sustainability issue and there is a need to explore how this has impacted the measurement of energy-related issues in GSCM and SSCM. Second, energy is one of the central sustainability issues in today's globally intense supply chains (Cucchiella and D'Adamo, 2013). There is therefore a need to direct particular attention to this important issue. Exploring the implications of the differences in the published energy-related metrics for green and sustainable SCM will provide much needed reference points in these areas (Cucchiella and D'Adamo, 2013).

Drawing on the requirements highlighted earlier, the purpose of this paper is to suggest a set of standardized metrics for measuring energy-related performance issues in sustainable supply chains. The development of the standardized metrics addressed the core research question of the paper, namely "*How should energy-related issues be measured in sustainable supply chains?*" To provide a starting point in the development of standardized metrics, the paper first identifies and analyzes the metrics that have been used to address energy-related issues in GSCM and SSCM. The analysis provides the basis for several recommendations on measuring energy-related issues in green and sustainable supply chains going forward. This paper is the first to provide an in-depth study of energy-related issues in GSCM and SSCM. It provides a summary of existing metrics in the literature and provides clear guidance on the development of standardized and context-specific metrics focused on energy-related issues in supply chains.

3. Research methodology

The first step in the research was to identify a list of all previously published metrics that contain the word "energy" in the literature on SSCM. The previously published metrics were identified based on an analysis of all relevant peer-reviewed papers published up to the end of the year 2012. The papers were identified based on a systematic search of the Scopus database. The initial focus was on identifying any papers that broadly addressed GSCM and/or SSCM. The keywords used in the search were "green supply chain management" and "sustainable supply chain management", along with "metrics", "indicators", and "performance measures". After excluding conference papers and reviews, the search focused on all peer-reviewed papers published in English language by setting the search for the "All Fields" category as well as all of the "Subject Areas" available in Scopus. Additional relevant publications were also identified through a search of the reference lists provided in the papers identified through the Scopus search. The Scopus database has previously been recognized as one of the two eminent data sources available for analyses of scientific publications (de Moya-Anegon et al., 2007). Therefore, it was employed for the systematic search conducted in this paper. An overview of the research approach conducted for this paper is shown in Fig. 1.

A total of 445 articles were identified, though only 115 of them contained metrics related to energy issues. A discussion of all of the metrics identified in the large sample of articles (i.e., 445) is provided in Ahi and Searcy (2015a). A total of 2555 unique metrics were identified in the large sample of 445 sources. Among them, a total of 113 unique metrics were identified that explicitly addressed energy-related issues. The yearly distribution of the sources containing energy-related metrics is shown in Fig. 2. The figure shows a growing momentum in the number of publications addressing energy related metrics for GSCM and SSCM since 2009. The large number of articles published in 2012 is indicative of the growing interest in this topic.

The distribution of the articles by the journals in which they were published is presented in Fig. 3. This figure highlights the multidisciplinary feature of the systematic literature search and review conducted in this study (Burgess et al., 2006). It should be noted that, the approach of conducting a systematic literature search and review has also been employed in a number of recent relevant literature reviews (i.e., Dubey et al.,2015; Pallaro et al.,2015; Montoya et al.,2015; Montoya et al.,2016).

The metrics were identified through a structured content analysis of each article. In each article, any metric that was highlighted in charts, tables, figures, boxes, bulleted lists, numbered lists, bold characters, or italics characters was recorded. In all cases, the exact wording of the identified metric was recorded. Moreover, in all articles examined, if a metric had been obtained from another source(s), the original article was considered as the basis of the identified metric(s). Through this process, a preliminary database for all metrics identified in the literature was developed.

Each of the collected metrics for GSCM and SSCM in the preliminary database was analyzed using a word-for-word content analysis (Krippendorf, 2004; Seuring and Gold, 2012). Any metrics that contained the word "energy" were extracted and used as a basis for the analysis in this paper. This provided a basis for a frequency analysis to determine how often the various metrics appeared in the literature. This analysis yields a greater understanding of the use of the metrics cited. It should be noted that there were some grammatically similar word-usages identified among the analyzed metrics (e.g., decrease of energy use, decreasing of energy use, decrease in energy usage). Each of the identified metrics was examined by two researchers independently. Where similarities in the metrics were identified by either researcher, a discussion was held regarding how each metric was constructed, and ultimately, the researchers jointly determined whether similarities in the word usage should be considered as grammatically alike. This procedure was employed to develop the final database, which was

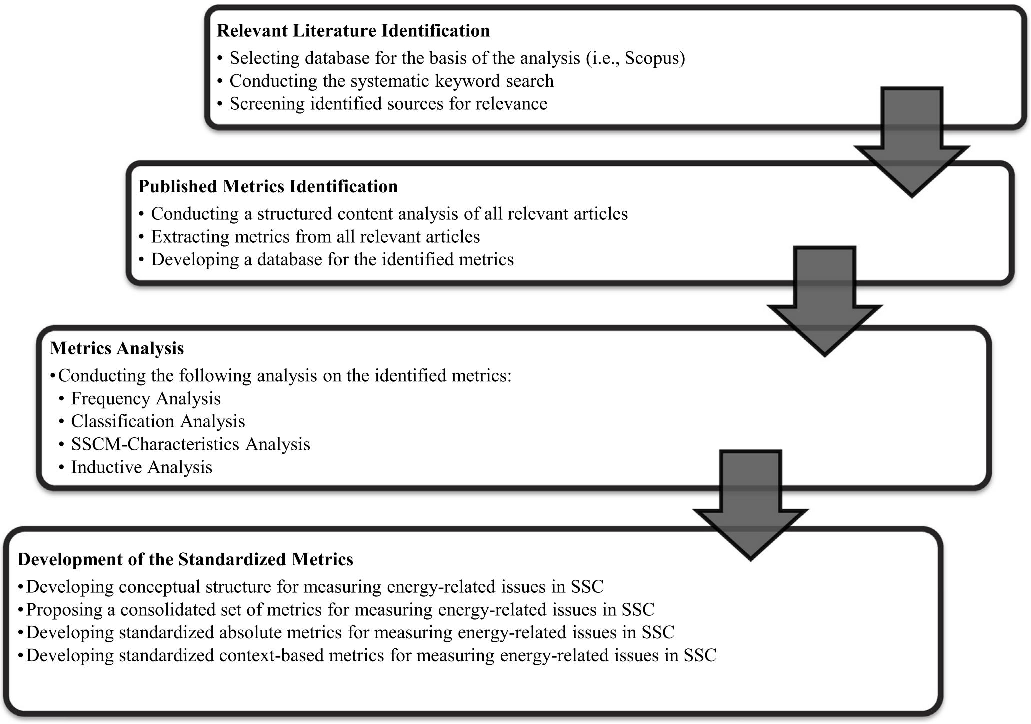

Fig. 1 – Overview of the research approach conducted.

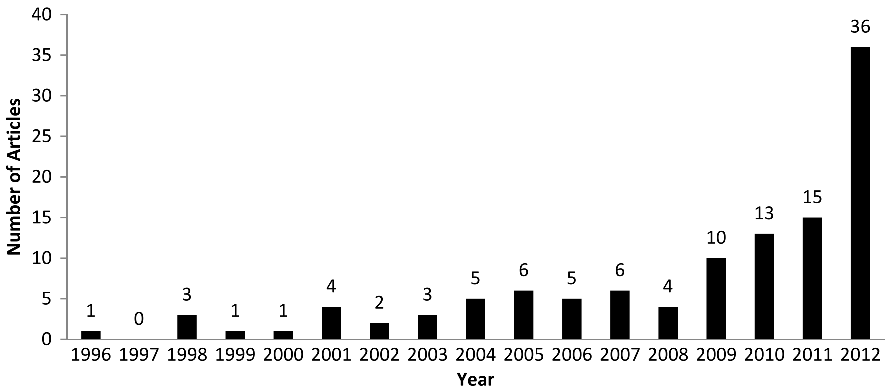

Fig. 2 – Yearly distribution of the sources reviewed.

used as the core basis for the analysis. As highlighted in Fig. 1, beyond the frequency analysis noted above, the identified metrics were categorized according to whether they were quantitative, qualitative, absolute, and/or relative metric types. The context-based metric category was also considered.

The metrics were also analyzed with respect to the 13 key characteristics highlighted earlier in the definition of SSCM given by Ahi and Searcy (2013). The SSCM characteristic analysis was conducted to determine which characteristic(s) of SSCM are typically addressed by the energy-related metrics for GSCM and SSCM. Each metric was individually examined against all 13 key characteristics to identify whether it addressed one or more of those characteristics. This analysis provides insight into the similarities and differences between the metrics reported. Although the specific name of the metric may vary, many metrics address similar core issues. Additionally, the metrics were analyzed to examine the extent to which they address environment-explicit issues other than energy, such as emissions, material usage, waste, and transportation. The analysis provided a needed starting point for the development of a conceptual structure and a suggested set of standardized metrics for measuring energy-related issues in SSCM.

As noted above, it is important to highlight that the data utilized in this paper is extracted from a wider review of metrics in sustainable supply chains (i.e., Ahi and Searcy, 2015a). There are therefore similarities in the methodology reported in the two papers. However, this paper differs from the wider review from the perspective of both the data presentation and analysis. The focus of the current paper is limited to the metrics that narrowly address energy-related issues. Metrics focusing on energy issues were not explored in-depth in the wider review presented in Ahi and Searcy (2015a). The development of standardized metrics was also not included in the earlier paper.

4. Results and discussion

This section presents an in-depth analysis of the previously published metrics related to energy issues in sustainable supply chains. First, the results of the frequency analysis will be discussed. Second, the SSCM-characteristics analysis

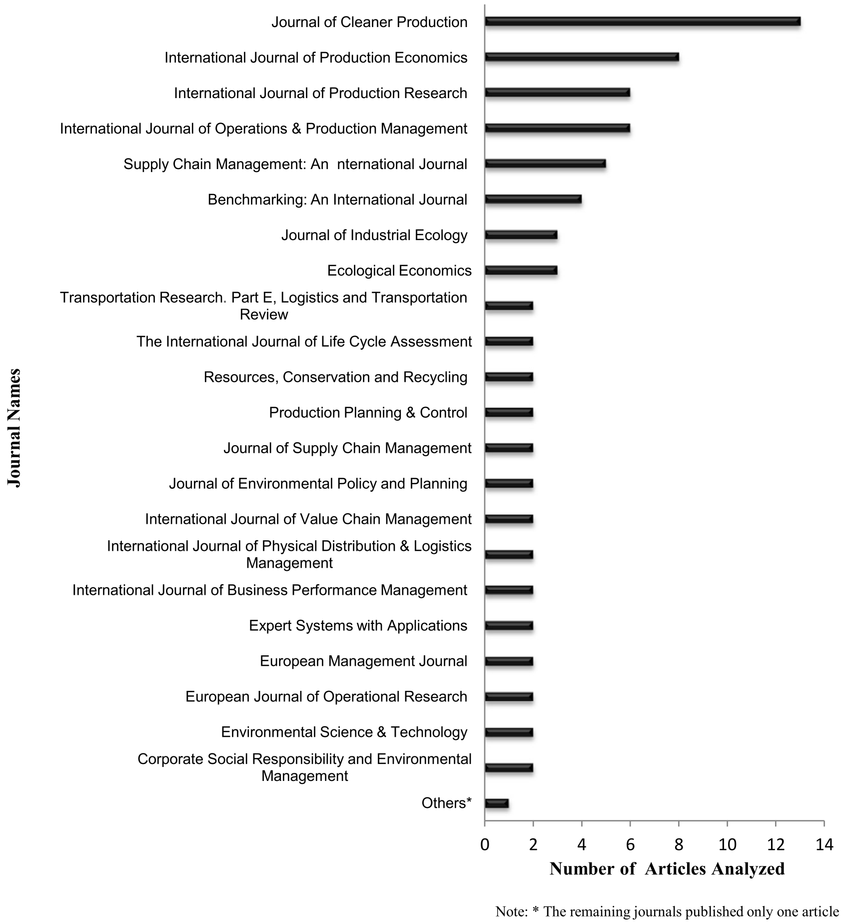

Fig. 3 – Distribution of the articles analyzed for energy-related metrics used in GSCM and SSCM by journal.

of the identified metrics is presented and systematically discussed. Last, an inductive analysis of the data is conducted and thoroughly discussed to identify the core issues in the published metrics. These analyses and discussions provide a fundamental basis for the development of the standardized metrics presented in the following section.

4.1. *Frequency analysis*

A total of 113 unique energy-related metrics were identified in the analysis. As summarized in Table 2, approximately 65% of these metrics appeared in the literature only once, while another 26% appeared only twice. The results also highlight that approximately about 3% of the identified metrics appeared three times. Analysis of the results also shows that just eight metrics (7%) appeared more than 4 times (i.e., "Energy use" (24 times), "Energy consumption" (21), "Energy efficiency" (11), "Energy used" (7), "Decrease of cost for energy consumption" (6), "Energy" (6), "Cumulative energy demand (primary energy used over the life cycle of a product or a process)" (5), and "Reduction of energy consumption" (4)). Table 2 also classifies the metrics based on their respective types (i.e., quantitative, qualitative, absolute, and relative).

The analysis shows that the majority of metrics are quantitative (i.e., 107 metrics, 94.7% of the total number of energy-related metrics), with only a small percentage of them being qualitative (i.e., 6%, 5.3%) metrics. Examples of quantitative metrics include "Energy use" (24 times), "Energy consumption" (21), and "Energy efficiency" (11). Examples of qualitative metrics include "Each type of energy used" (2 times), "Supporting the generation and distribution of renewable energy" (2), "Energy resources" (1), and "Access to energy" (1).

Additionally, a relatively large number of metrics were categorized as absolute metrics (i.e., 80 metrics or 70.8% of the overall total), while the remaining (i.e., 33 metrics or 29.2%) metrics fall into the category of relative metrics. Examples of absolute metrics include "Energy use" (24 times), "Energy consumption" (21), and "Decrease of cost for energy consumption" (6). Examples of relative metrics include "Energy efficiency" (11), "Energy intensity" (3), and "Percentage of energy supplied by renewable sources" (1). Overall, the results highlight that there are a variety of perspectives on how energy-related issues in GSCM and SSCM should be measured. Moreover, the analysis highlights that no context-based metric was found to address energy-related issues.

4.2. *SSCM-characteristics analysis of metrics*

Each of the identified metrics was classified according to the 13 key characteristics of SSCM. The analysis also focused on identifying metrics that addressed multiple characteristics of SSCM.

The SSCM-characteristics analysis shows that approximately 65% of the metrics focused explicitly on addressing environmental issues. "Energy use" (24 times), "Energy consumption" (21), and "Energy efficiency" (11) were some of the high frequency metrics that explicitly addressed environmental issues. "Energy return on investment" (1 time) and "Access to energy" (1) were the only metrics that exclusively addressed the economic and social issues, respectively. The flow, volunteer, resilience, and relationship focuses of GSCM or SSCM were not addressed by any of the energy-related metrics identified.

Table 2 – Identified energy-related metrics used in GSCM and SSCM.

Metrics[a]	FRQ[b]	Types[c]			
		QUAN	QUAL	ABS	REL
Energy use	24	√		√	
Energy consumption	21	√		√	
Energy efficiency	11	√			√
Energy used	7	√		√	
Decrease of cost for energy consumption	6	√		√	
Energy	6	√		√	
Cumulative energy demand (primary energy used over the life cycle of a product or a process)	5	√		√	
Reduction of energy consumption	4	√		√	
Operation energy saving	3	√		√	
Energy recovery	3	√		√	
Energy intensity	3	√			√
Cooperation with customers for using less energy during product transportation	2		√	√	
Use of cleaner technology processes to make savings (energy)	2	√		√	
Energy used per customer	2	√			√
Energy units saved due to energy conservation programmes	2	√			√
Other energy use	2	√		√	
Energy saved	2	√		√	
Purchase of energy for own consumption per enterprise	2	√			√
Design of products for reduced consumption of energy	2	√		√	
Energy efficiency per material (%)	2	√			√
Energy consumption (MJ/kg) levels	2	√			√
Energy use and recovery	2	√		√	
Significant reduction in terms of energy consumption	2	√		√	
Total energy use	2	√		√	
Energy used per year	2	√			√
Energy used per unit of product	2	√			√
Energy used per service	2	√			√
Each type of energy used	2		√	√	
Energy generated with by-products	2	√		√	
Energy generated with process streams	2	√		√	
On-site and off-site energy recovery	2	√		√	
Use of alternative sources of energy	2	√		√	
Conservation of energy	2	√		√	
Non-renewable energy	2	√		√	
Reduction of amount of energy used	2	√		√	
Tracking environmental information such as energy used	2	√		√	
Supporting the generation and distribution of renewable energy	2	√		√	
Identifying the role of IS [information system] in energy policy	2		√	√	
Energy and atmosphere	2	√		√	
ECO-design requirements for energy using product	2	√		√	

Notes:
[a]Only metrics that appeared 2 or more times are provided.
[b]FRQ = Frequency rate that signifies how many times a metric has been addressed.
[c]QUAN = Quantitative metric, QUAL = Qualitative metric, ABS = Absolute metric, REL = Relative metric.

Approximately 35% (i.e., 39 metrics) of the metrics addressed multiple characteristics of SSCM. The majority (i.e., 30 metrics) of these cross-cutting metrics addressed 2 characteristics of SSCM. "Energy efficiency" (11 times), "Decrease of cost for energy consumption" (6), and "Cumulative energy demand (primary energy used over the life cycle of a product or a process) (5)" were some of the high frequency metrics that address 2 different characteristics of SSCM. The remainder of the cross-cutting metrics addressed 3 and 4 characteristics. A complete summary of the energy-related metrics that addressed multiple characteristics of SSCM is provided in Table 3. Analysis highlights that there was no energy-related metric identified that addressed 5 or more characteristics of SSCM.

4.3. *Inductive analysis of metrics*

A number of distinct core issues were addressed by the energy-related metrics. "Use" and "consumption" of energy were by far the most frequently occurring themes in the metrics. A total of 29 metrics (25.7% of the total) highlighted the "use" of energy followed by 28 metrics (24.8%) that emphasized the "consumption" of energy. Collectively, issues associated with the usage of energy therefore accounted for over 50% of the total metrics identified. The next most common core issue in the metrics focused on the "source" of the energy used. Fifteen (13.3% of the total) metrics addressed this subject. This was followed by metrics that addressed core issues focused on "renewable" energy (10 metrics accounting for 8.9% of the total), energy "efficiency" (8 metrics, 7%), and energy "savings" (8 metrics, 7%). A number of other core issues were addressed by a smaller number of metrics. In this group, "cost", "intensity", and "conservation" of energy were each highlighted by 5 (4.4% of the total) metrics. Energy "recovery" and "generation" were each addressed by 3 (2.7%) of the metrics. Issues associated with "non-renewable" energy use and "demand" were each highlighted by 2 (1.8%) metrics. Finally, a number of core issues were addressed by only 1 (0.9%) metric. Among this group, energy "type", "revenues", "reuse", "return on investment", "payback time",

Table 3 – Overview of cross cutting energy-related metrics that addressed multiple key characteristics of SSCM.

Categories	SSCM characteristics	No. of metrics	Examples of cross-cutting metrics (frequency rates)
2 characteristics	Environmental and Economic focuses	14	Decrease of cost for energy consumption (6), Purchase of energy for own consumption per enterprise (2), Design of products for reduced consumption of energy(2)
	Environmental and Performance focuses	5	Operation energy saving (3), Energy units saved due to energy conservation programmes (2), Performance in using energy (1)
	Environmental and Efficiency focuses	5	Energy efficiency (11), Energy efficiency per material (%) (2), Possibilities of using energy efficient and clean technologies are considered (1)
	Environmental and Long-term focuses	2	Cumulative energy demand (primary energy used over the life cycle of a product or a process) (5), Reused energy (1)
	Environmental and Stakeholder focuses	1	Energy used per customer (2)
	Environmental and Value focuses	1	Energy requirement per unit of net value added (1)
	Environmental and Social focuses	1	Organizational energy use (1)
	Economic and Performance focuses	1	Production cost decreases as a result of energy and materials saving (1)
3 characteristics	Environmental, Economic and Performance focuses	3	Use of cleaner technology processes to make savings (energy) (2), Energy saving (1), Energy cost savings (1)
	Environmental, Economic and Efficiency focuses	2	Development of energy-efficient products (1), Manufacturing processes energy efficiency (1)
	Environmental, Economic and Social focuses	1	Product design for lower energy consumption when using the product (1)
	Environmental, Economic and Value focuses	1	Energy consumption per added industrial value (1)
	Environmental, Efficiency and Performance focuses	1	Optimization of efficiency through the use of energy efficient vehicles (1)
4 characteristics	Environmental, Social, Stakeholder and Coordination focuses	1	Cooperation with customers for using less energy during product transportation (1)

"policy", "atmosphere", "footprint (ha)", and "productivity" were specific issues addressed by the metrics. However, "energy", as a very generic issue, along with a number of other broad issues like "net" and "total" energy, "reduction" and "requirement" of energy, and "access" to energy were also addressed by 1 metric each.

Over 95% of the metrics identified focused, at least in part, on environmental concerns. This is to be expected, given the close association of energy with environmental issues in the sustainability literature. For example, the Global Reporting Initiative (GRI), the world's most widely applied sustainability reporting guidelines, classifies energy as an environmental aspect (GRI, 2013). Accordingly, the metrics did incorporate some other key environmental aspects identified by the GRI, including materials, emissions, waste, transport, and product and services issues. Examples of such metrics for material issues include "energy efficiency per material (%)" (2 times), "use of natural resources energy and raw materials (including: additives, auxiliaries and semi-manufactured goods)" (1), and "production cost decreases as a result of energy and materials saving" (1). "Renewable energy or energies without emission of CO_2 (e.g. biomass energy, solar, wind, geothermal, nuclear power, hydrogen energy)" (1 time), "reused energy" (1) and "energy used per service" (2) are examples of metrics that address emissions, waste, and services issues, respectively. Similarly, transport issues are addressed by "cooperation with customers for using less energy during product transportation" (2 times) and "energy consumption transportation" (1). As a final example, product-related issues are addressed by a number of metrics. Examples include "cumulative energy demand (primary energy used over the life cycle of a product or a process)" (5 times), "energy used per unit of product" (2), "ECO-design requirements for energy using product" (2), "energy consumption to produce products purchased externally" (1), "Energy intensity in MJ/m^3 of production (i.e., Annual total energy consumed by the firm in MJ/Annual production aggregated in m^3)" (1), "quantity of energy used per year or per unit of product" (1), and "improving production in relation to used energy and resource consumption" (1). No energy related metric was identified in the fields of GSCM and SSCM that explicitly addresses water, biodiversity, or compliance issues.

Drawing on the discussion provided earlier, renewable energy has recently been considered as one of the crucial topics in the broad context of energy (Montoya et al., 2016). On this note, it was deemed necessary to conduct further analysis of the identified metrics to determine, specifically, the extent to which they addressed renewable energy issues.

Accordingly, an analysis of the identified metrics shows that only a total of 10 (8.9%) metrics explicitly addressed renewable energy issues. These include 7 metrics that focused exclusively on the environmental characteristic of SSCM, namely "supporting the generation and distribution of renewable energy" (2 times), "renewable energy" (1), "percentage of energy supplied by renewable sources" (1), "renewable energy or energies without emission of CO_2 (e.g. biomass energy, solar, wind, geothermal, nuclear power, hydrogen energy)" (1), "possibilities of using renewable resources are considered when selecting energy" (1), "fraction of facilities using renewable energy" (1), and "percent of energy from renewable resources" (1). The other two metrics addressed both the economic and environmental characteristics of SSCM. These metrics are "renewable energy purchased" and "percentage of total annual consumption of energy (for electricity and heating) produced by the organization from renewable energy sources". Both of these metrics appeared only once in the literature. The review highlights the need for a greater emphasis on metrics addressing renewable energy issues.

5. Toward standardized metrics for measuring energy-related issues in SSCM

The analyses conducted in this paper highlight that there is a wide-range of metrics available for measuring energy-related issues in supply chains. Accordingly, the large number of metrics provides practitioners with a broad array of metrics to consider in the development of measures appropriate to their particular supply chain. However, the great variety of metrics also complicates the efforts to make comparisons between different supply chains. This is particularly problematic given that many different metrics address essentially the same core issue. Although decision-makers must always have the flexibility to create metrics suited to the unique needs of their supply chain, there is a need to promote greater standardization of a limited set of metrics in order to facilitate meaningful comparisons between supply chains. The development of a standardized set of metrics could also ensure that generally overlooked-metrics, such as those associated with the use of renewable energy, are more widely utilized. Furthermore, given the fact that substantial impacts could be prompted at any point in the supply chain, there is a need to take into account the usage of energy throughout all key players in the chain (i.e., suppliers, focal firm, distributors, retailers, etc.). For instance, the energy usage at one stage with poor or non-existent current measurement (e.g., raw material extraction) could be greater than that at a stage with relatively detailed measurement (e.g., at the level of the focal firm). Accordingly, failing to account for energy usage throughout the supply chain could contribute to skewed perceptions of overall SSCM performance. Considering all of the above, a set of recommendations for measuring energy-related issues in sustainable supply chains are offered below.

5.1. *A sustainable supply chain structure for measuring energy-related issues*

Based on the analysis conducted in the previous section, it is argued that a limited set of metrics is needed in order to consolidate the many existing metrics and to enhance the ability to make meaningful comparisons of performance between different supply chains. In this light, a conceptual structure for measuring energy-related issues in sustainable supply chains is proposed. As illustrated in Fig. 4, the proposed structure is comprised of six main components that are encompassed in the larger sustainability context (i.e., the local, regional, and global economic, natural, and social environments) within which the sustainable supply chain (SSC) operates. The components of the proposed SSC structure are: Supplier, Focal Firm, Distributor, Retailer, End-User, and End-of-life Management. The proposed structure therefore conceptualizes a six-echelon SSC that is in line with the conceptual frameworks suggested in Hassini et al. (2012) and Ahi and Searcy (2015a) for performance measurement in SSCM. Although other formulations of this structure are possible, the six suggested echelon arguably strikes the balance between capturing all relevant players in the supply chain and the need to present those concisely.

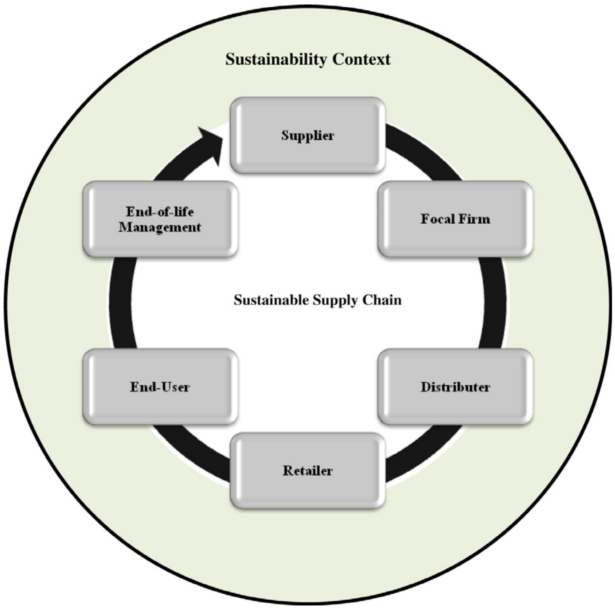

Fig. 4 – Proposed structure for measuring energy-related issues in sustainable supply chains.
Source: **Adapted from Ahi and Searcy (2015a).**

It is important to emphasize that any particular supply chain may be designed to accommodate various players. In the proposed structure, the manufacturer is seen as the focal firm, but it is possible that others could play this role. The most common entities used in studies focused on supply chains are the retailer, customer, supplier, whole enterprise, and manufacturer (Bonney and Jaber, 2011; Hassini et al., 2012). Functions of sourcing and converting raw materials are vital considerations in managing sustainable supply chains and may also serve as a unit of analysis. In any case, all key players are responsible for adopting and adjusting their practices in a way that is economically, environmentally, and socially responsible. Our emphasis on the manufacturer as the focal firm reflects the fact that the manufacturer is often (but clearly not always) able to exercise a degree of influence on the other players in the chain.

5.2. *A consolidated set of metrics for measuring energy-related issues in SSC*

Following the conceptual structure above, the metrics extracted from the literature have been condensed around the core themes emerging from the literature review. The results are presented in Table 4. As shown in the table, the metrics have also been mapped against each component level in a SSC to provide an indication of where the metrics may be most relevant.

As highlighted in Table 4, the proposed metrics could be used at different component levels (i.e., by different key players) in the chain, and hence, they provide a solid basis for meaningful, relatively comprehensive, and practical measurements. As a representative example, "Energy Efficiency" could be measured per material (i.e., at the supplier level), per service (i.e., at the focal firm level), and per product (i.e., at the end-user level in the form of an energy

Table 4 – Proposed set of energy-related metrics classified according to the components of sustainable supply chain.

Metrics	Components of sustainable supply chain					
	Supplier	Focal firm	Distributor	Retailer	End-user	End of life management
Energy efficiency	√	√	√	√	√	√
Energy usage	√	√	√	√	√	√
Reused energy	√	√	√	√	√	√
Energy source	√	√	√	√	√	√
Energy cost	√	√	√	√	√	√
Energy saving	√	√	√	√	√	√
Energy return on investment	√	√	√	√	√	√
Energy cost saving	√	√	√	√	√	√
Energy conservation	√	√	√	√	√	√
Energy demand (direct or cumulative)	√	√	√	√		√
Energy recovery	√	√	√	√		√
Energy productivity	√	√	√	√		√
Energy required per unit of net value added	√	√	√	√		√
Revenues from energy	√	√				√
Energy intensity		√				√
Energy generated		√				√

efficient product). Also, "Energy Usage" could be considered as a measurement of direct or indirect consumption (e.g., in the form of energy consumed in transportation) at different component levels in the chain. It could also be used as an important indicator for highlighting energy consumption over the life a product (see e.g., Gutowski et al., 2011).

Overall, since the majority of the proposed metrics could be commonly utilized across all the involved key players (i.e., components) in the chain, they provide a strong basis for conducting reasonable comparisons among different supply chains, provided that the metrics are computed using similar methodologies. As a brief caution, it is necessary to note that the proposed list of metrics is not intended to be exhaustive. Rather, they are intended to capture and classify the key metrics that emerged from the literature review. The metrics could, however, be utilized as a starting point going forward for evaluating energy-related issues in sustainable supply chains.

5.3. *Standardized absolute metrics for measuring energy-related issues in SSC*

Building on the analysis conducted earlier, it is proposed that a set of standardized absolute type of metrics is needed. Absolute metrics are appropriate in this instance given the difficulty of establishing relative measures appropriate to the vast array of possible supply chains. They also provide a clear indication of the scale of the supply chain's impacts with respect to energy-related issues. It is argued that metrics are needed to address the usage of energy, the source of energy, and the key players in the sustainable supply chain. These would address the majority of the core themes of metrics utilized in the existing literature. Table 5 presents a summary of the recommended standardized absolute metrics for energy-related issues in sustainable supply chains, including definitions.

Table 5 proposed the term "usage", since it is most obviously connected to "use" of energy. It is acknowledged that the term "consumption" could have just as appropriately been used, but it is important to propose some form of standardization of terms in order to move forward. Targets are not included in the proposed standard set of metrics since this may vary considerably depending on the purpose, goals, and current status of the supply chain. Nonetheless, it is essential that the standardized metrics are connected to goals and targets for energy usage throughout the supply chain.

5.4. *Standardized context-based metrics for measuring energy-related issues in SSC*

Following the proposition of standardized absolute type of metrics, it is proposed that a standardized metric is needed to relate the energy-usage of the sustainable supply chain to the broader context within which the supply chain operates. "Sustainability context" is one of the key principles of the GRI and suggests that performance should be presented in "the context of the limits and demands placed on environmental or social resources at the sector, local, regional, or global level" (GRI, 2013, p. 17).

Fundamentally, any effort to measure an aspect of sustainability must take into account the ability of the natural or social environment to support the activities undertaken. There was virtually no metric found in the literature that explicitly accounted for this important issue. One key exception though is the "energy footprint" metric contained in Carballo-Penela et al. (2012). This metric did not meet the strict definition of a context-based metric given earlier on since it does not address what the "impact ought to be". However, it does make a clear connection between the energy used and the ability of the environment to support that level of usage.

The energy footprint is an adaptation of the "ecological footprint" proposed by Wackernagel and Rees (1996) that measures the amount of land necessary to support the usage of energy. Accordingly, "energy footprint" accounts for the amount of land required to absorb the carbon dioxide emissions resulting from energy use. Environmental issues at the local level (e.g., high degrees of urbanization and/or industrialization resulting in a multitude of resource demands) as well as at the global level (e.g., deforestation, biodiversity loss, and/or desertification) have all significantly affected the ability of land to absorb carbon dioxide emissions. Therefore, it is important to take into account the broader local, regional, and/or global context within which the supply chain operates, whilst measuring vital issues (e.g., energy) in SSCs. Accordingly, context-based

Table 5 – Standardized absolute metrics for energy-related issues in sustainable supply chains.

Metric	Source	Player
Total energy usage	Total non-renewable energy usage by source Total renewable energy usage by source	Total energy usage by player

Notes:
- "Total energy usage" is defined as the amount of energy that is used during a defined period of time (normally 1 year).
- "Non-renewable energy usage" is defined as the amount of energy that is used from sources that are non-replenished within meaningful human time frames. Examples include petroleum, coal, and natural gas.
- "Renewable energy usage" is defined as the amount of energy that is used from sources that are replenished within meaningful human time frames. Examples include solar, wind, water (hydro), geothermal, and biomass.
- "Total energy usage by player" is defined as the amount of energy that is used by each key player in the sustainable supply chain. Examples include suppliers, the focal firm, distributors, and retailers.

Table 6 – Standardized context-based metrics for measuring energy-related issues in sustainable supply chains.

Metric	Source	Player
Total energy footprint	Total energy footprint of non-renewable energy by source Total energy footprint of renewable energy by source	Total energy footprint by player

Notes:
- "Total energy footprint" is defined as the amount of total energy (i.e., energy consumption units × energy intensity) over the total energy productivity (adapted from Carballo-Penela et al., 2012). Accordingly:
- Energy consumption units are defined as: "The amount of energy per consumption unit, in gigajoules (Gj), by means of multiplying the tonnes of each product by the amount of energy/tonne used to produce it (Gj/t)" (Carballo-Penela et al., 2012, p. 770).
- Energy intensity is defined as: "The amount of energy used to produce all the products included in the consumption land use matrix (CLUM) considering a standard life cycle". Carballo-Penela et al. (2012, p. 770). Accordingly, by encompassing energy, materials, services, wastes, land uses, agricultural and fishing resources, forest resources, and water as the main product categories designated, the CLUM applies the consumption of goods and services needed by companies, and ultimately, highlights the footprints for every designated category of goods and/or services consumed (Carballo-Penela et al., 2012, p. 770–771).
- Energy productivity is defined as: "Energy productivity, in Gj per hectare, shows how many tonnes of each fuel were needed to generate the CO_2 volume, which can be absorbed per hectare on an annual basis, applying an absorption rate per hectare/year of 5.21 t CO_2/ha/year (IPCC, 1997)" (Carballo-Penela et al., 2012, p. 770). It should be noted that an absorption rate of 3.67 t CO_2/ha/year has been set to be applied in the relevant calculations from 2010 forward (IPCC, 2007).
- "Energy footprint of non-renewable energy" is defined as the amount of total non-renewable energy (i.e., non-renewable energy consumption units × non-renewable energy intensity) over the total non-renewable energy productivity at the sources of non-renewable energy (i.e., sources that are non-replenished within meaningful human time frames. Examples include petroleum, coal, and natural gas).
- "Energy footprint of renewable energy" is defined as the amount of total renewable energy (i.e., renewable energy consumption units × renewable energy intensity) over the total renewable energy productivity at the sources of renewable energy (i.e., sources that are replenished within meaningful human time frames. Examples include solar, wind, water (hydro), geothermal, and biomass).
- "Total energy footprint by player" is defined as the amount of total energy (i.e., energy consumption units × energy intensity) over the total energy productivity by each key player in the sustainable supply chain. Examples include suppliers, the focal firm, distributors, and retailers.

metrics are required for measuring energy-related issues in sustainable supply chains. To respond to this need, a set of standardized context-based metrics is proposed. Table 6 presents the recommended standardized context-based metrics for measuring energy issues in sustainable supply chains by total, source, and player. Again, targets are not provided since they may vary between supply chains. However, the use of targets is one key way of addressing the "ought to be" requirement of a context-based metric.

6. Conclusions

This paper presented the first systematic analysis of the use of energy-related metrics in GSCM and SSCM. This is an important contribution given the importance of energy to the overall economic, environmental, social, and potentially other viable impacts of supply chains (e.g., resilience, efficiency). A total of 113 unique metrics were identified in 115 different journal articles published in Scopus up to the end of 2012. Nearly 90% of the metrics were used only once or twice in the literature. Just 3 of the metrics were used more than 10 times. Considering all of the metrics were limited in their focus to energy-related issues, there was a great range in the number of metrics utilized. Nevertheless, the results also showed that the metrics addressed a number of different core issues. Although the names of the specific metrics varied, more than half of the identified metrics (50.4%) focused on the core issue of energy usage. Other core issues addressed by the metrics include energy efficiency, intensity, conservation, generation, and recovery, among others. Of the 13 key characteristics of SSCM, the environmental focus was best represented by the identified metrics (64.6%). A further 35.4% of the metrics addressed two or more characteristics of SSCM.

It is important to note that although the Scopus database is considered as one of the most reliable search-engines used for scientific publications (de Moya-Anegon et al., 2007), employing other databases (e.g., Web of Science, Google Scholar, etc.) alongside Scopus might have resulted in a different, and possibly, greater data count. Nevertheless, despite this limitation, the study provided a clear indication of the key trends in the literature, and thus, a strong basis for several important implications when measuring energy-related issues in sustainable supply chains. In particular, the analysis of published metrics provided a strong basis upon which to build a set of proposed standardized metrics. Two sets of original standardized metrics were suggested as one for absolute metrics and another for context-based evaluations of energy issues in sustainable supply chains. The results of this paper should be of interest to practitioners as well as academics in the energy sector who intend to explore performance measurement issues in the GSCM and SSCM areas.

6.1. *Research implications*

It is recognized that there are many challenges in establishing standardized metrics for measuring energy-related issues in supply chains. The challenge of collecting accurate, high-quality data in a timely fashion across supply chains has been discussed extensively in the literature (see, e.g., Ahi and Searcy, 2015c). This can become even more problematic if the focus on measurement is extended from the forward supply chain to also incorporate the reverse supply chain (de la Fuente et al., 2008). Allocating energy usage to the supply chain can also be difficult, particularly when one of the supply chain players is involved in multiple chains. Allocation often introduces the need to make assumptions, which can result in a number of possible disparities. The requirements associated with collecting the data, making the allocation decisions, and reporting on the metrics may also impose additional costs on players throughout the supply chain. Academics and practitioners will need to pay particular attention to these challenges going forward.

With the above in mind, it is important to stress that the usefulness of employing standardized metrics will very much rely on the availability of data across all the entailed levels within the chain. However, as also highlighted in the literature (e.g., Veleva et al., 2003; Bjorklund et al., 2012 and Hassini et al., 2012), the issue of data availability has created a serious challenge regarding the applicability and usefulness of any metrics employed in the context of sustainable supply chains. This challenge indicates that there may be a clear need for more standardized, or perhaps regulated, procedures and frameworks for carefully reporting the required data across the whole SSC. This requirement will be more acute when the number of involved levels (i.e., key players) in the SSC is increased.

Finally, it is acknowledged that the standardized metrics focus on a relatively small set of metrics that do not comprehensively address the 13 SSCM characteristics. This is based on the belief that a standardized set of metrics must be concise in order to be broadly applicable within and between supply chains. Although environmental issues are thus addressed, other potentially critical characteristics of SSC (e.g., stakeholder, long-term focuses) are not explicitly covered. It is important to stress that these other areas could be addressed through discretionary metrics relevant to a particular supply chain that go beyond the standardized metrics proposed in this paper. Reporting should not necessarily be limited to the standardized metrics.

6.2. *Contributions*

The research presented in this paper makes several contributions to the literature. It provides the first database of metrics that explicitly address energy-related issues in the literature on GSCM and SSCM. Building on the analysis of published metrics, an original conceptual structure for measuring energy-related issues in sustainable supply chains was developed. The proposed SSC structure provided a basis for consolidating the many energy-related metrics in the literature. Since the majority of the consolidated metrics could be commonly utilized across all the involved levels of the SSC, they provide a reasonable starting point for making comparisons among different supply chains. Furthermore, the proposed SSC structure also provided a solid foundation for the development and proposition of standardized "absolute" and "context-based" metrics for measuring energy-related issues in sustainable supply chains and proposed metrics to those ends. Absolute metrics are required due to the difficulty of establishing relative measures suitable for the extensive range of possible supply chains. Moreover, the proposed context-based metrics provide opportunities to connect the energy-related issues investigated to the broader (i.e., local, regional, and/or global) sustainability context in which sustainable supply chains operate.

6.3. *Future research*

The research presented in this paper may be extended in several ways. One particularly interesting avenue of future research would be to analyze the identified energy-related metrics according to the industry sectors where they are applied. This would provide insight into the directions necessary for enhancing the use of energy-related metrics within each sector so that sector-specific needs are addressed. Future work on the standardization of the metrics is also needed, particularly with respect to their implementation in practice. Research along these lines could further underscore the importance of measuring energy-related issues in sustainable supply chains.

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