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Authors

Feng Ming Tsai

- Department of Shipping and Transportation Management, National Taiwan Ocean University, Taiwan

E-mail: chucktsai@email.ntou.edu.tw

Tat-Dat Bui

- Department of Shipping and Transportation Management, National Taiwan Ocean University, Taiwan

E-mail: btdat1991@gmail.com

Ming-Lang Tseng*

- Institute of Innovation and Circular Economy, Asia University, Taiwan
- Department of Medical Research, China Medical University Hospital, Taiwan
- Faculty of Economics and Management, Universiti Kebangsaan Malaysia, Malaysia

E-mail: tsengminglang@gmail.com

Mohd Helmi Ali

- School of Management, Faculty of Economics and Management, National University of Malaysia, Malaysia
- Institute for Manufacturing, University of Cambridge, United Kingdom

Email: mohdhelmiali@ukm.edu.my

Ming K. Lim

- Faculty Research Centre for Business in Society, Coventry University, United Kingdom

E-mail: ac2912@coventry.ac.uk

Anthony SF Chiu

- Department of Industrial Engineering, De La Salle University, Manila, Philippines

E-mail: anthony.chiu@dlsu.edu.ph

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Abstract

This study proposes a data-driven analysis that describes the overall situation and reveals the factors hindering improvement in the sustainable supply chain management field. The literature has presented a summary of the evolution of sustainable supply chain management across attributes. Prior studies have evaluated different parts of the supply chain as independent entities. An integrated systematic assessment is absent in the extant literature and makes it necessary to identify potential opportunities for research direction. A hybrid of data-driven analysis, the fuzzy Delphi method, the entropy weight method and fuzzy decision-making trial and evaluation laboratory is adopted to address uncertainty and complexity. This study contributes to locating the boundary of fundamental knowledge to advance future research and support practical execution. Valuable direction is provided by reviewing the existing literature to identify the critical indicators that need further examination. The results show that big data, closed-loop supply chains, industry 4.0, policy, remanufacturing, and supply chain network design are the most important indicators of future trends and disputes. The challenges and gaps among different geographical regions is offered that provides both a local viewpoint and a state-of-the-art advanced sustainable supply chain management assessment.

Keywords: sustainable supply chain management; data-driven analysis; fuzzy Delphi method; entropy weight method; fuzzy decision-making trial and evaluation laboratory

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1. Introduction

Sustainable supply chain management (SSCM) has grown significantly and has become a subject of increased concern due to environmental resource limitations, a global population explosion, the corruption of logistics production and consumption activities, and waste and pollution increases (Rebs et al., 2019). Over the last decade, academics and practitioners have endeavored to expand the frontier of sustainable development into supply chain management (SCM) to investigate SSCM (Bui et al., 2021; Tseng et al., 2016; Tseng and Chiu, 2013). The progression of exploration into sustainability has resulted in an increased emphasis on understanding various aspects of the sustainable supply chain (Brandenburg et al., 2014; Hu et al., 2020; Rajeev et al., 2017). As a result, the literal concept of SSCM is wide-ranging and varied and needs to be explored as a whole together with different viewpoints (Ansari and Kant, 2017). Integrated perception approaches are required to address firms' internal operations along with their external upstream and downstream operations while also considering the potential diverging opinions regarding the overall benefits.

The literatures have presented summaries of the SSCM evolution across different aspects (Rajeev et al., 2019; Tseng et al., 2019; Mohammed et al., 2020). For Instance, Gómez-Luciano et al. (2018) linked supply markets and globalization based on the theoretical foundation of SSCM and the related literature. Ciccullo et al. (2018) addressed the integration of the lean, agile and SSCM paradigms with sustainable environmental and social dimensions. Bastas and Liyanage (2018) adopted an interorganizational view to study the state of the art of sustainable supply chain quality management. Meherishi et al. (2019) provided a better understanding of sustainable packaging in SCM in the circular economy through a systematic approach. Wang et al. (2019) categorized the research on precast SCM for off-site construction. Rajeev et al. (2019) delineated the SSCM trends across theoretical angles over various stages of economic growth. Prior studies have yet to distinguish different parts of the supply chain as independent entities, treating them instead with conventional imprecise consideration (Govindan et al., 2020; Ni and Sun, 2019). A comprehensive integrated assessment of SSCM is still absent in the extant literature, making it necessary to identify potential opportunities for new study directions (Ansari and Kant, 2017; Farooque et al., 2019). This study proposes a data-driven analysis to illustrate a clear overall concept of SSCM and reveals factors hindering improvement of the field.

SSCM helps to link development and environmental issues and drives political and economic change locally, nationally and globally (Bui et al. 2020b; Mangla et al., 2017). Sustainable practices must focus on local social development and interconnected environmental issues as well as on global economic consequences (Bendul et al., 2017; Tan et al., 2016). Grimm et al. (2014) and Wu and Pullman (2015) argued that environmental and social corollaries regularly depend on the production site and cultural elements, causing prospects to deviate among supply chain partners. Ciccullo et al. (2018) claimed that the geographical concentration of the supply base improves operational performance due to integration within the sustainable supply chain paradigm. Firms may lack prominence in the supply base beyond the primary tier of their supply chain partner; others may view them as sites where environmental and existing execution is uncertain. The supply chain is characterized as complicated, composed of different players, and detached across various levels and different geographies; thus, the distinction between different areas poses serious challenges to sustainability (Carter et al., 2015; Koberg and Longoni, 2018). An emphasis on setting aside an overall viewpoint to explore the regional phenomena of state-of-the-art SSCM is necessary. This study has the following the aims as follows:

- To identify data-driven indicators for future trends and debates
- To determine the challenges and knowledge gaps among geographical regions

This study contributes to identifying the boundary of fundamental SSCM knowledge to advance future studies and support practical execution. Valuable direction is provided by the existing data-driven literature and identifying the critical indicators needed for further examination. The challenges and gaps among different geographical regions are addressed not only to provide a local standpoint for advanced assessment but also to comprehensively capture the global SSCM state-of-the-art. Since the supply chain environment has suffered uncertainties due to the urgent need to endorse sustainable development and create competitive advantages (Tseng et al, 2019, Liu et al., 2019a). This study employs both quantitative and qualitative approaches. A hybrid approach combining data-driven analysis, the fuzzy Delphi method (FDM), the entropy weight method (EWM) and the fuzzy decision-making trial and evaluation laboratory (FDEMATEL) is adopted due to the uncertainty and complexity of SSCM. The VOSviewer is applied to identify the SSCM indicators based on the big data in the Scopus database (Shukla et al., 2019). The FDM is used to refine the valid indicators by computing their perception levels from experts' linguistic references (Bui et al., 2021; Tsai et al., 2020; Tseng and Bui, 2017). The EWM is to convert the indicator occurrence information into comparable weights to determine the indicators' performance among regions; and the FDEMATEL identifies the perceptions through linguistic preferences and the important indicators that require urgent attention in future research to improve SSCM (Tseng, 2017; Tseng et al., 2018a).

The rest of this study is arranged into five sections. The next section discusses the related literature on SSCM. The data collection process, methodologies, and proposed analysis steps are reviewed in the third section. The fourth section presents the results. Then, the study trends, future challenges and regional implications are addressed in the fifth section. The last section remarks upon the conclusions and limitations of this study and provides suggestions for future studies.

2. Literature review

This section presents the related literature on SSCM from a regional perspective.

2.1. Sustainable supply chain management

Seuring and Muller (2008) defined SSCM as managing the flow of materials, information and capital as well as cooperation and collaboration among firms within the supply chain while adopting all the sustainable development goals entailed by the economic, environmental, and social aspects (the triple bottom line; TBL) expectations of stakeholders and customers. Carter and Rogers (2008) describe SSCM as the strategic, transparent, and complete integration of the TBL in the systematic coordination of business processes to improve the long-term relationship between organizations and their supply chain. Ahi and Searcy (2015) defined SSCM as the design of coordinated supply chains including voluntary TBL integration to effectively and efficiently manage product or service acquisition, manufacture, and distribution to meet the requirements of stakeholders and improve the organization's profitability, resilience, and competitiveness in the short and long term.

Many classifications have been proposed. Türkay et al. (2016) proposed integrating dimensions of sustainability in supply chain design and organization to comprehensively assess supply chain sustainability strategies. Franco (2017) identified the challenges faced by supply chain participants from product design to the recovery and reprocessing of products in circular production. Golev and Corder (2017) performed an in-depth examination of the sustainable supply chain associated with e-waste management in the production chain. Liu et al. (2018) highlighted the significance of collaboration with different third parties at distinct stages of supplier resourcefulness. The external and internal sustainable supply chain perspectives are considered related viewpoints in which tensions arising from inequitably distributed benefits are apparent (Rebs et al., 2018). The SSCM literature reiterates that information flow, collaboration, coordination, and connectivity across the supply chain network are key to achieving a higher level of organizational and supply chain sustainability performance (Liebetruth, 2017; Rajeev et al., 2017; Reefke and Sundaram, 2016). Few contributions cover both environmental and social influences, since focusing on the economic scope is part of the conventional supply chain archetype (Feng et al., 2017; Ciccullo et al., 2018).

In this context, environmental supply chains, green supply chains, and closed-loop supply chains have been presented and used interchangeably to extend the integration concepts of SSCM (Gurtu et al., 2015; Govindan et al., 2015; Leszczynska and Maryniak, 2017). Shaharudin et al. (2019a) identify past, present and future research developments for low-carbon SCM. Tseng et al. (2019) reviewed green SCM to present insights and directions for future investigation. Jia et al. (2020) established fundamental premises, tendencies and new paths for exploration through a structured systematic review of sustainable supply chain finance motivations, accomplishments and performance. SSCM is essentially the effort to integrate sustainable development into supply chain monitoring. Incorporating sustainability concepts into principal business areas enables the organization to achieve competitive advantages, especially given the dynamics of the global environment (Khodakarami et al., 2015). Although the concept of SSCM has risen to prominence in recent decades in response to growing challenges, the implications are that focusing on progression and competences in the supply chain is not sufficient for an organization to gain an advantageous position in the market (Ansari and Kant, 2017). Firms are facing serious threats to the sustainability of their existing supply chains due to globalization, uncertain demand, challenging markets, and pecuniary effectiveness (Roy et al., 2018). The literature on SSCM has expanded; nevertheless, guidance for scholars and future research opportunities are needed.

2.2. Sustainable supply chain management among regions

SSCM offers opportunities for regions to improve their ecological and social performance as well as their competitiveness and to achieve business goals (McMurray et al., 2014; van Hoof and Thiell, 2015). Silvestre et al. (2018) stated that the supply chain consists of various participants in different geographical regions; for example, manufacturers are usually located in developing countries. Ciccullo et al. (2018) indicated that suppliers' proximity concentrates the geographical supply base, reduces supply lead time, and facilitates suppliers' relationships and deliveries. Mancheri et al. (2019) claimed that the supply chain's complexity and resilience are not reliant on physical disruptions alone but also on dynamic factors such as societal and geopolitical factors. Thus, it is important to confirm that regional issues are one of the key elements influencing global SSCM because they drive global relevance.

Prior studies do not adequately address this specific issue (Fahimnia et al., 2015; Khalid et al., 2015). Bendul et al. (2017) debated whether sustainable development and the SCM relationship not only relate to broader interconnected environmental issues with global consequences but also express local community development. Vásquez et al. (2019) argued that a lack of adequate infrastructure among regions is a major barrier to adopting SSCM practices and expanding business in a context of heavy demand coupled with requests for rapid supply. There is a lack of studies originating regionally as well as discontent among local suppliers who are underrepresented by common business policies and strategies for sustainability (Jia et al., 2018). Hence, this study seeks to fill this gap by proposing a regional comparison in the SSCM context.

3. Method

The proposed analysis steps are presented in this section to provide a clear explanation of the data collection process, data-driven analysis, the FDM, the EWM, and the FDEMATEL.

3.1. Proposed methods

Prior studies have identified the components of a big database for building capabilities in the SCM (Akter et al., 2016; Zhan and Tan, 2020). Pereira and Frazzon (2020) proposed a data-driven approach that combines machine-learning petition estimating and operational planning simulation-based optimization for adaptive demand and supply synchronization in retail supply chains. Maroufkhani et al. (2020) used the technological-organizational-environmental model to examine the implementation of data-driven analysis to enhance sustainable solutions for resource and emission reduction among supply chain systems. Majeed et al. (2021) developed a modeling structure by uniting big data analytics, additive manufacturing, and sustainable smart manufacturing technologies, which is advantageous for additive manufacturing initiatives. There is a lack of big data assessments using multi-attribute decision making to enrich SSCM (Tseng et al., 2019). The capacity to refine and validate important indicators for future directions, and the numerical description for data incidences are absent in traditional data-driven analysis (Tsai et al., 2020). Interdependence and interrelationships among attributes and the integration of augmented data-driven solutions into supply chain networks must be addressed to achieve greater efficiency and effectiveness (Tseng et al., 2018b).

Due to the uncertainty and complexity of SSCM, this study proposed a hybrid multi-attribute decision-making approach including data-driven analysis, fuzzy set theory combined in the FDM, the EWM and the FDEMATEL. The FDM is used to refine and validate the indicators by computing their perceived levels from experts' linguistic references (Tseng and Bui, 2017). The EWM is used to convert the indicator occurrence information into comparable weights to determine the indicators' performance among regions (Tseng, 2017). The FDEMATEL method is used to identify the perceptions through linguistic preferences and the important indicators that require urgent attention in future research to improve SSCM (Tseng et al., 2018a). Still, the fuzzy interpretive structural modelling or analytic network process are more focusing on constructing the hierarchical framework compared to other multi-criteria decision-making technique (Bui et al. 2020b, Tseng et al., 2018a). FDEMATEL is more suitable to indicate the important indicators in the field by addressing the causal inter-relationship between the trends and challenges. Tsai et al. (2020) used a hybrid method, including a data-driven bibliometric analysis, FDM, and EWM to address to future study trend and challenges of municipal solid waste management in a circular economy. Bui et al. (2021) applied a combination of data-driven analysis based on content-bibliometric analyses, FDM, EWM, and FDEMATEL to obtain the experts' evaluation on SSWM towards disruption and organizational ambidexterity. Hence, this study not only provides in-depth technique for data-driven analysis, determine the SSWM performance of different regions, but also distinguish the critical indicators as gaps for supplementary knowledge for future studies provisions and practical executions.

3.2. Proposed analysis steps

This study offers a data-driven analysis, identifies indicators for the improvement of future studies and outlines the differences in state-of-the-art regional SSCM. A board of 30 experts, with no threshold for experiences time, was selected to ensure the reliability of the evaluation processes. The expert committee was gathered from among researchers and practitioners with at least 10 years of experience working in and studying SSCM, including 14 experts from academia, 5 experts from government and nongovernment organizations (NGOs) and 11 experts from the practical field. From regional viewpoint, the committee includes 10 experts from Asia and Oceania region, 5 experts from North America region, 8 experts from Europe, 4 experts from Latin America and Caribbean region (shown in Appendix A). The analysis steps are proposed as follows:

1. Feasible search terms are identified to filter the SSCM big data from the Scopus database for data collection.
2. The data-driven analysis of the collected database is conducted with VOSviewer to identify the SSCM indicators as well as country couplings based on the authors, keywords, titles, and abstracts.
3. The FDM is used to refine the valid indicators following Equations (1)-(2). The experts' assessment of the proposed indicators is solicited using the questionnaire.
4. The indicators' frequency is calculated, and the EWM is employed to convert the indicators' entropy into comparable scales using Equations (3)-(7). The regional comparison is specified for this study.
5. The important indicators for each region and the overall SSCM are identified using the FDEMATEL and Equations (8)-(15) to examine future study gaps.

A systematic diagram of the data analysis steps is presented in Figure 1.

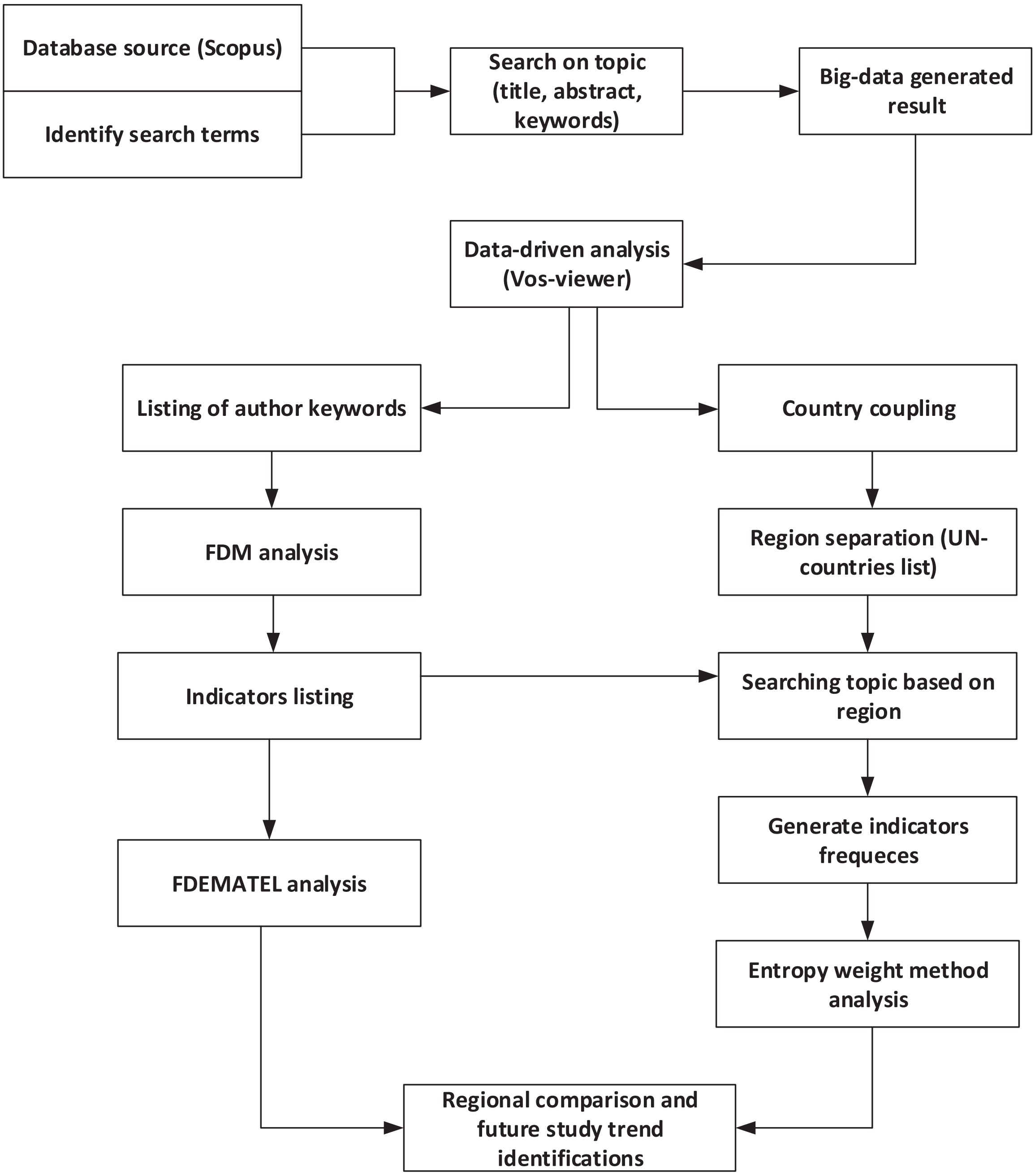


Figure 1. Analytical process

3.3. Data collection

Koberg and Longoni (2019) employed data on SSCM in global supply chains from Proquest, JSTOR Archival Journals, Business SourcePremier, PLoS, ScienceDirect, the Arts and Humanities Citation Index, Emerald Journals, Dialnet Plus, the Social Sciences Citation Index, and the Science Citation Index. Rebs et al. (2019) used Web of Science to retrieve relevant data on SSCM. These databases cover a smaller array of information. In this study, the Scopus database is employed because it covers a broader range of data than other data sources (Ansari and Kant, 2017; He et al., 2017; Jin et al., 2018). To generate the SSCM database, the search terms “(*"sustainable supply chain management"*) OR (*"supply chain management"* AND *"sustainability"*)” were used, with the results being generated from the titles, abstracts, or keywords. The search was limited to English-language articles and reviews.

3.4. Data-driven analysis

This study performs a data-driven analysis using VOSviewer version 1.6.11, open source software that creates scientific topographies by categorizing documents that have similar meaning into the same cluster to describe the relationships between them (van Eck and Waltman, 2018). In the supply chain context, Feng et al. (2017) used VOSviewer to develop a quantitative illustration of the knowledge structure and the intellectual progress of corporate social responsibility in SCM. Wang et al. (2019) created a taxonomy to properly classify SCM indicators for off-site construction using VOSviewer. Thus, VOSviewer is suitable for use to visualize the SSCM indicators because it reveals study gaps and opportunities for future investigation.

3.5. Fuzzy Delphi method

The combination of fuzzy set theory and the Delphi method helps decision groups address the lack of expert references and improve questionnaire quality (Ishikawa et al. 1993). It is used to screen out invalid indicators by generating experts’ linguistic references (Tseng and Bui, 2017). The method has advantages in reducing the quantity of responses and feedback time, providing an effective assessment of experts’ judgment and relevant remarks to transform their fuzzy evaluation into exact numbers (Lee et al., 2018).

In the analytical process, assuming that there are n experts and m indicators, expert a has to evaluate the magnitude of indicator b. This evaluation is transformed into triangular fuzzy numbers as $j = (x_{ab}; y_{ab}; z_{ab})$, $a = 1,2,3, \dots, n$; $b = 1,2,3, \dots, m$, where the j_b weight of b is presented as $j_b = (x_b; y_b; z_b)$ with $x_b = min(x_{ab})$, $y_b = (\prod_1^n y_{ab})^{1/n}$, and $z_b = max(z_{ab})$. Formally, the experts’ linguistic references are converted into triangular fuzzy numbers, as presented in Table 1.

The convex combination value D_b is computed using a γ cut as:

$$u_b = z_b - \gamma(z_b - y_b), l_b = x_b - \gamma(y_b - yx_b), b = 1,2,3, \dots, m \quad (1)$$

This γ value can be customized from 0 to 1 to reflect a positive or negative tendency in evaluators’ perceptions. The value of 0.5 is used to represent a balance (Bui et al., 2020a).

Then, D_b is determined by:

$$D_b = \int(u_b, l_b) = \delta[u_b + (1 - \delta)l_b] \quad (2)$$

with δ representing the positivity perception of the evaluators; a balance in the ultimate assessment of the expert committee is represented by a value of 0.5.

The threshold to refine the valid indicators is calculated using $t = \sum_{a=1}^{n}(D_b/n)$. If $D_b \geq t$, indicator b is accepted. Otherwise, it must be removed.

Table 1. Transformation table of linguistic terms for FDM.

Linguistic terms (performance/importance)	Corresponding triangular fuzzy numbers (TFNs)
Extreme	(0.75, 1.0, 1.0)
Demonstrated	(0.5, 0.75, 1.0)
Strong	(0.25, 0.5, 0.75)
Moderate	(0, 0.25, 0.5)
Equal	(0, 0, 0.25)

The FDM process is implemented in 2 rounds in this study. A face-to-face interview with the expert committee is held to refine the SSCM keywords and select the indicators for the FDM analysis. Round 1 aims to eliminate the unnecessary attributes by assimilating expert judgments, and round 2 allows experts to use their knowledge and experience to simplify the complex attribute set from round 1 through discussion (Lee et al., 2018). The process allows group decision making, reducing the number of selections through rapid convergence in predicting sentiments and thereby helping decision makers validate the decision requirement (Bui et al., 2020a; Bui et al., 2021; Tsai et al 2020).

3.6. Entropy weighted method

The differences across geographical regions are determined by adopting the entropy weighted method. All tracking activities are coded in an equivalent Excel file to prevent repeating the same actions and to improve the results' reliability. A content analysis is used for regional consistency checks of independent coding to count the indicator frequencies for each specific region by searching the SSCM regional data generated from the Scopus database (see Appendix B). For instance, the search term used to generate the regional data for Africa is "TITLE-ABS-KEY ("Cameroon" or "Egypt" or "Ethiopia" or "Ghana" or "Kenya" or "Morocco" or "Nigeria" or "South Africa" or "Tanzania" or "Tunisia" or "Uganda" or "Zimbabwe")". The search terms are used to search the title, abstracts, and keywords. Therefore, studies and authors addressing multiple regions can be avoided, while the geographical issues in the studies' scope are still accounted for.

The indicator frequency ε takes a coefficient value between zero and one. The value is generally set to 0.5 to reflect the general effects of the indicators on the structure (Tseng, 2017), with:

$$\tau_{0,i} = \sum_{m=1}^{n} w_m \varepsilon_{0,i}(m) \text{ for } i = 1,2, \dots m \tag{3}$$

where the weight $(w_m, \sum w_m = 1)$ for each distinguishing indicator is calculated using the entropy method.

The entropy method quantifies a disorganized structure by employing weight measurement. An indicator with large entropy means and high response diversity has a more substantial effect when it reacts to the structure (Wen et al., 1998; Tseng, 2017). The method comprises functionf_i: $[0,1] \to [0,1]$ and justifies three constraints, (1) $f_i(0) = 0$, (2) $f_i(x) = f_i(1-x)$, and (3) $f_i(x)$, to enlarge the range of $x \in (0, 0.5)$. The largest value of this function is at $x = 0.5$, and the value $(\partial^{0.5} - 1)$ puts the result in the range $[0,1]$. The entropy weighted computational processes are as follows:

The coefficient arrangements for each indicator are computed as follows:

$$C_j = \sum_{i=1}^{n} \varepsilon_i(j) \quad (4)$$

Each indicator's entropy weight is generated using:

$$e_j = k \sum_{j=1}^{n} w_e \left(\frac{\varepsilon_i(j)}{e_j}\right) \quad (5)$$

The total entropy values are calculated as follows:

$$E = \sum_{j=1}^{p} e_j \quad (6)$$

Each indicator's weighted value is determined as follows:

$$w_j = \frac{\frac{1}{p} - E(1-e_j)}{\sum_{j=1}^{p} 1/p - E(1-e_j)}, j = 1,2,3,\dots,p \quad (7)$$

3.7. Fuzzy decision-making trial and evaluation laboratory

In this method, fuzzy set theory is employed to measure equivocal perceptions related to linguistic judgments in an uncertain environment and generate a crisp value, while the DEMATEL technique is designed to causally construct intercorrelations among indicators under complex conditions (Tseng et al., 2018a).

The method uses the defuzzification technique to convert linguistic information into fuzzy triangular numbers and then transforms them into crisp values. The fuzzy membership functions $\tilde{e}_{ij}^{k} = (\tilde{e}_{1ij}^{k}, \tilde{e}_{2ij}^{k}, \tilde{e}_{3ij}^{k})$ are used to compute the total weighted values. Formally, the left and right values are calculated by the minimum and maximum fuzzy numbers. The crisp values are subsequently obtained in the form of a total direct relation matrix that can be used to draw a diagram to simplify the analytical results. The interrelationship structure contains certain indicators that represent important means in the system. A set of indicators is addressed as $F = \{f1, f2, f3, \cdots, fn\}$, and accurate pairwise evaluation is then used to create the mathematical relation.

In particular, this study obtained and accumulated crisp values using linguistic scales from VL (very low influence) to VHI (very high influence), as presented in Table 2. If there are k experts involved in the evaluation procedure, $\tilde{e}_{ij}^{k}$ specifies the fuzzy weight of the i^{th} indicator's influence on attribute j^{th} evaluated by expert k^{th}.

Table 2. TFNs linguistic scale for FDEMATEL

Scale	Linguistic terms	Corresponding TFNs
1	No influence	(0.0, 0.1, 0.3)
2	Very low influence	(0.1, 0.3, 0.5)
3	Low influence	(0.3, 0.5, 0.7)
4	High influence	(0.5, 0.7, 0.9)
5	Very high influence	(0.7, 0.9, 1.0)

The fuzzy numbers are abridged as follows:

$$F = \left(f\tilde{e}_{1ij}^{k}, f\tilde{e}_{2ij}^{k}, f\tilde{e}_{3ij}^{k}\right) = \left[\frac{(e_{1ij}^{k} - mine_{1ij}^{k})}{\Delta}, \frac{(e_{2ij}^{k} - mine_{2ij}^{k})}{\Delta}, \frac{(e_{3ij}^{k} - mine_{3ij}^{k})}{\Delta}\right] \quad (8)$$

where$\Delta = maxe_{3ij}^{k} - mine$

The left (lv) and right (rv) normalized values are determined using:

$$\left(lv_{ij}^{n}, rv_{ij}^{n}\right) = \left[\frac{(fe_{2ij}^{k}}{\left(1+fe_{2ij}^{k}-fe_{1ij}^{k}\right)}, \frac{fe_{3ij}^{k}}{\left(1+fe_{3ij}^{k}-fe_{2ij}^{k}\right)}\right] \quad (9)$$

The total normalized crisp values (cv) are formulated as:

$$cv_{ij}^{k} = \frac{[lv_{ij}^{k}\left(1-lv_{ij}^{k}\right)+(rv_{ij}^{k})^{2}]}{(1-lv_{ij}^{k}+rv_{ij}^{k})} \quad (10)$$

The synthetic values' symbolization to accrue individual insight from k respondents is afterward implemented by:

$$\tilde{e}_{ij}^{k} = \frac{(cv_{ij}^{1}+cv_{ij}^{2}+cv_{ij}^{3}+\cdots+cv_{ij}^{3})}{k} \quad (11)$$

A pairwise comparison is manipulated to acquire a direct relation (IM) $n \times n$ initial matrix, where $\tilde{e}_{ij}^{k}$ refers to the efficient level of indicator i on indicator j, moderated as $IM = [\tilde{e}_{ij}^{k}]_{n\times n}$.

The normalized direct relation matrix (U) is formed as:

$$U = \tau \otimes IM$$

$$\tau = \frac{1}{\max\limits_{1\le i\le k} \sum_{j=1}^{k} \tilde{e}_{ij}^{k}} \quad (12)$$

The interrelationship matrix (W) is obtained from the normalized direct relation matrix using:

$$W = U(I-U)^{-1} \quad (13)$$

where W is$[w_{ij}]_{n\times n}$ $i,j = 1,2,\cdots n$

The values of the driving power (α) and dependence power (β) are assimilated from the summation of the row and column values in the interrelationship matrix using:

$$\alpha = [\textstyle\sum_{i-1}^{n} w_{ij}]_{n\times n} = [w_{i}]_{n\times 1} \quad (14)$$

$$\beta = [\textstyle\sum_{j-1}^{n} w_{ij}]_{n\times n} = [w_{j}]_{1\times n} \quad (15)$$

The indicators are positioned in an interrelationship diagram derived from $[(\alpha + \beta), (\alpha - \beta)]$, which in turn presents horizontal and vertical axes. The indicators are grouped into cause and affect groups based on whether the $(\alpha - \beta)$ values are positive or negative. $(\alpha + \beta)$ displays the importance of the indicators: the higher the $(\alpha + \beta)$ value an indicator has, the more important it is. This study uses the average value of $(\alpha + \beta)$ to identify the most important causal indicators, which then require further focus.

4. Results

The SSCM data-driven method is shown in this section. The FDM and EWM results are also shown. The critical indicators for identifying future implications obtained from the FDEMATEL analysis are examined.

4.1. Data-driven analysis

This study generates co-occurrence couplings of author keywords extracted from Scopus (see Appendix C). There are 251 keywords listed with at least 5 occurrences. There are 92 countries/territories listed, with the minimum number of documents for a country being equal to

1. Then, for further evaluation, the countries/territories are separated into 5 geographical regions based on the UN countries list (2019), namely, Asia and Oceania, Europe, North America, Latin America and the Caribbean, and Africa (shown in Appendix D).

4.2. Fuzzy Delphi method

There are 127 indicators identified from the 151 author keywords that co-occur. The summaries from rounds 1 and 2 of the FDM are shown in Appendix E and Appendix F, along with the weights and the threshold for validating the indicator attributes. In round 1, the set of SSCM indicators is evaluated based on the experts' experience and judgment, and the linguistic terms are converted into conforming triangular fuzzy numbers in Table 1. The FDM refines the indicator, which can be found in Appendix E. There are 54 barriers that are accepted with a threshold of 0.302.

Then, the refined set is used for input in round 2. In this round, the indicators set in round 1 are reproduced for the experts' redefinition. The results show that 22 out of 54 indicators are accepted, while the other 32 are rejected (as presented in Appendix F) with a threshold of 0.298. The final FDM indicator set is shown in Table 3.

Table 3. Final List of FDM indicator result

ID	Indicators	Description	References
I1	Big data	The big data concept is defined as high volume, high velocity and high variety data that are used in the decision-making process and require innovative techniques to be managed.	Beyer and Laney, 2012
I2	Circular economy	Circular economy is a closed loop supply chain which focuses on the restorative and regenerative aspects that aim to eliminate the use of toxic materials, reuse and eliminates the wastage through the explicit implementation of the design models, product systems and design of the materials.	Rajput and Singh, 2019
I3	Cleaner production	Cleaner production regards to better management practices, substitution of toxic and hazardous materials, process modifications, and reuse of waste products to improve resource use efficiency, reduce loss and recover resources from waste.	Pingmuanglek et al., 2017
I4	Closed-loop supply chain	Closed-loop supply chain include two fundamental phases: the forward and the reverse supply chain, in which the forward chain refers to the flow of new products that are delivered from manufacturers to consumers, while the reverse chain is described as the return flow of used, defective, and open box products collected from consumers and transferred to manufacturers or recycling centers .	Amin and Zhang, 2012; Assarzadegan and Rasti-Barzoki, 2019
I5	Eco-efficiency	Eco-efficiency refers to a quantitative management solution that enables a product system to balance resource use through the adoption of a more sustainable concept while still bringing profit to stakeholders.	Vásquez et al., 2019
I6	Emerging markets	Emerging markets (also called the emerging economies) refer to the markets which have developed to a state which has some similarities as the developed markets but are not yet fully developed.	Choi and Luo, 2019
I7	Ethics	An ethical supply chain focuses on the need for corporate social responsibility, working to produce products and services in a way that incorporate social, human rights and environmental considerations into the way they do business	Quintens, 2017
I8	Financial performance	Firm financial performance refers to how well a firm fulfils its financial goals compared with the firm's primary competitors which comprise growth in return on sales, growth in profit, growth in market share, return on investment, and return on assets	Yu et al., 2019
I9	Globalization	Globalization has been a strategical trend for the past decades, leading to international supply chains.	Kandil et al., 2020
I10	Industry 4.0	The concept of industry 4.0 is founded based on three principal elements: cyber-physical systems, the internet of things, and smart factories.	Hofmann and Rusch, 2017; Tseng et al., 2018b
I11	Knowledge management	Knowledge management transforms information, data and intellectual assets to firms' perdurable value through recognizing useful knowledge for running and managing operations.	Lim et al., 2017

I12	Optimization	Optimization models can be used to consider the deterministic characteristics in the supply chain and translated into recommended actions to support management decisions to achieve the best solution.	Aqlan and Lam, 2016
I13	Policy	The policy and influence of regulation legislation in forming the SSCM is one of the key tactical elements requiring focused attention.	Manavalan and Jayakrishna, 2019
I14	Raw materials	Better raw material management helps to (1) decrease the manufacturing complexity related to sourced components, (2) focusing on new product development as firms have more information about the raw material, better predict the problems in new product development cycle, and thereby develop more robust products, (2) reduce costs of sourcing by cost control at the design stage of components.	Agrawal, 2014
I15	Remanufacturing	Remanufacturing is a multi-process that transforms end-of-use products by recovering, checking, disassembling, polishing, renovating, and reassembling to a “like-new” product	Govindan et al., 2016; Kafuku et al., 2016.
I16	Reverse logistics	Reverse logistics is the process of moving products from their typical final destination with the purpose of revalorization or proper disposal.	Bouzon et al., 2018
I17	Risk management	Risk management defines supply chain responses that will contradict vulnerabilities by choosing the most appropriate risk response solution and planning how that solution should be applied.	Manuj et al., 2014, Sahebjamnia et al., 2018
I18	Social sustainability	Social sustainability is one of the pillars of the TBL, addresses three points: well-being of human beings, society, and safety of consumers.	Govindan et al., 2020
I19	Supply chain collaboration	Supply chain collaboration is a model in which members of the supply chain share risks and resources in order to improve the competitive advantage of the entire supply chain.	Manthou et al., 2004
I20	Supply chain network design	Supply chain network design represents the facility location problem, and SCM contains facility location determination, magnitude, network capabilities and the material flow among the located facilities.	Pishvaee and Razmi, 2012
I21	Sustainable supplier selection	Supplier selection process considers the processes resulting in adopting a developed evaluation approach to select the most potential suppliers from a pool of candidates.	Ghadimi et al., 2019
I22	System dynamics	System dynamics is a technique to model and simulate complex systems, e.g., the relationships between economic, environmental, and social variables in connection with societal action to uncover alternative paths of evolution	Rebs et al., 2019

4.3. Entropy weighted method

Table 4 presents the indicator entropy weights for each region. The EWM uses entropy to represent the amount of information. The higher the indicator values are, the more information they contain. In other words, the larger the entropy value is, the smaller the entropy weight (He et al., 2016) and the more information the indicator provides. Hence, this study uses the average weighted technique to determine the level of indicator information in each region. If the weight is greater than the average, the indicator must be improved, shown in Table 5. The results show that Asia and Oceania have the highest amount of information in the field of SSCM, followed by Europe and North America. In contrast, Africa and Latin America and the Caribbean have less information, and there is still much room for SSCM development in these regions.

Table 4. Regional entropy weights

	Indicators	Asia and Oceania	Europe	North America	Africa	Latin-America and Caribbean	Overall
I1	Big data	0.0454708	0.0454850	0.0454850	0.0454850	0.0454850	0.0454822
I2	Circular economy	0.0454494	0.0454180	0.0454559	0.0454850	0.0454212	0.0454459
I3	Cleaner production	0.0454708	0.0454850	0.0454850	0.0454850	0.0454212	0.0454694
I4	Closed-loop supply chain	0.0454636	0.0454448	0.0454267	0.0454850	0.0454850	0.0454610
I5	Eco-efficiency	0.0454779	0.0454716	0.0454850	0.0454850	0.0454850	0.0454809
I6	Emerging markets	0.0454708	0.0454716	0.0454559	0.0454850	0.0454531	0.0454673
I7	Ethics	0.0454779	0.0454448	0.0454267	0.0453733	0.0454850	0.0454415
I8	Financial performance	0.0454494	0.0454716	0.0454559	0.0453733	0.0454850	0.0454470
I9	Globalization	0.0453923	0.0454046	0.0453976	0.0454850	0.0453254	0.0454010
I10	Industry 4.0	0.0454708	0.0454850	0.0454850	0.0454850	0.0454850	0.0454822
I11	Knowledge management	0.0454494	0.0454180	0.0454850	0.0454850	0.0454850	0.0454645
I12	Optimization	0.0454708	0.0454180	0.0453101	0.0454850	0.0454531	0.0454274
I13	Policy	0.0454066	0.0454582	0.0453976	0.0453733	0.0453254	0.0453922
I14	Raw materials	0.0454636	0.0454850	0.0454559	0.0454850	0.0454531	0.0454685
I15	Remanufacturing	0.0454850	0.0454716	0.0454850	0.0454850	0.0454850	0.0454823
I16	Reverse logistics	0.0454351	0.0454582	0.0454850	0.0454850	0.0454531	0.0454633
I17	Risk management	0.0454066	0.0454716	0.0454850	0.0454850	0.0454850	0.0454667
I18	Social sustainability	0.0454422	0.0454582	0.0454559	0.0452615	0.0454850	0.0454206
I19	Supply chain collaboration	0.0454351	0.0454448	0.0454559	0.0454850	0.0453892	0.0454420
I20	Supply chain network design	0.0454779	0.0454582	0.0454850	0.0454850	0.0454850	0.0454782
I21	Sustainable supplier selection	0.0454708	0.0454582	0.0454559	0.0453733	0.0454850	0.0454486
I22	System dynamics	0.0454636	0.0454180	0.0454850	0.0454850	0.0454850	0.0454673

Table 5. Region Entropy weight comparison

	Indicators	Asia and Pacific Ocean	Europe	North America	Africa	Latin-America and Caribbean
I1	Big data	↓	↑	↑	↑	↑
I2	Circular economy	↑	↓	↑	↑	↓
I3	Cleaner production	↑	↑	↑	↑	↓
I4	Closed-loop supply chain	↑	↓	↓	↑	↑
I5	Eco-efficiency	↓	↓	↑	↑	↑
I6	Emerging markets	↑	↑	↓	↑	↓

I7	Ethics	↑	↑	↓	↓	↑
I8	Financial performance	↑	↑	↑	↓	↑
I9	Globalization	↓	↑	↓	↑	↓
I10	Industry 4.0	↓	↑	↑	↑	↑
I11	Knowledge management	↓	↓	↑	↑	↑
I12	Optimization	↑	↓	↓	↑	↑
I13	Policy	↑	↑	↑	↓	↓
I14	Raw materials	↓	↑	↓	↑	↓
I15	Remanufacturing	↑	↓	↑	↑	↑
I16	Reverse logistics	↓	↓	↑	↑	↓
I17	Risk management	↓	↑	↑	↑	↑
I18	Social sustainability	↑	↑	↑	↓	↑
I19	Supply chain collaboration	↓	↑	↑	↑	↓
I20	Supply chain network design	↓	↓	↑	↑	↑
I21	Sustainable supplier selection	↑	↑	↑	↓	↑
I22	System dynamics	↓	↓	↑	↑	↑

Notes: ↑ *: above the average (Need for improvement)*

↓ *: below the average*

4.4. Fuzzy decision-making trial and evaluation laboratory

From the FDM indicator set, the experts evaluated the indicator interrelationships using the provided linguistic scales (see Table 2). The fuzzy direct relation matrix and the defuzzification are characterized to compute the average crisp value for all respondents and used to create the initial direction matrix, presented in Table 6. The total interrelationship matrix is generated (see Table 7), as is the interrelationship among indicators, shown in Table 8. Figure 2 presents the interrelationship diagram among regions based on the $(\alpha + \beta)$ and $(\alpha - \beta)$ axes. The average value of $(\alpha + \beta)$ is used to identify the most important causal indicators that require attention. The results show that there are some differences between regions. In particular, Asia and Oceania focus on big data (I1), industry 4.0 (I10), policy (I13), remanufacturing (I15), and supply chain network design (SCND) (I20). The important indicators for Europe are big data (I1), closed-loop supply chain (I4), policy (I13), and remanufacturing (I15). The most important indicators of the Latin American and Caribbean regions include industry 4.0 (I10), policy (I13), remanufacturing (I15), and risk management (I17) SCND (I20). For North America, the important indicators consist of big data (I1), closed-loop supply chain (I4), industry 4.0 (I10), remanufacturing (I15), and SCND (I20). Big data (I1), eco-efficiency (I5), policy (I13), risk management (I17), and SCND (I20) are important indicators for Africa.

Overall, the most important indicators for SSCM are big data (I1), closed-loop supply chain (I4), industry 4.0 (I10), policy (I13), remanufacturing (I15), and SCND (I20). These indicators are considered to have continuing effects as well as response effects within SSCM. They are identified as the most critical study trends enhancing SSCM.

Table 6. Overall initial direction matrix

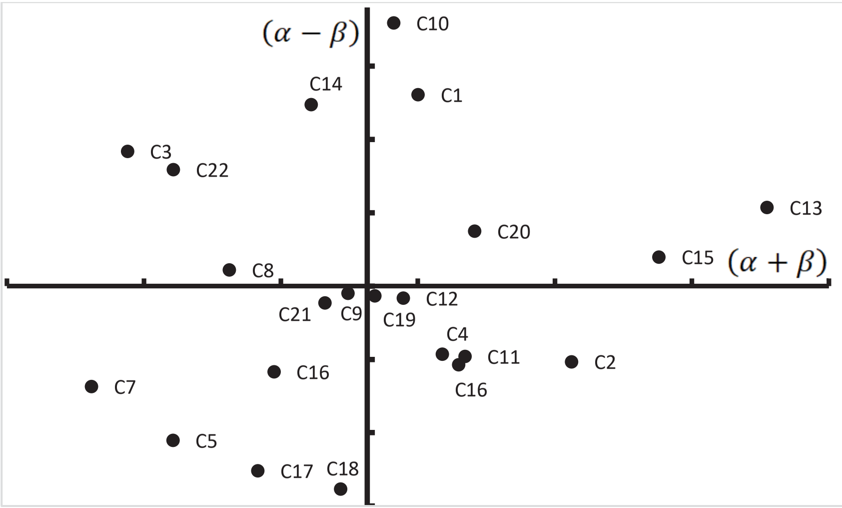
	I1	I2	I3	I4	I5	I6	I7	I8	I9	I10	I11	I12	I13	I14	I15	I16	I17	I18	I19	I20	I21	I22
I1	0.776	0.543	0.463	0.471	0.520	0.518	0.445	0.534	0.549	0.503	0.528	0.512	0.508	0.523	0.445	0.518	0.538	0.481	0.486	0.492	0.537	0.510
I2	0.530	0.758	0.461	0.516	0.433	0.397	0.383	0.388	0.453	0.406	0.397	0.519	0.484	0.519	0.434	0.441	0.473	0.502	0.434	0.481	0.479	0.523
I3	0.466	0.495	0.758	0.478	0.461	0.471	0.386	0.506	0.461	0.526	0.489	0.462	0.453	0.467	0.439	0.469	0.456	0.535	0.499	0.462	0.460	0.511
I4	0.550	0.454	0.460	0.763	0.499	0.455	0.415	0.458	0.480	0.487	0.489	0.475	0.407	0.448	0.503	0.493	0.494	0.554	0.487	0.495	0.435	0.458
I5	0.515	0.492	0.447	0.541	0.759	0.529	0.437	0.500	0.446	0.473	0.457	0.524	0.459	0.431	0.458	0.449	0.443	0.463	0.434	0.460	0.465	0.433
I6	0.389	0.496	0.391	0.485	0.466	0.761	0.499	0.493	0.454	0.402	0.474	0.415	0.451	0.402	0.531	0.447	0.481	0.458	0.408	0.457	0.465	0.395
I7	0.382	0.335	0.457	0.449	0.446	0.448	0.760	0.414	0.395	0.332	0.385	0.429	0.468	0.551	0.612	0.418	0.403	0.439	0.401	0.448	0.550	0.492
I8	0.415	0.487	0.451	0.461	0.448	0.491	0.422	0.773	0.444	0.389	0.445	0.356	0.453	0.405	0.486	0.656	0.502	0.487	0.440	0.414	0.468	0.466
I9	0.380	0.418	0.411	0.417	0.420	0.469	0.355	0.411	0.779	0.474	0.431	0.344	0.502	0.511	0.420	0.441	0.650	0.463	0.430	0.447	0.491	0.460
I10	0.455	0.542	0.490	0.477	0.458	0.487	0.406	0.453	0.513	0.778	0.513	0.422	0.517	0.505	0.466	0.506	0.545	0.682	0.512	0.479	0.546	0.537
I11	0.457	0.489	0.411	0.521	0.478	0.428	0.323	0.420	0.487	0.474	0.766	0.434	0.422	0.461	0.401	0.449	0.496	0.491	0.559	0.386	0.451	0.459
I12	0.369	0.458	0.433	0.400	0.482	0.521	0.366	0.508	0.512	0.485	0.403	0.770	0.470	0.417	0.400	0.474	0.528	0.566	0.426	0.662	0.498	0.396
I13	0.440	0.479	0.480	0.518	0.513	0.506	0.451	0.533	0.503	0.529	0.447	0.497	1.000	0.488	0.418	0.500	0.513	0.527	0.419	0.513	0.770	0.454
I14	0.413	0.541	0.459	0.418	0.462	0.414	0.378	0.444	0.472	0.496	0.493	0.446	0.496	0.774	0.367	0.442	0.526	0.488	0.483	0.468	0.466	0.650
I15	0.508	0.506	0.444	0.546	0.490	0.565	0.502	0.547	0.574	0.441	0.488	0.553	0.528	0.665	0.642	0.439	0.498	0.528	0.536	0.421	0.391	0.611
I16	0.507	0.544	0.472	0.482	0.428	0.449	0.446	0.483	0.516	0.471	0.427	0.482	0.478	0.504	0.468	0.628	0.309	0.497	0.474	0.350	0.557	0.549
I17	0.534	0.521	0.464	0.426	0.480	0.488	0.479	0.477	0.464	0.466	0.492	0.547	0.495	0.231	0.589	0.291	0.633	0.478	0.319	0.565	0.451	0.380
I18	0.526	0.537	0.485	0.457	0.479	0.525	0.555	0.472	0.500	0.428	0.506	0.461	0.412	0.207	0.640	0.530	0.503	0.565	0.475	0.470	0.552	0.355
I19	0.509	0.475	0.401	0.437	0.447	0.498	0.477	0.427	0.447	0.421	0.463	0.548	0.575	0.266	0.582	0.530	0.470	0.441	0.626	0.470	0.451	0.413
I20	0.488	0.424	0.478	0.527	0.409	0.473	0.499	0.529	0.504	0.451	0.461	0.546	0.590	0.609	0.393	0.573	0.614	0.581	0.532	0.632	0.438	0.542
I21	0.414	0.470	0.420	0.472	0.415	0.445	0.408	0.476	0.394	0.488	0.448	0.492	0.512	0.605	0.429	0.299	0.562	0.589	0.557	0.586	0.775	0.594
I22	0.494	0.464	0.452	0.450	0.453	0.467	0.466	0.502	0.457	0.395	0.485	0.436	0.488	0.517	0.547	0.534	0.479	0.468	0.498	0.461	0.499	0.636

Table 7. Overall total inter-relationship matrix

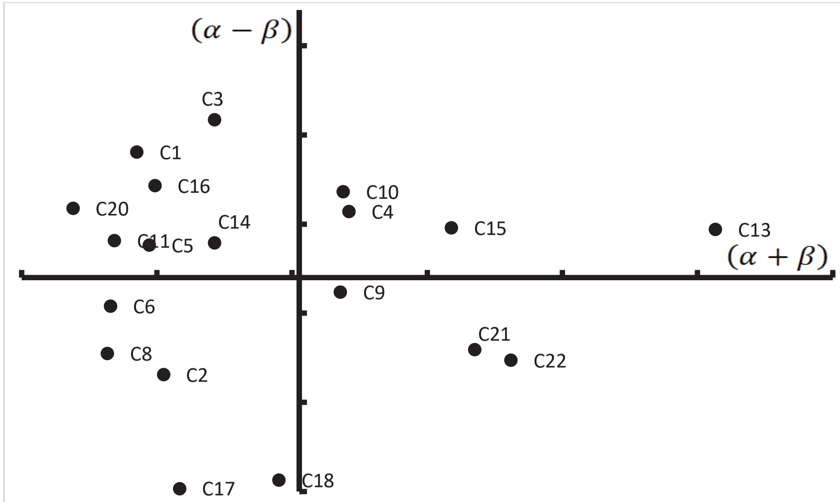
	I1	I2	I3	I4	I5	I6	I7	I8	I9	I10	I11	I12	I13	I14	I15	I16	I17	I18	I19	I20	I21	I22
I1	0.644	0.647	0.598	0.628	0.618	0.637	0.578	0.636	0.640	0.609	0.620	0.630	0.657	0.620	0.623	0.621	0.657	0.660	0.613	0.626	0.662	0.637
I2	0.573	0.614	0.549	0.581	0.560	0.575	0.526	0.571	0.580	0.551	0.559	0.580	0.602	0.570	0.571	0.564	0.598	0.608	0.559	0.574	0.603	0.587
I3	0.582	0.606	0.590	0.593	0.577	0.597	0.540	0.597	0.596	0.576	0.582	0.589	0.615	0.580	0.587	0.582	0.612	0.627	0.580	0.587	0.617	0.601
I4	0.592	0.605	0.566	0.621	0.583	0.598	0.545	0.596	0.601	0.576	0.585	0.593	0.613	0.581	0.596	0.587	0.619	0.632	0.581	0.593	0.617	0.599
I5	0.581	0.601	0.558	0.593	0.599	0.597	0.540	0.592	0.590	0.567	0.574	0.590	0.610	0.572	0.584	0.575	0.606	0.616	0.569	0.582	0.612	0.589
I6	0.549	0.579	0.532	0.567	0.552	0.596	0.526	0.570	0.569	0.540	0.555	0.559	0.587	0.548	0.569	0.554	0.587	0.593	0.546	0.560	0.590	0.564
I7	0.539	0.554	0.529	0.554	0.541	0.559	0.540	0.553	0.554	0.524	0.537	0.550	0.579	0.553	0.567	0.541	0.570	0.581	0.536	0.550	0.587	0.563
I8	0.558	0.586	0.545	0.572	0.557	0.580	0.526	0.602	0.575	0.545	0.559	0.561	0.595	0.555	0.573	0.580	0.596	0.603	0.556	0.564	0.598	0.577
I9	0.543	0.567	0.530	0.556	0.543	0.566	0.509	0.558	0.593	0.542	0.546	0.548	0.587	0.553	0.555	0.548	0.598	0.588	0.543	0.555	0.587	0.565
I10	0.611	0.641	0.595	0.623	0.607	0.629	0.570	0.623	0.631	0.628	0.614	0.616	0.652	0.612	0.620	0.615	0.652	0.672	0.610	0.619	0.657	0.634
I11	0.558	0.581	0.536	0.573	0.556	0.569	0.512	0.565	0.574	0.549	0.583	0.563	0.587	0.555	0.560	0.556	0.591	0.598	0.562	0.557	0.591	0.572
I12	0.564	0.594	0.553	0.577	0.571	0.593	0.530	0.589	0.592	0.564	0.565	0.608	0.607	0.567	0.575	0.574	0.610	0.621	0.565	0.597	0.611	0.581
I13	0.621	0.648	0.606	0.639	0.623	0.643	0.585	0.642	0.643	0.618	0.619	0.635	0.709	0.623	0.627	0.626	0.662	0.672	0.614	0.634	0.690	0.638
I14	0.571	0.604	0.557	0.581	0.571	0.585	0.533	0.585	0.591	0.568	0.576	0.582	0.612	0.601	0.574	0.573	0.612	0.616	0.572	0.581	0.611	0.607
I15	0.621	0.644	0.596	0.635	0.615	0.642	0.583	0.637	0.643	0.603	0.617	0.633	0.659	0.633	0.641	0.615	0.654	0.664	0.618	0.619	0.649	0.646
I16	0.576	0.601	0.555	0.583	0.565	0.585	0.536	0.585	0.591	0.562	0.567	0.581	0.607	0.574	0.580	0.586	0.589	0.614	0.568	0.567	0.616	0.594
I17	0.566	0.586	0.543	0.566	0.558	0.577	0.528	0.573	0.574	0.550	0.561	0.575	0.596	0.537	0.579	0.544	0.606	0.599	0.542	0.575	0.593	0.567
I18	0.583	0.606	0.562	0.587	0.575	0.598	0.552	0.590	0.596	0.564	0.579	0.586	0.607	0.553	0.601	0.583	0.612	0.626	0.574	0.584	0.621	0.583
I19	0.569	0.587	0.542	0.572	0.560	0.583	0.533	0.574	0.578	0.551	0.563	0.581	0.609	0.545	0.583	0.571	0.596	0.601	0.574	0.571	0.599	0.575
I20	0.613	0.630	0.594	0.627	0.602	0.627	0.578	0.629	0.630	0.598	0.609	0.627	0.658	0.621	0.613	0.620	0.657	0.663	0.611	0.632	0.647	0.633
I21	0.584	0.611	0.567	0.600	0.580	0.602	0.549	0.602	0.597	0.580	0.586	0.600	0.628	0.599	0.594	0.574	0.630	0.640	0.592	0.606	0.653	0.616
I22	0.581	0.600	0.560	0.587	0.573	0.593	0.544	0.594	0.593	0.561	0.578	0.584	0.615	0.581	0.594	0.584	0.611	0.618	0.576	0.584	0.617	0.609

Table 8. Causal inter-relationship among indicators.

	Asia and Oceania				Europe				Latin America and Caribbean				North America				Africa				Overall			
	α	β	$(\alpha+\beta)$	$(\alpha-\beta)$	α	β	$(\alpha+\beta)$	$(\alpha-\beta)$	α	β	$(\alpha+\beta)$	$(\alpha-\beta)$	α	β	$(\alpha+\beta)$	$(\alpha-\beta)$	α	β	$(\alpha+\beta)$	$(\alpha-\beta)$	α	β	$(\alpha+\beta)$	$(\alpha-\beta)$
I1	10.053	8.748	18.801	1.305	8.744	8.033	16.777	0.711	13.355	13.733	27.087	(0.378)	7.137	6.366	13.503	0.771	6.198	5.741	11.939	0.457	13.861	12.780	26.641	1.082
I2	9.422	9.938	19.361	(0.516)	8.163	8.712	16.875	(0.550)	13.651	14.795	28.446	(1.143)	5.973	6.081	12.054	(0.108)	5.333	5.476	10.809	(0.143)	12.656	13.292	25.948	(0.637)
I3	9.330	8.410	17.740	0.919	8.979	8.087	17.066	0.892	13.627	13.562	27.189	0.065	6.135	6.012	12.147	0.123	5.436	5.382	10.818	0.053	13.011	12.362	25.373	0.649
I4	9.213	9.677	18.889	(0.464)	8.970	8.671	17.641	0.299	13.617	14.031	27.648	(0.414)	6.792	6.015	12.807	0.777	5.066	5.382	10.448	(0.316)	13.077	13.014	26.091	0.063
I5	8.427	9.479	17.906	(1.052)	8.502	8.394	16.896	0.108	12.987	13.417	26.404	(0.430)	6.217	6.224	12.441	(0.007)	6.280	5.075	11.355	1.205	12.895	12.687	25.582	0.209
I6	9.207	9.742	18.949	(0.535)	8.261	8.470	16.730	(0.209)	13.423	14.012	27.435	(0.589)	5.608	6.235	11.842	(0.627)	5.251	5.583	10.835	(0.332)	12.391	13.133	25.525	(0.742)
I7	8.462	9.147	17.609	(0.684)	7.691	8.133	15.824	(0.443)	13.639	12.597	26.236	1.042	5.816	5.448	11.264	0.368	5.343	4.868	10.211	0.475	12.161	11.962	24.123	0.199
I8	9.112	9.001	18.112	0.111	8.119	8.547	16.667	(0.428)	13.072	14.009	27.080	(0.937)	6.194	6.376	12.571	(0.182)	5.397	5.712	11.109	(0.315)	12.561	13.062	25.623	(0.501)
I9	9.248	9.297	18.545	(0.049)	8.924	8.808	17.732	0.115	13.646	13.298	26.944	0.348	5.419	6.242	11.662	(0.823)	4.553	5.898	10.450	(1.345)	12.281	13.131	25.412	(0.850)
I10	10.253	8.459	18.711	1.794	9.016	8.530	17.546	0.486	14.497	13.697	28.193	0.800	7.011	5.482	12.494	1.529	5.296	5.807	11.104	(0.511)	13.730	12.526	26.257	1.204
I11	9.246	9.726	18.972	(0.480)	8.450	8.242	16.692	0.209	12.557	13.368	25.924	(0.811)	5.664	6.319	11.983	(0.655)	5.499	5.059	10.558	0.440	12.449	12.734	25.183	(0.285)
I12	9.332	9.414	18.746	(0.083)	8.107	7.941	16.048	0.166	14.120	13.182	27.302	0.938	6.068	6.215	12.284	(0.147)	5.495	6.149	11.644	(0.654)	12.807	12.970	25.777	(0.163)
I13	10.305	9.769	20.074	0.536	9.603	9.330	18.933	0.274	14.750	13.556	28.306	1.193	5.900	6.250	12.150	(0.350)	6.345	6.105	12.450	0.239	14.018	13.591	27.608	0.427
I14	9.824	8.586	18.410	1.237	8.632	8.435	17.067	0.197	13.902	12.879	26.782	1.023	6.098	6.417	12.516	(0.319)	4.964	5.733	10.698	(0.769)	12.863	12.734	25.597	0.129
I15	9.939	9.740	19.680	0.199	9.117	8.834	17.951	0.283	14.787	14.233	29.020	0.554	6.854	5.619	12.474	1.235	5.747	5.404	11.151	0.342	13.868	12.965	26.833	0.903
I16	8.845	9.429	18.275	(0.584)	8.683	8.161	16.844	0.521	13.670	14.046	27.716	(0.376)	6.007	6.195	12.203	(0.188)	5.586	5.242	10.828	0.344	12.782	12.775	25.558	0.007
I17	8.478	9.738	18.216	(1.260)	7.872	9.064	16.936	(1.192)	14.312	13.905	28.218	0.407	5.671	6.663	12.334	(0.992)	5.795	5.674	11.470	0.121	12.496	13.526	26.022	(1.030)
I18	8.567	9.951	18.518	(1.384)	8.082	9.226	17.308	(1.144)	14.445	15.223	29.667	(0.778)	6.261	5.864	12.125	0.396	5.966	6.024	11.990	(0.058)	12.922	13.712	26.634	(0.790)
I19	9.288	9.355	18.643	(0.066)	8.204	8.017	16.221	0.187	13.421	13.685	27.106	(0.264)	5.766	6.066	11.832	(0.301)	5.575	5.398	10.973	0.177	12.617	12.662	25.279	(0.045)
I20	9.691	9.316	19.007	0.375	8.465	8.072	16.537	0.393	14.195	13.960	28.155	0.234	6.475	6.266	12.741	0.209	6.604	5.638	12.242	0.965	13.719	12.918	26.637	0.802
I21	9.173	9.288	18.461	(0.115)	8.814	9.222	18.036	(0.407)	13.434	13.736	27.170	(0.302)	6.109	6.404	12.513	(0.294)	6.150	6.359	12.509	(0.209)	13.192	13.627	26.819	(0.434)
I22	9.351	8.557	17.908	0.794	8.852	9.321	18.173	(0.469)	13.672	13.854	27.527	(0.182)	6.127	6.542	12.669	(0.415)	5.333	5.501	10.834	(0.168)	12.938	13.134	26.072	(0.196)
Average			18.615				17.114				27.525				12.300				11.201				25.936	



Asia and Oceania



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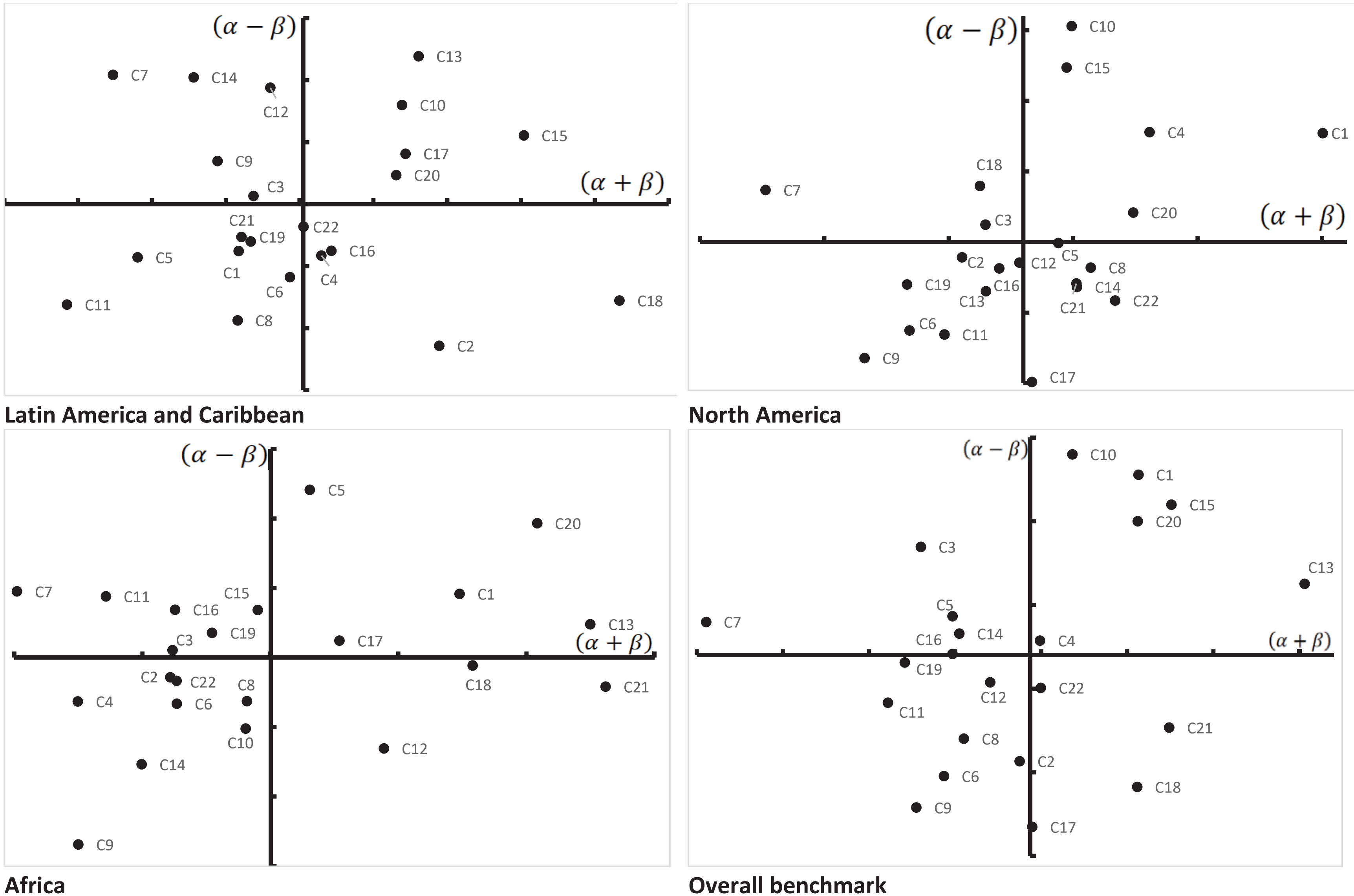

Figure 2. Causal inter-relationship of indicators among regions

5. Discussions

This section discusses the state-of-the-art of SSCM, future study trends and challenges and the geographical regional implications.

5.1. SSCM state-of-the-art, study trends, and challenges

The results show that the most important indicators for SSCM are big data, closed-loop supply chain, industry 4.0, policy, remanufacturing, and SCND. These indicators are considered to play critical roles in guiding the research and posing challenges for SSCM enhancement.

5.1.1. Big data

Big data has attracted researchers and practitioners' attention in the past few years because of its ability to generate insights in real time that can then be incorporated (Kaur and Singh, 2018). Big data is defined as high volume, high velocity and high variety data that are used in the decision-making process and require innovative techniques to be managed (Beyer and Laney, 2012). The parameters for big data based on inter-intra heterogeneity with the 3Vs—variety, volume and velocity—in which (i) variety considers development sources involving multiple products, periods, suppliers, and carriers; numerous emissions, capacity, cost, and demand issues; and supplier, product, time, and carrier functions; (ii) volume refers to big data storage with the number of suppliers, available carriers, number of products and periods; and (iii) velocity is related to data acquisition and reflects the propensity of data to adjust on a real-time basis, an example being the supplier and carrier capability and product demand fluctuations that occur within each period (Lamba and Singh, 2016). Big data has rapidly grown and extended based on its application and operating procedures in each specific business. Two additional parameters are (iv) value-added with the intention of generating value from cloud computing or the internet of things and (v) veracity regarding the effectiveness and efficiency of the big data analysis used by manufacturing, because the value of big data cannot be scrutinized only by simple statistics (Sandhu and Sood, 2015; Addo-Tenkorang and Helo, 2016; Wang et al, 2016; Wang and Hajli, 2017).

Indeed, big data analytics now plays a crucial role in SSCM (Li et al., 2019). It is useful to develop supply chain capability in practice using new technologies, such as data-driven analysis, providing instruments to optimize the data generation process, offering data integration from various foundations, conforming different categories of findings to the business process, and visualizing the data to simplify decision-making (Dubey et al., 2018; Ren et al., 2019, Zhang et al., 2017). Big data influences the supply chain and integrates both upstream and downstream operations to improve the organization's sustainable performance (Singh and El-Kassar, 2019). Therefore, the big data concept contributes to SSCM by building knowledgeable decisions, providing administration and risk mitigation, enhancing operational processes, presenting new products to the market, and scrutinizing the market (Schoenherr and Speier-Pero, 2015). This also has positive impacts on supply chain and operational performance, business values, sustainable procurement, and sustainable manufacturing (Kaur and Singh, 2018; Ren et al., 2019). These help to form an expressive understanding that supports multifaceted SSCM assessments (Gandomi and Haider, 2015; Tsai et al., 2015; Wang et al., 2018).

In the literature, a social media data analytics technique has been developed for analyzing supply chain and logistics operations (Singh et al., 2018). An environmentally sustainable procurement and logistics model for a supply chain has been proposed that uses big data to assess the variety of real-time boundaries from the purchaser and supplier sides, including lead times, capabilities, costs, and discharge (Kaur and Singh, 2018). SSCM knowledge was explored by determining barriers to big data analytics in manufacturing supply chains (Moktadir et al., 2019a). The role of big data in extending sustainable capabilities was examined as driven by the firm's commitment, the practices of green human resources and SCM to improve sustainability performance (Singh and El-Kassar, 2019). Big data addresses capabilities to handle the problem of carbon emission costs by coordinating a low-carbon supply chain, along with identifying a firm's financial situation by providing advanced technological tools for data management wherein datasets are aggregated in a structured manner (Liu, 2019, Raut et al., 2019). Therefore, the decision-making efficiency and effectiveness of big data must be utilized to offer competitive advantages to firms and to make their supply chain resilient as it approaches SSCM performance.

Failures still exist due to a lack of big data assessment infrastructure and understanding, and other data utilization and implementation issues related to supply chains (Moktadir et al., 2019a). Traditional big data collection, retrieval and evaluation methods are no longer appropriate for the current challenges and opportunities of SSCM and business operations, though they have the potential to renovate business and guarantee organizational response implementation (Hampton et al., 2013; Papadopoulos et al., 2017; Seles et al., 2018;). In SCM, firms are challenged by insufficient resources, time-consuming behavioral issues, return on investment and financial problems, and privacy-security anxieties (Arunachalam et al., 2018). Despite the enormous scope of big data, very few attempts have been made to develop big data applications in SSCM. The fundamental competencies, capabilities, internal mechanisms and processes through which big data formulation may result in better performance strategies have not yet been fully investigated (Singh and El-Kassar, 2019). Most supply chain resolutions have yet to integrate big data features into the decision-making process despite the enormous amount of data generated for both the supplier and buyer sides (Kaur and Singh, 2018). Hence, there is a substantial need to jointly consider big data in SSCM. Because big data are essential in highly uncertain and competitive marketplaces, there is much room for further development and investigation.

5.1.2. Closed-loop supply chain

Closed-loop supply chains (CLSCs) are studied and implemented because they play a substantial role by taking advantage of recyclable resources and inhibiting waste inflows into the environment (Wang et al, 2018). CLSCs include two fundamental phases: the forward and reverse supply chains (Amin and Zhang, 2012). The forward chain refers to the flow of new products that are delivered from manufacturers to consumers, while the reverse chain is described as the return flow of used, defective, and open box products collected from consumers and transferred to manufacturers or recycling centers (Assarzadegan and Rasti-Barzoki, 2019, Das and Dutta, 2016; Fathollahi-Fard and Hajiaghaei- Keshteli, 2018). The practices include identifying product waste, collecting, separating, packing, storing, recalling, transferring, distributing and recovering value (Mohtashami et al., 2020). The aim is to optimize the product used throughout its entire life cycle by incorporating reverse logistics as a preliminary advanced supply chain from purchase to final sale for used product recovery (Guide and Van Wassenhove, 2009). Hence, an efficient CLSC design may result in reducing the environmental impact in addition to meeting economic and social goals.

The CLSC is essential to creating supplementary logistics infrastructure in terms of synchronizing a robust return supply chain involving steps such as sorting, remanufacturing and allocating to disposal centers (Darbari et al., 2019). Previous studies have addressed different issues related to CLSCs, such as network design, production planning, and inventory management. Two-level reverse logistics were compared between online recycling and traditional recycling to investigate CLSC design and coordination (Feng et al., 2017). A risk and disruption handling model for the CLSC was proposed to minimize costs while identifying facility distribution and quantities for transportation (Jabbarzadeh et al., 2018). A decision model for service, pricing, and third-party recycling in three distinct remanufacturing positions and authorized technology was developed (Zhao et al., 2019). Multiproduct circular supplier selection decision-making and order allocation were assessed considering multiple depots and green routing capacity using heterogeneous vehicles (Govindan et al., 2020). Closed-loop optimal operational planning of supply chains with rapid product quality dynamics was studied, with byproduct quality dynamics and environmental conditions explicitly considered (Lejarza and Baldea, 2020).

Although the CLSC has been positively assessed, as it recovers returned products' value, ensures that environmental standards are upheld and enhances customer rights, few studies have developed quantitative approaches to adopting a holistic perspective of sustainability (Heydari et al., 2017). Most attention has been directed toward economic perspectives, though considerations have been given to capability positioning decisions and multiple stakeholders themselves (Sahebjamnia et al., 2018). Few scholars have sought to design sustainable networks to solve such problems because of the uncertainty and low demand for remanufactured products (Bouzon et al., 2018; Govindan and Bouzon, 2018; Chouman et al., 2018). In addition, managerial measures, extended manufacturer responsibility systems, regulatory guidance for intellectual property protection, technical and quality standards for recycling systems, and social issues such as consumers' awareness and quality concerns regarding remanufactured products are still under investigation (Rahmaniani et al., 2018; Shi et al., 2019). Because CLSCs are highly important due to their direct impact on political, economic, and environmental problems, accurate and efficient solutions are required.

5.1.3. Industry 4.0

The concept of industry 4.0 is founded on three principal elements: cyber-physical systems, the internet of things, and smart factories (Hofmann and Rusch, 2017; Tseng et al., 2018b). Industrial evolution is reflected in smart production or integrated manufacturing capabilities, which affect the entire industry in terms of product design, manufacturing and transportation (Hofmann and Rüsch, 2017). Industry 4.0 provides more efficient solutions for monitoring the production system and transforming the manufacturing industry scenario by changing supply chain processes, changing business activities and integrating sustainability to enhance the flexibility of supply chain operations (Bechtsis et al., 2017; de Sousa Jabbour et al., 2018). Industry 4.0 is recognized as a future development in SSCM, with prearranged interrelationships among materials, equipment, and products and sufficient consumer demand in a dynamic situation. Industry 4.0 represents the application of a mixture of digital technology and intelligence to interlocking supply chain networks and enables product customization (Lasi et al., 2014). It can be applied to production lines and can advance a total cyber-corporal system of equipment, machines, and smart infrastructure to achieve superior data interchange and mechanisms using appropriate information technology safety solutions, product maintenance and human skills through professional skill sets and shared information among supply chain partners (Branke et al., 2016).

Industry 4.0 considerably changes the approach to SCM (Tjahjono et al., 2017). Its applications beyond a sustainability orientation encompass environmental protection and mechanical advantages as well as advanced safety issues, resource efficiency, human resources, communication, and smarter and flexible measurement in the supply chain (Luthra and Mangla, 2018). Rajput and Singh (2019) found a hidden relationship between the circular economy and industry 4.0 from the two sides of enablers and barriers in the supply chain context. Singh et al. (2019) approached SSCM development through the enhancement of resource utilization and proficiency along with the improvement of the supply chain functions of automated procurement, production, and delivery. There are four significant SSCM paradigms, agile, green, lean, and resilient, to industry 4.0 machines to increase supply chain performance and sustainability (Ramirez-Peña et al., 2019). Different aspects of embedded sustainable supply chains and formulated an outline for evaluating organizational readiness to meet the requirements of the industry 4.0 revolution (Manavalan and Jayakrishna, 2019). An intelligent sustainable supplier selection using multiagent technology for industry 4.0 supply chains to offer advanced communication networks, information exchange structures and transparency among supply chain partners (Ghadimi et al., 2019). Organizational supply chains and sustainability are now forced to adopt industry 4.0 modern technological improvements and promote innovation. These advances provide vast opportunities for industry 4.0 supply chain intelligence and autonomy, creating a critical role for these features in terms of sustainability development (Kamble et al., 2018).

The concept requires in-depth understanding and empirical practice (Hofmann and Rüsch, 2017). Although the exploratory use of industry 4.0 to identify sustainability in the supply chain has gained considerable attention, it may not yet be fully recognized. Academic and managerial implications are limited and still at an early stage of development (Tseng et al., 2018b). Little effort has been made to incorporate sustainability issues, and the sustainability TBL dimensions (environmental, social, and economic) still lack integration within SSCM for an extended industry 4.0 (Ghadimi et al., 2016; Ghadimi et al., 2019; Wang et al., 2019). Coordination and collaboration problems, security concerns, a lack of governmental support and policies, and the absence of sufficient financial resources to make investments may make it challenging for small-scale industries to implement industry 4.0 (Govindan and Hasanagic, 2018, Pfohl et al. 2017; Manavalan and Jayakrishna, 2019). Additionally, industry 4.0 is difficult to integrate with SSCM due to data quality and credibility problems, unemployment, complexity, reduced human control, and higher negative environmental impacts. Problems with a lack of technological innovation; strategic, ethical, and global policy; the management of supply chain disruptions; facilities planning; and the development of international manufacturing networks remain unsolved (Branke et al., 2016; Pereira et al. 2017; Singh et al., 2019). Hence, further studies are needed to address such issues based on the value of smart industry.

5.1.4. Supply Chain Policy

The supply chain is a complicated phenomenon and flexible system affected not only by technical upheaval but also by dynamic and uncertain factors, for example, sociocultural and geopolitical issues such as export bans, unpredictable markets, and environmental regulations (Mancheri et al., 2019). The influence of regulatory legislation on the formation of the SSCM is one of the key tactical elements requiring focused attention (Manavalan and Jayakrishna, 2019). Supply chain policy endorsements aim to control the effects of location, production, inventory and the disposal of products and create a trade-off between transportation, holding costs and profit (Waltho et al., 2018). Supply chain policy is considered to encourage remanufacturing and improved resource efficiency (Zhang et al., 2019a). The policy generally plays an important role in modifying the sustainable development of the whole supply chain, being integrated as a decision-maker to maximize sustainable benefits rather than as a measured constraint on firm profit functions in the effort to synchronize supply chain operations (Liu et al., 2019b).

An increasing number of researchers have turned their attention to this area of study, as policies have begun to impact SSCM. The influence of government taxes and policy related to environmental protection on the optimum assessment of the supply chain considering government financial involvement has been analyzed (Hafezalkotob, 2015; Hafezalkotob et al., 2016). The effect of three types of government policies on two rival supply chain decision-making processes is under either decentralization or centralization (Zhang and Wang, 2017). Different environmental tax policies in a multi-tiered supply chain network rivalry under stable governing circumstances were captured (Yu and Cruz, 2018). A sustainable supply chain optimization system considering lead time in different production-distribution and inventory scenarios was proposed, with three carbon emission policies: strict carbon capping, carbon cap and trade, and a carbon tax (Manupati et al., 2019). The influence of critical success factors on the development of energy-efficient supply chains and their energy policy implications were presented (Moktadir et al., 2019b). A trade credit policy that enriches SSCM under green manufacturing optimization and payment records (Tiwari et al., 2018). The impacts of transfer pricing policies and subsidy policies on CLSCs with retailer and third-party dual collection channels have been analyzed (Wan and Hong, 2019). The optimal inspection policy for customers to encourage responsible sourcing efforts and the relationship of this mechanism to customer awareness was investigated in the context of the supply chain (Zarei et al., 2020).

Nevertheless, the appropriate policy and legislative framework to regulate supply chain actors in the direction of sustainable goals has presented a constant challenge. It was found that some national legislation does not satisfy the objective of environmental protection and violates international policy (Gavin, 2013; Mancheri, 2015; Mancheri et al., 2019). Advancements in carbon emission standards due to rapid industrialization require SCM assessment to avoid compromising social responsibility, environmental performance, and economic mechanisms (Babazadeh et al., 2017; Samadi et al., 2018). Globalization policies have eliminated restrictions on market boundaries, making it hard for small and medium-sized firms to compete with large global organizations, as small firms are incapable of adapting advanced technologies to process new types of materials or of effectively utilizing resources and reducing energy consumption (Thomas and Trentesaux, 2014).

Although many countries and geographical regions are employing standard environmental mechanisms, including incentives or mandatory targets for firms to reduce their environmental impacts, the advocated interventions still address internal problems in SSCM, such as illegal production, transaction and processing; lack of innovation; congestion; and poor legal and regulatory systems (Yu and Cruz, 2018, Zhang and Yousaf, 2019). In developing regions, inadequate laws and regulations result in serious social problems, such as manufacturing using child labor, unsustainable performance, and unsanctioned activities, which arise in the early stages of the supply chain (Awaysheh and Klassen, 2010; Silvestre, 2015; Jia et al., 2020). Hence, there are opportunities in the optimization of the number of manufacturers and stowage to integrate sustainability elements, improve supply chain network allocation, and enhance capacity in supply chain facilities and infrastructure, and other solutions present themselves in supplier selection and remanufacturing regulatory systems. The lack of study in this direction hinders the transition to SSCM for both policy makers and their initial stakeholders.

5.1.5. Remanufacturing

Remanufacturing is defined as a multi-processes that transforms end-of-use products by recovering, checking, disassembling, polishing, renovating, and reassembling to produce a "like-new" product (Govindan et al., 2016; Kafuku et al., 2016). The processes consist of raw material acquisition, reverse delivery, manufacturing procedures, and distribution operations, which ultimately offer large reductions in resource and energy consumption and waste emissions, increased care for the environment, and support for sustainable development (Jiang et al., 2019). Remanufacturing is emphasized as an urgent innovation strategy to slow resource circles. It calls for the integration of design and business system innovations supporting new forms of collaboration, including multiple transactions between suppliers and manufacturers and among manufacturers and buyers and consumers, to comprehend and apply new circular business models combined with new product design considerations (Opresnik and Taisch, 2015). Hence, benefits from remanufacturing implementation could be realized by all business firms, their consumers, the environment, society, and several third parties (Ansari et al., 2019).

Remanufacturing is an emergent but rapidly developing sector that slows environmental degradation and resource diminution through material reuse and recycling to meet the sustainable goals of SCM (Zhang et al., 2011; Subramoniam et al., 2013; Liu et al., 2017). Case studies in four remanufacturing organizations were conducted to study the influence of implementing lean practices on reducing needless processes and decreasing lead time, thus improving the organizations' operational performance (Kurilova-Palisaitiene et al., 2018). A remanufacturing process that adopts adaptive design was proposed to classify the factors that influence environmental and economic performance (Krystofik et al., 2018). The prioritized performance outcomes obtained via implementing critical success factors in supply chain remanufacturing were investigated (Ansari et al., 2019). Recycling and remanufacturing approaches in the supply chain were explored through the heterogeneous considerations of consumers (Long et al., 2019). An integrated perspective for determining sustainable value creation was investigated in the context of remanufacturing models (Jensen et al., 2019). A supply chain consisting of a manufacturer and retailer was assessed in terms of managing a CLSC with process innovation for remanufacturing (Reimann et al., 2019). The trade-offs related to cap-and-trade and carbon taxes were analyzed based on a CLSC model (Hu et al., 2020). Integrating remanufacturing into the supply chain is a critical strategy that positively encourages sustainable organizational performance.

Although remanufacturing is one of the economic and environmental factors that has received considerable attention, the literature mostly focuses on technology and management, and relatively few studies have evaluated sustainability (Taleizadeh et al., 2017, 2019; Zerang et al., 2018; Shaharudin et al., 2019b). Ensuring the evaluation of remanufacturing sustainability would be helpful for generating insights into resource utilization and environmental safety and should be prioritized by researchers (Zhang et al., 2019b). Gaps remain in the TBL indicator measurements (Jensen et al., 2019). To date, previous studies have only scratched the surface and are limited to exploring each single indicator, and the full picture of the social, environmental and economic problems of remanufacturing has not been fully recognized as an integral part of SSCM (Souza, 2013; Reimann et al., 2019). While the fact that economic concerns are positioned at the forefront of remanufacturing is widely acknowledged, there is little awareness of the possibility of improving remanufacturability to support environmental protection and benefit social wellbeing.

There is still immense recklessness due to the inadequate study and expansion of remanufacturing systems. In reality, the reselling and remarketing of remanufactured products is challenging because consumers may have few incentives to purchase remanufactured products (Xu et al., 2017). Only a few studies integrate both collaboration and competition into remanufacturing optimization systems, which would adjust the functional level and organizational strategies (Rau et al., 2019). The manufacturer may distrust third-party remanufacturers or retailers due to their limited production scope or brand issues while charging them an inconstant or stationary rate (Zhao et al., 2019). Many studies do not consider multilevel construction or discrete changes in value parameters such as pricing or demand patterns, even though these may have long-term negative influences (Hong et al., 2017). Further investigation of remanufacturing supply chain behavior is urgent and requires more attention. In addition, the lack of laws and policies, the evaluation of waste product remanufacturability, energy conservation problems, comparisons of different remanufacturing systems, how to ensure that the quality of new and remanufactured products is the same, and technology licenses have been discussed (Taleizadeh et al., 2019; Zhang et al., 2019b). Remanufacturing studies have several shortcomings and are still far from fulfilling the needs of the current context.

5.1.6. Supply chain network design

SCND plays a major role in manipulating supply chain operations (Waltho et al, 2018). The concept refers to constructing an effective network for different supply chain entities (Farahani et al., 2014). It represents the facility location problem, and SCM encompasses facility location determination, magnitude, network capabilities and the material flow among the located facilities (Pishvaee and Razmi, 2012). In designing a sustainable supply chain, SCND attempts to delineate the best supply chain alignment to maximize economic profitability, environmental performance, and social performance in the long term (Chaabane et al., 2012). Considering all parts of the system together and inspecting the product flow and information effects through the network are essential to making a supply chain ready for operation (Rodger, 2014). Because the supply chain network is a set of people, activities, and information that interact to convert raw material into useful products and deliver them to the end customer, the SCND covers decisions regarding supplier selection, transportation, production technology, storage capacity, and market demand allocation (Moreno-Camacho et al., 2019). Integration creates more complex problems for the supply chain, with multiple conflicts and contradictory intent in multidimensional decision making (Sherafati et al., 2019).

Recent studies have considered SCND perspectives. An optimization model for SCDN was developed that accounted for financial resources such as trade credit and bank credit (Alavi and Jabbarzadeh, 2018). The SCND problem with the assembly balancing process was analyzed considering a three-layer supply chain including manufacturers, assemblers, and customers that could be decomposed into an upper-level problem and two lower-level problems (Sun and Wang, 2019). A bilevel programming model for hierarchized SCND that thoroughly considers inducements to use cleaner technologies was presented (Chalmardi and Camacho-Vallejo, 2019). Three pillars of sustainability were considered and discussed to design a supply chain network that maximizes turnover while seizing opportunities for social development in less developed regions as a priority (Sherafati et al., 2019). An optimal multi-objective multiproduct supply chain network was designed for efficient and optimal product quantity plans (Mohammed and Duffuaa, 2020).

These studies have only considered regional development and concentrated on balancing economic development. Environmental objectives such as pollutant emissions play a significant role but have been ignored in network design problems (Zohal and Soleimani, 2016). The innovative design and planning of supply chain networks needs to give more consideration to all TBL dimensions due to the global sustainable development trend. There should be further investigation into the optimal solution for SCND entities. Increasing competitiveness, a global market and a dynamic environment are required to meet customers' demand while minimizing costs (Sherafati et al., 2019). This sequence has a substantial effect on society and the environment (Manupati, 2019). The uncertainty in SCND could be an interesting topic for future studies. Few studies have developed strong simulations for resolving multi-objective SCND, and reverse logistics and closed-loop supply chain networks are significant issues (Mohammed and Duffuaa, 2020). The development of a model considering facility disruptions will also further SCND. Hence, proposals for sustainable SCND should still be pursued and need to be improved as a future trend in SSCM research.

5.2. Regional implications

The results show that Latin America and the Caribbean and Africa are two regions that need to improve their SSCM performance. These regions also show different trends than the other regions. In particular, Latin America and the Caribbean should focus more on risk management, industry 4.0, policy, remanufacturing, and SCND, while Africa shows concerning patterns related to eco-efficiency and risk management, in addition to the other common trends.

5.2.1 Latin America and the Caribbean

Supply chains involve complex environmental and social elements aligned with varied participant prospects that aggravate risk-related sustainability (Rebs et al., 2018). Firms refuse to change their goods to satisfy regulations, bribe government agencies to fake inspection documents to gain legitimacy, and lack operational transparency (Azmat and Ha, 2013). Suppliers cheat their customers by buying guarantees through certification labels from third-party auditors without satisfying the practical requirements (Jia et al., 2018). Purchasers continue to buy products produced with child labor or that causes environmental pollution due to their low price without calling for responsible practices (Otanez and Glantz, 2011). There is acquiescence to crises and imitation among supply chain stakeholders, certification providers and the government (Silvestre, 2015), implying that SSCM may expose a high level of risk that corrupts network performance. The perceived impacts and effects from the risks that actually exist may cause serious damage to SCs (Soni and Kodali, 2013). Nevertheless, the region is a fast-growing market; poor infrastructure, booming urbanization, expensive and inefficient logistics, and many social issues continue to cause major problems, as noted by both practitioners and scholars (Yoshizaki et al., 2018). Therefore, future studies should invest in offering better support for the risk management decision-making process in Latin America and the Caribbean region.

Risk management entails supply chain responses that counteract vulnerabilities by choosing the most appropriate risk response solution and planning how that solution should be applied (Manuj et al., 2014, Sahebjamnia et al., 2018). The main practice is to ensure the capability to prevent the unnecessary disruption of barriers, which represents a disadvantage for environmental performance due to the negative impact of supply chain activities on resource consumption (Carvalho and Cruz-Machado, 2011). The type of response chosen by decision makers is affected by the risk consequences (Heckmann et al., 2015). In fact, uncertainty drives firms to move from an effective approach to integrated efficient solutions where efficiency is only important when it ensures an adequate level of SCM to address unpredicted events. The increasing market volatility in the region, as well as the increasing fluctuation of demand and risk of supply disruption lead to a push for more agile, less expensive and more flexible supply chain design due to natural disasters or human activity.

Supply chain risk management practices could impact environmental performance, but studies do not investigate further whether this impact is positive or negative (Govindan et al., 2014). More elaboration of the complex challenges associated with SSCM methods is needed, given that the multidimensional sustainable viewpoints proposed by SSCM bring together a set of goals and agendas that include a potential risk of conflict between organizations and insiders (Bastas and Liyanage, 2018). This requires firms to standardize and replicate their virtual supply chain process as globalization advances. Risk identification, assessment, management, monitoring, control, and communication and the development of simulation models and optimization technology combined with efficient SCND models represent potential gaps for further exploration (Oliveira et al., 2019). The Latin America and Caribbean supply chain sector now has great potential to invest in not only practical implementation but also academic development with the aggregate of countries having high production capabilities and global interaction.

5.2.2 Africa

Africa holds a small market share in the global supply chain network but has high potential to reduce the risk for new entrants, as manufacturing is expected to expand widely due to active investment from India and China. The region faces complex elements that have permanently changed the supply chain environment. This context requires strong analytical ability, a holistic competitive model design, and significant improvement in decision-making ability to meet the market demand or even the global standard. Only a few countries can achieve the distinct capability to develop economic development-based, ongoing innovation and the technology associated with low-cost labor. Poor supply chain infrastructure and facilities, a lack of training and education, a large knowledge gap, energy consumption problems, a lack of leadership, payment delays on initial investments, an unequal structure and high management risks are issues that remain unsolved (Moktadir et al., 2019b). The integration of multidimensional assessments into SCM will result in more balanced, comprehensive and efficient SSCM implementation, thereby minimizing the risk by prioritizing certain aspects over others (Bastas and Liyanage, 2018).

In addition, eco-efficiency is also a critical challenge that the region must tackle to improve its SSCM. Eco-efficiency refers to a quantitative management solution that enables a product system to balance resource use through the adoption of a more sustainable concept while still bringing profit to stakeholders (Vásquez et al., 2019). Sustainability concerns have highlighted the significant role of eco-efficient supply chain identification in balancing social, environmental, and economic objectives (Jonkman et al., 2019). The solution quantifies the operating costs associated with reducing environmental impacts without changing consumption and resource productivity, which is calculated as the value or produced quantity divided by the natural resources required for production of the product (Kulak et al., 2016).

Experiential and reliable data are not sufficient to develop more eco-efficient modes in Africa. As national and local data are difficult to collect, the impact of uncertainty on the TBL and other eco-efficient solutions must be quantified through measurement. Nevertheless, most studies in this region assume all data to be deterministic, and uncertainty is rarely taken into account when presenting decision support models for eco-efficient supply chains (Banasik et al, 2019), which presents challenges for further investigation. There are limitations, and research gaps have been identified. The conceptual framework between “efficiency” and “eco-efficiency” in theoretical, practical and empirical studies is not clearly addressed (Huang et al., 2018). Procurement and infrastructure activities are not precise and do not clearly define how they meet sustainable development targets, and a lack of sound legislation and policy frameworks hinders SSCM implementation (Vásquez et al., 2019). Operational barriers; a lack of administration commitment, financial costs and constraints; environmental sustainability problems; poorly integrated monitoring information and traceability systems; poor multitier suppliers; low consumer awareness and demand; and inadequate provision and leadership from industry alliances, NGOs and development agencies still need to be addressed (Agyemang et al., 2018, Jové-Llopis and Segarra-Blasco, 2018).

6. Concluding remarks

SSCM has grown rapidly in recent decades and has received much attention from both scholars and practitioners. Although different aspects of the literature and its evolution have been summarized, previous studies have evaluated different parts of the supply chain as independent entities. An integrated assessment is still missing in the extant literature, making it necessary to reveal potential directions for future studies. Hence, this study proposed a hybrid method integrating data-driven analysis, the FDM, the EWM, and the FDEMATEL to (1) identify the critical indicators for future study trends and debate and (2) determine the challenges and knowledge gaps among geographical regions. Quantitative and qualitative approaches are proposed to complement the systematic review and address the challenges of uncertainty and complexity in SSCM. The data-driven analysis applied the VOSviewer and identified the SSCM indicators based on big data from Scopus, with the results represented as visualized information. The FDM is used to refine the valid indicators by computing their perception levels from experts' linguistic references. The EWM is applied to convert the indicator occurrence information into comparable weights to determine the indicator performance among regions. The FDEMATEL method is used to capture the perceptions through linguistic preferences and identify the substantial indicators that should be urgently addressed in future work to improve SSCM. This study contributes to detecting critical indicators as gaps to provide knowledge that assists further studies and practical implementations.

- A data-driven analysis is delivered to determine the critical indicators as gaps for future studies. There are 251 keywords listed, and 21 indicators are of critical concerns based on the experts' evaluation. The most important indicators are chosen as essential for future research and include big data, closed-loop supply chain, industry 4.0, policy, remanufacturing, and SCND.
- A prioritization of exploration opportunities is proposed. Since supply chain systems are large and complex, integrating and considering the effect of the flow of products, services, and information through the network are important to operational management (Mohammed et al., 2020). The relationship between the trends and challenges is also worth investigating in future studies.
- The identified gaps between geographical regions not only contribute local viewpoints but also delineate the comprehensive global state of the art of SSCM. Ninety-two countries/territories were accumulated and then rearranged to provide results for 5 regions: Asia and Oceania, Europe, North America, Africa, Latin America and the Caribbean. The results showed that the largest amount of SSCM information is provided for Asia and Oceania, followed by Europe and North America. Latin America and the Caribbean and Africa show a need for improvement. Latin America and the Caribbean should focus more on risk management, while Africa shows a distinct pattern of concern regarding eco-efficiency and risk management, in addition to other common trends.
- SSCM actors can treat this study as a reference source for decision making. Firms, governments and professionals can refer to this study for useful information supporting practical design, policy strategies and perceived planning based on regional insights to endorse innovative accomplishments.

Some limitations exist in this study. The data-driven analysis may not be sufficiently detailed to initiate quality assessment because Scopus also includes low-impact sources and is limited to the most recent information (Shukla et al., 2019). A future study is proposed that engages a more refined database for better results. Third, the expert committee consisted of only 30 members, which may result in biases in the analysis process due to their experience, knowledge, and familiarity with the research field. Increasing the volume of respondents is recommended to avoid this problem. As this study offers an exhaustive method for data-driven analysis, both academic and practical investigations are encouraged to exploit it in other sectors.

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Appendix A. Respondents' demographic

Expert	Position	Education levels	Years of experience	Organization type (academia/practice)	Regional location
1	Professor	Ph.D.	10	Academia	Asia and Oceania
2	Professor	Ph.D.	13	Academia	Asia and Oceania
3	Professor	Ph.D.	12	Academia	North America
4	Distinguished Professor	Ph. D	12	Academia	Asia and Oceania
5	Professor	Ph.D.	11	Academia	Europe
6	Professor	Ph.D.	10	Academia	Europe
7	Professor	Ph.D.	15	Academia	North America
8	Professor	Ph.D.	11	Academia	Europe
9	Professor	Ph.D.	17	Academia	Asia and Oceania
10	Professor	Ph.D.	11	Academia	North America
11	Professor	Ph.D.	10	Academia	Europe
12	Professor	Ph.D.	16	Academia	Latin America and Caribbean
13	Professor	Ph.D.	14	Academia	North America
14	Distinguished Professor	Ph.D.	10	Academia	Africa
15	Researcher & Section Chief (Professor)	Ph.D.	13	NGOs (Research center)	Asia and Oceania
16	Researcher & Section Chief (Professor)	Ph.D.	15	NGOs (Research center)	Europe
17	Researcher & Section Chief	Ph.D.	12	NGOs (Research center)	Africa
18	Researcher	Master	11	NGOs (Research center)	Latin America and Caribbean
19	Researcher	Master	11	NGOs (Research center)	Asia and Oceania
23	Chief supply chain Officer	Ph.D.	10	Practices	Asia and Oceania
21	Chief Operating Officer	Ph.D.	10	Practices	Latin America and Caribbean
22	Information Officer	Ph.D.	11	Practices	Africa
20	Financial Officer	Master	13	Practices	Asia and Oceania
24	Financial Officer	Master	14	Practices	Europe
25	Operating Officer	Master	10	Practices	North America
26	Executive manager	Master	11	Practices	Asia and Oceania
27	Supply chain manager	Master	14	Practices	Europe
28	Project manager	Master	10	Practices	Latin America and Caribbean
29	Supply chain manager	Master	10	Practices	Europe
30	Executive manager	Master	15	Practices	Asia and Oceania

The expert committee was approach thanks to the connections of Institute of Innovation and Circular Economy, Asia University, Taiwan.

Appendix B. Region search terms

Region	Search terms
Asia and Oceania	TITLE-ABS-KEY ("Australia" or "Bangladesh" or "Cambodia" or "China" or "Hong Kong" or "India" or "Indonesia" or "Iran" or "Iraq" or "Israel" or "Japan" or "Kazakhstan" or "Kuwait" or "Lebanon" or "Macau" or "Malaysia" or "Myanmar" or "New Zealand" or "Oman" or "Pakistan" or "Palestine" or "Papua New Guinea" or "Philippines" or "Qatar" or "Saudi Arabia" or "Singapore" or "South Korea" or "Sri Lanka" or "Taiwan" or "Thailand" or "Turkey" or "United Arab Emirates" or "Viet Nam")
North America	TITLE-ABS-KEY ("Canada" or "United States")
Latin America and Caribbean	TITLE-ABS-KEY ("Argentina" or "Brazil" or "Chile" or "Colombia" or "Dominican Republic" or "Ecuador" or "Mexico" or "Peru" or "Puerto Rico" or "Uruguay")
Europe	TITLE-ABS-KEY ("Austria" or "Belgium" or "Bulgaria" or "Croatia" or "Czech Republic" or "Denmark" or "Estonia" or "Finland" or "France" or "Germany" or "Greece" or "Hungary" or "Iceland" or "Cyprus" or "Ireland" or "Italy" or "Latvia" or "Netherlands" or "Poland" or "Russian Federation" or "Spain" or "Switzerland" or "United Kingdom" or "Lithuania" or "Romania" or "Serbia" or "Slovakia" or "Slovenia" or "Sweden" or "Norway" or "Monaco" or "Portugal")
Africa	TITLE-ABS-KEY ("Cameroon" or "Egypt" or "Ethiopia" or "Ghana" or "Kenya" or "Morocco" or "Nigeria" or "South Africa" or "Tanzania" or "Tunisia" or "Uganda" or "Zimbabwe")

Appendix C. List of co-occurrences of author keywords

ID	Label
1	Agriculture
2	Ahp
3	Analytic hierarchy process
4	Analytic network process
5	Anp
6	Asia
7	Automotive industry
8	Balanced scorecard
9	Barriers
10	Base of the pyramid
11	Beef
12	Benchmarking
13	Bibliometric analysis
14	Big data
15	Bioenergy
16	Biomass
17	Brazil
18	Business model
19	Business strategy
20	Buyer-supplier relationships
21	Carbon emission
22	Carbon emissions

23	Carbon footprint
24	Carbon management
25	Case studies
26	Case study
27	Certification
28	China
29	Circular economy
30	Cleaner production
31	Climate change
32	Closed-loop supply chain
33	Closed-loop supply chains
34	CO_2 emissions
35	Cocoa
36	Collaboration
37	Competitive advantage
38	Competitiveness
39	Conceptual framework
40	Construction
41	Content analysis
42	Corporate responsibility
43	Corporate social responsibility
44	Corporate social responsibility (csr)
45	Corporate sustainability
46	Critical success factors
47	Csr
48	Data envelopment analysis
49	Data envelopment analysis (dea)
50	Dea
51	Decision making
52	Decision support systems
53	Decision-making
54	Delphi method
55	Dematel
56	Developing countries
57	Distribution management
58	Drivers
59	Dynamic capabilities
60	Eco-design
61	Eco-efficiency
62	Economic performance
63	Economic sustainability
64	Ecosystem services
65	Efficiency
66	Emerging economies
67	Emerging economy
68	Emerging markets
69	Empirical study

70	Energy
71	Energy efficiency
72	Environment
73	Environmental
74	Environmental impact
75	Environmental impacts
76	Environmental issues
77	Environmental management
78	Environmental performance
79	Environmental supply chain management
80	Environmental sustainability
81	Ethics
82	Extended producer responsibility
83	Factor analysis
84	Fashion industry
85	Financial performance
86	Firm performance
87	Flexibility
88	Food
89	Food industry
90	Food security
91	Food supply chain
92	Food system
93	Food waste
94	Framework
95	Fuzzy dematel
96	Fuzzy inference system
97	Fuzzy set theory
98	Game theory
99	Germany
100	Global supply chain
101	Global supply chains
102	Globalization
103	Goal programming
104	Governance
105	Green
106	Green logistics
107	Green manufacturing
108	Green marketing
109	Green supply chain
110	Green supply chain management
111	Green supply chain management (gscm)
112	Green supply chain practices
113	Green supply chains
114	Greenhouse gas emissions
115	Gscm
116	India
117	Industrial ecology

118	Industry 4.0
119	Innovation
120	Institutional theory
121	Integration
122	Interpretive structural modeling
123	Interpretive structural modelling
124	Ism
125	Just-in-time
126	Knowledge
127	Knowledge management
128	Lca
129	Lean
130	Life cycle assessment
131	Life cycle assessment (lca)
132	Literature review
133	Logistics
134	Logistics service providers
135	Malaysia
136	Management
137	Manufacturing
138	Manufacturing industry
139	Mathematical programming
140	Mcdm
141	Metrics
142	Multi-criteria decision making
143	Multi-criteria decision-making
144	Multi-objective optimization
145	Network design
146	New zealand
147	Oil and gas
148	Operational performance
149	Operations management
150	Optimization
151	Organizational performance
152	Outsourcing
153	Packaging
154	Palm oil
155	Performance
156	Performance analysis
157	Performance assessment
158	Performance evaluation
159	Performance management
160	Performance measurement
161	Performance measures
162	Policy
163	Practices
164	Pricing
165	Procurement

166	Product development
167	Production
168	Purchasing
169	Quality
170	Quality management
171	Raw materials
172	Recycling
173	Remanufacturing
174	Renewable energy
175	Research
176	Resilience
177	Resource efficiency
178	Resource-based view
179	Reverse logistics
180	Reverse supply chain
181	Review
182	Risk
183	Risk management
184	Scm
185	Simulation
186	Smes
187	Social
188	Social performance
189	Social responsibility
190	Social sustainability
191	Sscm
192	Stakeholder
193	Stakeholder theory
194	Stakeholders
195	Standards
196	Strategy
197	Structural equation modeling
198	Structural equation modelling
199	Supplier development
200	Supplier evaluation
201	Supplier management
202	Supplier selection
203	Supply chain
204	Supply chain collaboration
205	Supply chain design
206	Supply chain integration
207	Supply chain management
208	Supply chain management (scm)
209	Supply chain network design
210	Supply chain risk management
211	Supply chain strategy
212	Supply chain sustainability
213	Supply chains

214	Supply management
215	Supply-chain management
216	Survey
217	Survey methods
218	Sustainability
219	Sustainability assessment
220	Sustainability indicators
221	Sustainability performance
222	Sustainability practices
223	Sustainability reporting
224	Sustainable
225	Sustainable development
226	Sustainable innovation
227	Sustainable manufacturing
228	Sustainable operations
229	Sustainable operations management
230	Sustainable performance
231	Sustainable practices
232	Sustainable production
233	Sustainable sourcing
234	Sustainable supplier selection
235	Sustainable supply chain
236	Sustainable supply chain management
237	Sustainable supply chain management (sscm)
238	Sustainable supply chains
239	System dynamics
240	Systematic literature review
241	Textile industry
242	Topsis
243	Traceability
244	Trade
245	Transportation
246	Triple bottom line
247	Trust
248	Uncertainty
249	Value chain
250	Vietnam
251	Waste management

Appendix D. List of productive countries/territories according to region (UN, 2019)

Asia and Oceania	North America	Latin America and Caribbean	Europe	Africa
Australia	Canada	Argentina	Austria	Cameroon
Bangladesh	United States	Brazil	Belgium	Egypt
Cambodia		Chile	Bulgaria	Ethiopia
China		Colombia	Croatia	Ghana
Hong Kong		Dominican Republic	Czech Republic	Kenya
India		Ecuador	Denmark	Morocco
Indonesia		Mexico	Estonia	Nigeria
Iran		Peru	Finland	South Africa
Iraq		Puerto Rico	France	Tanzania
Israel		Uruguay	Germany	Tunisia
Japan			Greece	Uganda
Kazakhstan			Hungary	Zimbabwe
Kuwait			Iceland	
Lebanon			Cyprus	
Macau			Ireland	
Malaysia			Italy	
Myanmar			Latvia	
New Zealand			Netherlands	
Oman			Poland	
Pakistan			Russian Federation	
Palestine			Spain	
Papua New Guinea			Switzerland	
Philippines			United Kingdom	
Qatar			Lithuania	
Saudi Arabia			Romania	
Singapore			Serbia	
South Korea			Slovakia	
Sri Lanka			Slovenia	
Taiwan			Sweden	
Thailand			Norway	
Turkey			Monaco	
United Arab Emirates			Portugal	
Viet Nam				
Total				

Appendix E. FDM indicators refined – round 1

Indicators	l_b	u_b	D_b	Decision
Balanced scorecard	0.000	0.500	0.250	Unaccepted
Barriers	0.000	0.500	0.250	Unaccepted
Benchmarking	0.000	0.500	0.250	Unaccepted
Big data	(0.025)	0.900	0.444	Accepted
Bioenergy	0.000	0.500	0.250	Unaccepted
Biomass	0.000	0.500	0.250	Unaccepted
Business model	0.000	0.500	0.250	Unaccepted
Business strategy	0.000	0.500	0.250	Unaccepted
Buyer-supplier relationships	0.000	0.500	0.250	Unaccepted
Carbon emissions	(0.348)	0.848	0.337	Accepted
Carbon footprint	0.000	0.500	0.250	Unaccepted
Carbon management	0.000	0.500	0.250	Unaccepted
Certification	0.000	0.500	0.250	Unaccepted
Circular economy	(0.042)	0.917	0.448	Accepted
Cleaner production	(0.030)	0.905	0.445	Accepted
Climate change	0.000	0.500	0.250	Unaccepted
Closed-loop supply chain	(0.411)	0.911	0.353	Accepted
CO_2 emissions	0.000	0.500	0.250	Unaccepted
Collaboration	0.000	0.500	0.250	Unaccepted
Competitive advantage	(0.386)	0.886	0.346	Accepted
Corporate responsibility	0.000	0.500	0.250	Unaccepted
Corporate social responsibility	(0.363)	0.863	0.341	Accepted
Corporate sustainability	0.000	0.500	0.250	Unaccepted
Decision support systems	0.000	0.500	0.250	Unaccepted
Developing countries	0.000	0.500	0.250	Unaccepted
Distribution management	0.000	0.500	0.250	Unaccepted
Dynamic capabilities	(0.367)	0.867	0.342	Accepted
Eco-design	(0.381)	0.881	0.345	Accepted
Eco-efficiency	(0.361)	0.861	0.340	Accepted
Economic performance	0.000	0.500	0.250	Unaccepted
Economic sustainability	(0.328)	0.828	0.332	Accepted
Ecosystem services	(0.037)	0.912	0.447	Accepted
Emerging economy	(0.328)	0.828	0.332	Accepted
Emerging markets	(0.383)	0.883	0.346	Accepted

Energy efficiency	(0.348)	0.848	0.337	Accepted
Environmental impact	(0.348)	0.848	0.337	Accepted
Environmental issues	0.000	0.500	0.250	Unaccepted
Environmental management	0.000	0.500	0.250	Unaccepted
Environmental performance	0.000	0.500	0.250	Unaccepted
Environmental supply chain management	0.000	0.500	0.250	Unaccepted
Environmental sustainability	(0.006)	0.881	0.439	Accepted
Ethics	(0.334)	0.834	0.333	Accepted
Extended producer responsibility	0.000	0.500	0.250	Unaccepted
Financial performance	(0.023)	0.898	0.443	Accepted
Firm performance	0.000	0.500	0.250	Unaccepted
Flexibility	0.000	0.500	0.250	Unaccepted
Global supply chain	0.000	0.500	0.250	Unaccepted
Globalization	(0.014)	0.889	0.441	Accepted
Governance	0.000	0.500	0.250	Unaccepted
Green logistics	(0.425)	0.925	0.356	Accepted
Green manufacturing	0.000	0.500	0.250	Unaccepted
Green marketing	0.000	0.500	0.250	Unaccepted
Green supply chain management	(0.400)	0.900	0.350	Accepted
Green supply chain practices	0.000	0.500	0.250	Unaccepted
Greenhouse gas emissions	0.000	0.500	0.250	Unaccepted
Industrial ecology	0.000	0.500	0.250	Unaccepted
Industry 4.0	(0.055)	0.930	0.451	Accepted
Innovation	0.000	0.500	0.250	Unaccepted
Institutional theory	0.000	0.500	0.250	Unaccepted
Integration	0.000	0.500	0.250	Unaccepted
Just-in-time	(0.332)	0.832	0.333	Accepted
Knowledge	0.000	0.500	0.250	Unaccepted
Knowledge management	(0.429)	0.929	0.357	Accepted
Lean	0.000	0.500	0.250	Unaccepted
Life cycle assessment	(0.423)	0.923	0.356	Accepted
Logistics	0.000	0.500	0.250	Unaccepted
Logistics service providers	(0.411)	0.911	0.353	Accepted
Multi-objective optimization	0.000	0.500	0.250	Unaccepted
Network design	0.000	0.500	0.250	Unaccepted
Operational performance	(0.051)	0.926	0.450	Accepted

Operations management	0.000	0.500	0.250	Unaccepted
Optimization	(0.020)	0.895	0.442	Accepted
Organizational performance	0.000	0.500	0.250	Unaccepted
Outsourcing	(0.353)	0.853	0.338	Accepted
Packaging	(0.068)	0.943	0.454	Accepted
Performance analysis	0.000	0.500	0.250	Unaccepted
Performance assessment	0.000	0.500	0.250	Unaccepted
Performance evaluation	0.000	0.500	0.250	Unaccepted
Performance management	0.000	0.500	0.250	Unaccepted
Performance measurement	0.000	0.500	0.250	Unaccepted
Policy	(0.409)	0.909	0.352	Accepted
Pricing	0.000	0.500	0.250	Unaccepted
Product development	0.000	0.500	0.250	Unaccepted
Production	0.000	0.500	0.250	Unaccepted
Purchasing	0.000	0.500	0.250	Unaccepted
Quality management	(0.402)	0.902	0.350	Accepted
Raw materials	(0.392)	0.892	0.348	Accepted
Recycling	0.000	0.500	0.250	Unaccepted
Remanufacturing	(0.391)	0.891	0.348	Accepted
Renewable energy	0.000	0.500	0.250	Unaccepted
Resilience	0.000	0.500	0.250	Unaccepted
Resource efficiency	0.000	0.500	0.250	Unaccepted
Resource-based view	0.000	0.500	0.250	Unaccepted
Reverse logistics	(0.422)	0.922	0.356	Accepted
Reverse supply chain	0.000	0.500	0.250	Unaccepted
Risk management	0.004	0.871	0.437	Accepted
Simulation	(0.382)	0.882	0.345	Accepted
Social performance	0.000	0.500	0.250	Unaccepted
Social responsibility	0.000	0.500	0.250	Unaccepted
Social sustainability	(0.376)	0.876	0.344	Accepted
Stakeholder	0.000	0.500	0.250	Unaccepted
Standards	0.000	0.500	0.250	Unaccepted
Strategy	(0.095)	0.970	0.461	Accepted
Supplier development	(0.402)	0.902	0.350	Accepted
Supplier evaluation	0.000	0.500	0.250	Unaccepted
Supplier management	(0.409)	0.909	0.352	Accepted
Supplier selection	0.000	0.500	0.250	Unaccepted

Supply chain collaboration	(0.395)	0.895	0.349	Accepted
Supply chain design	0.000	0.500	0.250	Unaccepted
Supply chain integration	(0.387)	0.887	0.347	Accepted
Supply chain network design	(0.032)	0.907	0.446	Accepted
Supply chain risk management	0.000	0.500	0.250	Unaccepted
Supply chain strategy	0.000	0.500	0.250	Unaccepted
Sustainable innovation	0.000	0.500	0.250	Unaccepted
Sustainable manufacturing	0.000	0.500	0.250	Unaccepted
Sustainable operations	(0.050)	0.925	0.450	Accepted
Sustainable production	(0.371)	0.871	0.343	Accepted
Sustainable sourcing	(0.383)	0.883	0.346	Accepted
Sustainable supplier selection	(0.365)	0.865	0.341	Accepted
System dynamics	(0.380)	0.880	0.345	Accepted
Traceability	(0.375)	0.875	0.344	Accepted
Transportation	0.000	0.500	0.250	Unaccepted
Triple bottom line	(0.368)	0.868	0.342	Accepted
Trust	0.000	0.500	0.250	Unaccepted
Uncertainty	(0.387)	0.887	0.347	Accepted
Value chain	(0.383)	0.883	0.346	Accepted
Waste management	0.000	0.500	0.250	Unaccepted
Threshold			**0.302**	

Appendix F. FDM indicators refined – round 2

Indicators	l_b	u_b	D_b	Decision
Big data	(0.368)	0.868	0.342	Accepted
Carbon emissions	0.000	0.500	0.250	Unaccepted
Circular economy	(0.353)	0.853	0.338	Accepted
Cleaner production	(0.383)	0.883	0.346	Accepted
Closed-loop supply chain	(0.064)	0.939	0.453	Accepted
Competitive advantage	0.000	0.500	0.250	Unaccepted
Corporate social responsibility	0.000	0.500	0.250	Unaccepted
Dynamic capabilities	0.000	0.500	0.250	Unaccepted
Eco-design	0.000	0.500	0.250	Unaccepted
Eco-efficiency	(0.056)	0.931	0.452	Accepted
Economic sustainability	0.000	0.500	0.250	Unaccepted

Ecosystem services	0.000	0.500	0.250	Unaccepted
Emerging economy	0.000	0.500	0.250	Unaccepted
Emerging markets	(0.019)	0.894	0.442	Accepted
Energy efficiency	0.000	0.500	0.250	Unaccepted
Environmental impact	0.000	0.500	0.250	Unaccepted
Environmental sustainability	0.000	0.500	0.250	Unaccepted
Ethics	(0.380)	0.880	0.345	Accepted
Financial performance	(0.402)	0.902	0.350	Accepted
Globalization	(0.366)	0.866	0.342	Accepted
Green logistics	0.000	0.500	0.250	Unaccepted
Green supply chain management	0.000	0.500	0.250	Unaccepted
Industry 4.0	(0.300)	0.800	0.325	Accepted
Just-in-time	0.000	0.500	0.250	Unaccepted
Knowledge management	(0.391)	0.891	0.348	Accepted
Life cycle assessment	0.000	0.500	0.250	Unaccepted
Logistics service providers	0.000	0.500	0.250	Unaccepted
Operational performance	0.000	0.500	0.250	Unaccepted
Optimization	(0.361)	0.861	0.340	Accepted
Outsourcing	0.000	0.500	0.250	Unaccepted
Packaging	0.000	0.500	0.250	Unaccepted
Policy	(0.394)	0.894	0.348	Accepted
Quality management	0.000	0.500	0.250	Unaccepted
Raw materials	(0.338)	0.838	0.335	Accepted
Remanufacturing	(0.091)	0.966	0.460	Accepted
Reverse logistics	(0.392)	0.892	0.348	Accepted
Risk management	(0.356)	0.856	0.339	Accepted
Simulation	0.000	0.500	0.250	Unaccepted
Social sustainability	(0.042)	0.917	0.448	Accepted
Strategy	0.000	0.500	0.250	Unaccepted
Supplier development	0.000	0.500	0.250	Unaccepted
Supplier management	0.000	0.500	0.250	Unaccepted
Supply chain collaboration	(0.356)	0.856	0.339	Accepted
Supply chain integration	0.000	0.500	0.250	Unaccepted
Supply chain network design	(0.325)	0.825	0.331	Accepted
Sustainable operations	0.000	0.500	0.250	Unaccepted
Sustainable production	0.000	0.500	0.250	Unaccepted
Sustainable sourcing	0.000	0.500	0.250	Unaccepted

Sustainable supplier selection	(0.398)	0.898	0.349	Accepted
System dynamics	(0.378)	0.878	0.345	Accepted
Traceability	0.000	0.500	0.250	Unaccepted
Triple bottom line	0.000	0.500	0.250	Unaccepted
Uncertainty	0.000	0.500	0.250	Unaccepted
Value chain	0.000	0.500	0.250	Unaccepted
Threshold			**0.298**	