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# Causality sustainable supply chain management practices in the Indonesian coffee industry using qualitative information: Digitalization integration leads performance improvement

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## Abstract

Sustainable supply chain management practices (SSCMPs) aim to address transparent information, which includes social, environmental, and economic perspectives and Industry 4.0 (I4.0) technology, in the Indonesian coffee industry, SSCMPs highlight those attributes in complex causality interrelationships. Although the effects of I4.0 are discussed in the literature, little attention enables addressing how this digitalization integration can handle the transition of the agricultural supply chain to sustainability. This study aims to (1) validate the interdependent hierarchical structure of SSCM for I4.0, (2) identify the causal interrelationships among attributes, and (3) determine the critical attributes for SSCM in Indonesian coffee industry practices. An approach consisting of the fuzzy Delphi method, fuzzy decision-making trial and evaluation laboratory, and analytic network process is designed to fulfill the proposed objectives. The results show that digitalization integration leads to labor conditions, supply chain financing accessibility, and social responsibility being the top causal attributes in the cause-and-effect model.

***Keywords***: sustainable supply chain management; Industry 4.0; fuzzy decision-making trial and evaluation laboratory; analytic network process; digitalization integration.

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## 1. Introduction

The transition of the agriculture supply chain (ASC) toward sustainability has been evident in recent years. Especially, coffee consumption has increased 2.4% annually over the last 40 years due to global population expansion and millennials' increased consumption of coffee drinks, placing significant demand on coffee supply (Akenroye et al., 2021). After Brazil, Vietnam, and Colombia, Indonesia is the fourth largest coffee producer worldwide. In 2019, approximately 753.9 thousand metric tons of coffee were produced, with an export value of USD 610 million (Ministry of Agriculture of Indonesia, 2019). Furthermore, unsustainable levels have been observed in the coffee production process, leading to ground water exhaustion, monoculture, and soil effluence from fertilizer usage. As demand grows, arable land availability certainly decreases, exerting even more tension on water and soil nutrient usage. Thousands of smallholder farmers, as well as individuals whose livelihoods are dependent on the coffee industry, are affected by these difficulties (Akenroye et al., 2021; Jezeer et al., 2018; Watteyn et al., 2022). However, the wide trade, consumption, and pursuit of revenue have made sustainable supply chain management practices (SSCMPs) regarding coffee receive considerably less attention and remain scientifically unexplored (Campos et al., 2021; Zhu et al., 2022).Therefore, SSCMPs need to be addressed in the coffee industry to improve the effectiveness of resources for human needs without damaging the environment.

The Integration of sustainable practices and the triple bottom line (TBL) in SSCMPs has gained much interest from both academia and practitioners (Mahroof et al., 2021; Campos et al., 2021; Watteyn et al., 2022). These perspectives have a strong bond with sustainability and are critical approaches to realizing ASC sustainability. Firms directly consider social, environmental, and economic perspectives as a combination to design ASC sustainable development plans (Bubicz et al., 2019; Fernando et al., 2022; Jiang et al., 2022). However, to maximize SSCMP productivity, advancing the conventional ASC to more smart systems using a variety of emergent Industry 4.0 (I4.0) technologies is necessary (da Silveira et al., 2021; Benyam et al., 2021; Tseng et al., 2022; Zhu et al., 2022). Firms are seeking to embrace various technologies to create a globally competitive market for sustainable agricultural products because of the importance of agricultural commodities in daily life. Rose et al. (2021) claimed that the main function of technology application and I4.0 is to help the ASC achieve sustainability. Mahroof et al. (2021) argued that SSCMPs have been significantly demanded to be established as an increasing concern in sustainability practice in the ASC and the utilization of innovative technologies for sustainable business practices. However, guaranteeing smooth and transparent operation throughout the ASC is a major problem in terms of aligning the technology with the ASC system. As a result, the capabilities of I4.0 for sustainability and minimizing the operational expenses of the SSCMP system should be considered to push agricultural businesses toward digital technology changes to support sustainable practices.

The advantages of I4.0, as well as the contribution of technology to radically changing both business and society in the agricultural setting, have been discussed (Bui et al., 2021; Chien et al., 2021; Esmaeilian et al., 2020). For instance, Kamble et al. (2020) debated whether highly technological SSCMPs, such as the Internet of Things, or other digital technologies to enable real-time data sharing and gathering can strongly foster agreement farming and local producer development. Sharma et al. (2020) suggested that information technology adoption in the ASC, transportation, post-harvesting, and sustainability are frequently high priorities in food safety and quality. Kumar et al. (2021) argued that the utilization of innovative technologies in I4.0 at various stages of the ASC contributes to tackling uncertainty in SSCMPs. I4.0 has led to the adoption of technology in precision agriculture, and it also enables an improved effectiveness of agricultural production and practices. However, little attention has been paid to how these new technologies handle sustainability issues, particularly in agriculture's transition to SSCMPs in I4.0. This study aims to measure the structural TBL and I4.0 as a supporting perspective to realize SSCMPs.

Uncertainty and complexity in the industry have generated various attributes that remain one of the primary challenges that must be addressed in SSCMP applications (Despoudi, 2021; Hervani et al., 2022; Ming et al., 2021; Nematollahi & Tajbakhsh, 2020). This study proposes the fuzzy Delphi method (FDM), the fuzzy decision-making trial and evaluation laboratory (FDEMATEL), and the analytical network process (ANP) as approaches to realize sustainable practices (Tsai et al., 2021). The FDM technique is used to eliminate the less important aspects and criteria by processing experts' linguistic preferences, which has been shown to justify practical improvement. The DEMATEL technique is then applied to analyze and develop the interrelationships between complex attributes (Tseng & Bui, 2017; Tseng et al., 2021). However, the proposed attribute set is a multihierarchical structure with interdependent relationships; thus, the ANP is adopted to determine the consistency of the SSCMP hierarchical structure (Tseng, 2011, Tsai et al., 2021). The objectives of this study are as follows:

- To determine a valid interdependent hierarchical structure of attributes in SSCMPs
- To determine the structural SSCMPs along with the I4.0 attributes in the cause-effect model
- To identify critical attributes for the transition to SSCMPs in Indonesian coffee industry practices

This study adds to the literature on SSCMPs in I4.0 by (1) specifying insights through the identification and determination of valid structural attributes, (2) providing the causal interrelationships among attributes, and (3) providing inclusive practical findings and critical criteria for coffee industry supply chain improvement.

This study is divided into six sections. The first section introduces SSCMPs and I4.0. Section 2 discusses the potential methodology and measures, as well as the literature on SSCMPs and I4.0. Section 3 explains the case background and the methodology used. The findings are given in Section 4. The implications for theoretical and managerial issues are discussed in Section 5. Finally, Section 6 presents the conclusion.

## 2. Literature Review

The literature on SSCMPs and I4.0, the proposed methodology, and the proposed measurements are discussed in this section.

### 2.1. Sustainable supply chain management practices

SSCMPs are described as the application of the sustainability concept to ASC management, not only focusing on improving agricultural productivity but also helping to improve the environment, the ecosystem and social benefits, exponentially promoting a more competitive market (Nematollahi & Tajbakhsh, 2020; Sharma et al., 2020; Tseng et al., 2022). Nematollahi & Tajbakhsh (2020) stated that SSCMPs were responsible for agricultural raw materials and final products procured from fields and consumed by humans or animals with the maximum possible speed and smallest possible product impairment from farmers to the end consumer. Ming et al.

(2021) and Sharma et al. (2020) claimed that SSCMPs also contain several procedures and information flows from preproduction to production, storage, processing, and distribution. Indeed, with regard to realizing sustainable development, agriculture has been given the greatest priority, with an emphasis on implementing the finest management procedures. Therefore, an SSCMP has the potential to advance environmental and socioeconomic performance (Akenroye et al., 2021; Elfarouk ET AL., 2022; Kamble et al., 2020).

In the literature, Mahroof et al. (2021) clarified that the application of SSCMPs offers sustainable solutions for cleaner agriculture since it helps to minimize pollution and enhance soil fertility by reducing hazardous substances, while the process also becomes a more ethical practice since it produces safer products. van Bergen et al. (2019) and Jiang et al. (2022) focused on agricultural product transactions in SSCMPs, which have a positive effect on the whole supply chain process from planting to transactions and consumption by increasing product quality, significantly improving the environment, and increasing economic gains. However, the literature still pays less attention to addressing critical issues such as materials that are hazardous to health, increasing environmental pollution, and economic returns, especially the social aspect (Watteyn et al., 2022; Rose et al., 2021; Jezeer et al., 2018). Mahroof et al. (2021) argued that to explore and maximize sustainable performance, the role of stakeholders in SSCMPs should be taken into consideration. Liu et al. (2021) indicated that SSCMPs need policy makers and market actors to be engaged in developing and adopting interventions such as policies, movements, certifications, and technologies. Furthermore, Kumar et al. (2021) suggested the importance of adopting I4.0 in the ASC process to enable sustainable practices. Hence, there are still numerous gaps that must be filled to ensure long-term SSCMP development.

### 2.2. Industry 4.0 in sustainable supply chain management practices

I4.0 was originally intended to be the fourth manufacturing revolution, but its definition has evolved over time. I4.0 is described as the digitization and smartization of distribution systems, factories, and value chain members, such as collaborators from academia, government, and industry (Bui et al., 2021; Fernando et al., 2022; Tseng et al., 2021b). From smart manufacturing to complete value delivery channels, I4.0 now encompasses the digital transformation of the entire industrial and consumer sectors. Indeed, the concept relies on continuously changing high-tech innovations. Ghobakhloo (2020) indicated that for I4.0 to implement underlying design principles and technological trends, numerous technologies must be integrated simultaneously across the supply chain. da Silveira et al. (2021) argued that the concept aims to intensify the collected data, to advance the connectivity of devices, and to advance suitable ecosystems to proceed and use data. However, the benefits and challenges of integrating I4.0, as well as the role of advanced technologies such as artificial intelligence, big data, drones, and the Internet of Things and their impact on supply chain management performance, are not coherent.

In SSCMPs, I4.0 is developing in a certain way, and it important for the transformation of agricultural growth, with succinct information on the benefits for people, manufacturers, and the environment (Chien et al., 2021; Liu et al., 2021; Zhu et al., 2022). I4.0 is critical for determining SSCMP improvement by embracing technological innovation, and the concept aids in the facilitation and integration of sustainability with digitalization and smartization. Technology adoption has improved the quality of agricultural production and distribution networks while simultaneously creating adverse environmental impacts due to overuse. Rose et al. (2021) argued that SSCMPs with I4.0 capabilities that integrate numerous services are needed to improve the network's responsiveness and flexibility. Sharma et al. (2020) discussed the necessity of a social and technological transformation to reap the full benefits for SSCMPs. However, the adoption of I4.0 in SSCMPs could take years to be accepted and embraced by stakeholders since the I4.0 concept has raised some major challenges in business models, such as socioeconomic barriers in adoption processes (Kamble et al., 2020). As a result, understanding the role of I4.0 in SSCMPs is important and must be precisely examined.

### 2.3. Proposed method

Prior studies have employed various methods to analyze SSCMPs. For instance, Despoudi (2021) applied an in-depth interview method to gain insights into respondents' interpretations of the challenges in SSCMPs. Ming et al. (2021) employed signal transmission control, fuzzy big data and large-scale group decision making to ensure the superiority and security of the supplied items. However, this method lacks valid indicators and might still have unnecessary attributes (Hervani et al., 2022). It is necessary to explain how aspects and criteria interact in turn with interrelationships and interdependences among each other to offer a performance measurement framework for businesses. Due to the complexity and ambiguity of sustainable supply chain management (SSCM), a more appropriate tool is necessary.

The FDM, the FDEMATEL and ANP methods are employed in this study. The FDM is used in the literature to authenticate qualities using experts' linguistic preferences, to detect and delete extraneous attributes, and to calculate their important performance level (Tseng & Bui, 2017). This integrated strategy allows experts to exchange judgments with one another, reducing the uncertainty and complexity in expert judgments and ensuring the quality of survey analysis (Bui et al., 2020; Tseng et al., 2021a). The FDEMATEL approach is used to determine attributes' interrelationships using human perceptions, as reflected by linguistic preference (Tsai et al., 2021; Tseng et al., 2021a). However, the interdependent relationships of the SSCMP hierarchical structure have yet to be identified (Bui et al., 2021). This study critically validates the interdependence of aspects and criteria among the multilevel hierarchical structure using the ANP technique and expert judgment input from the FDEMATEL (Saaty, 2008; Tseng, 2011). Tseng (2011) used the FDEMATEL and ANP to evaluate firms' environmental knowledge management hierarchical structure under uncertainty. Tsai et al. (2021) used this kind of method to build a valid sustainable solid waste management hierarchical structure based on qualitative data. Hence, the proposed method is suitable for this study to assess the hierarchical structure of SSCMP attributes in I4.0.

### 2.4. Proposed measures

The literature has given assorted attributes that contribute to helping decision-makers evaluate their decisions, resulting in sustainability performance. This study identifies 33 criteria and nine aspects under the four perspectives of the TBL and I4.0 (see Appendix A).

The social perspective is one of the main perspectives, yet it has rarely been discussed. This study proposes two aspects of the social dimension: *social responsibility* and *labor or farmer conditions*. *Social responsibility* is defined as a concept in which a firm voluntarily incorporates social issues into its commercial operations to live harmoniously with its stakeholders (Nematollahi & Tajbakhsh, 2020; Tseng et al., 2022). The aspect indicates the main social measures, such as social welfare and job generation, supporting small enterprises that are being used. Greater attention to social and environmental concerns in the places where firms operate could also be interpreted as social responsibility (Akenroye et al., 2021). Jiang et al. (2022) mentioned that the social responsibility effect on SSCMPs is reflected in farmers' willingness to engage in green planting practices, and the greater the farmers' environmental social responsibility, the better the planting behavior they have, which benefits the ASC's long-term sustainability. Thus, firms declare that social responsibility serves as a check to ensure that they are not only financially viable but also socially viable.

*Labor or farmer conditions* have been a top priority over the years and are mainly related to labor conditions and health and safety issues to increase SSCMPs (Bubicz et al., 2019). The ubiquitous use of pesticides in agriculture causes health hazards, health expenses, productivity losses, and environmental degradation, which can be addressed by regulating farmers' risk perceptions of pesticide residues. Thus, promoting better labor or farmer conditions could help farmers and society generally improve their quality of life. For example, Akenroye et al. (2021) mentioned that because the conventional harvesting procedure requires farmworkers to pick by hand, posing health and safety dangers to farmworkers, supplying personal protective equipment and safety equipment in farms would ensure innocuous working conditions. Furthermore, the aspect assists farmers in dealing with the problems brought by climate change, resulting in greater productivity, resource efficiency, and profit.

Environmental friendliness has become a trend in agricultural development as a preventive strategy and a solution for improving the performance of firm operations and products, and it entails a better environmental control level across the ASC. This study proposes three aspects of this dimension: *environmental management systems*, *supplier management*, and *government policy*. *Environmental management systems* refer to the dynamic concept of sustainable agriculture and focus on stopping and avoiding pollution, achieving resource efficiency, and diminishing climate change (Akenroye et al., 2021). This aspect considers the organization’s impacts on land, air, water, and ecosystems. Moreover, Luthra et al. (2017) indicated that environmental management improves a firm’s ability to design products, establish markets, and run business operations while also gaining a competitive advantage. Thus, the environment has a noteworthy meaning for the existence of agricultural production, such as the coffee industry.

*Supplier management* covers criteria from integrated sustainable supply selection via the evaluation of strategic tasks, in which the constructs of supplier performance have a fundamental effect on the success or failure of the organization (Luthra et al., 2017; Seuring et al., 2019). Choosing the correct supplier is a strategy for improving agriculture by providing information, developing and disseminating knowledge, mobilizing funding, and participating in sustainable agricultural innovations through their actions and capacities. Watteyn et al. (2022) mentioned that supplier management is critical for a firm to ally its suppliers with its commercial goals by integrating with its suppliers to create openness and efficiency in SSCMPs as well as a better understanding of how to become more environmentally friendly. Moreover, Nematollahi and Tajbakhsh (2020) argued that when companies use SSCMPs and include their suppliers in their strategy, they gain a competitive edge in terms of both commercial and environmental performance.

*Government policy* aims to improve the functioning of sustainable agriculture and supply chain operations (Liu et al., 2021). Jiang et al. (2022) claimed that policy support is essential for long-term agricultural development because it helps farmers transition from traditional to sustainable behavior while also controlling the price of high-quality agricultural products, cultivating consumer routines, and promoting the entire supply chain's long-term development. Additionally, the adoption and growth of an SSCMP have been aided by policy regulation and instruments. For example, Akenroye et al. (2021) indicated that policy measures targeted at promoting the development and use of energy-efficient appliances in agricultural production and distribution would result in a competitive advantage. Hence, a competent policy regulatory approach could encourage SSCMPs to take on more product responsibility.

The economic dimension measures the success of a firm's activities by connecting the purchase of materials, product creation, delivery, and distribution together (Esfahbodi et al., 2017). This study uses two aspects from the economic perspective: *economic performance* and *supply chain finance accessibility*. *Economic performance* compares firm execution with different hatching and response administrations and evaluates economic indicators, including investment recovery, labor productivity, revenue/profit, and others, to allow a comprehensive performance analysis (Jezeer et al., 2018). Stronger economic performance has been shown to open new opportunities for adding value to core business initiatives. However, economic performance is clearly not achieved by short-term sales performance and profitability because cost is the primary concern for stakeholders regardless of whether or not they embrace sustainability in agricultural businesses.

Another crucial aspect for businesses to implement sustainability is financial success (Esfahbodi et al., 2017). *Supply chain finance* plans have the ability to increase profit for both buyers and suppliers, affecting both financial and operational decisions (van Bergen et al., 2019). This aspect is gaining traction among decision makers as a collection of methods for allocating financial resources and optimizing financial flows through collaboration among key supply chain stakeholders as well as outside service providers. Supply chain finance improves traditional procurement measures such as accounts receivable and payable, and its implementation is frequently led in partnership with a buyer's procurement office, focusing on broader supply chain implications (van Bergen et al., 2019). Therefore, this aspect can enhance buyers' and suppliers' perceptions as well as their financial costs and operational decisions, allowing them to better follow customers' development patterns.

I4.0 is characterized by a set of associated cyber-physical devices that are able to apply data inside the production and manufacturing spheres (Esmaeilian et al., 2020). The perspective aims to not only provide contemporary data collection technologies to industrial systems but also generate value and innovative services. In the ASC, the concept relies on continuously changing high-tech, such as *digitalization integration* and *agricultural production technology*. *Digitalization integration* concerns technology that improves the amount of information integration throughout supply chains and between diverse actors (Esmaeilian et al., 2020). The aspect is paired with I4.0-interrelated measures and digitizing processes that significantly influence businesses as re-engineering processes after digitalization (Amaral & Peças, 2021). Thus, the adoption of this aspect may result in a number of agricultural and environmental advantages. For example, the systematic practice of digital information monitoring, such as blockchain in agriculture, may increase customers' awareness of food issues and environmental sustainability (Benyam et al., 2021). Digital foundations such as nanotechnology might aid in precision agriculture, leading to more effective practices related to agrochemicals and feeding condiments, hence reducing agricultural leftover (Benyam et al., 2021). Therefore, it is vital to concentrate on digitalization integration rather than addressing the general I4.0 maturity level (Amaral & Peças, 2021).

*Agricultural production technology* minimizes resource degradation and carbon emissions and mitigates concerns over climate change. Green fertilizer technology, plastic film recovery, straw inclusion, multifaceted subsoiling and tillage, and water-saving irrigation are all examples of agricultural technology. Straw integration is one type of agricultural technology; it consists of breaking up straw immediately after harvest and incorporating it into the soil by spinning, plowing and other methods to use it as a base compost (Mao et al., 2021). This approach has the potential not only to reduce pollution and recycle resources but also to increase land output. On the other hand, the cost disparities in adopting agricultural technology, which are caused by the farm scale, have an impact on agricultural technology adoption activities (Benyam et al., 2021). Additionally, the size of the farm has a large impact on whether or not green agriculture technology is used (Ghobakhloo, 2020). It is easier for large-scale farms to realize economic benefits by embracing technology, making adoption more likely since for them, the costs of new technology adoption are decreased.

## 3. Methodology

This section provides the detailed case background, the details of the methodology used, and the data analysis steps.

### 3.1. Industrial background

Indonesia is one of the world's largest coffee growers, and in 2019, it accounted for 9% of global coffee production (Ministry of Agriculture of Indonesia, 2019). However, even though the country is the second largest in terms of planting area, it produces less than three other countries and not even one-fifth as much as Brazil. Moreover, the coffee industry has significantly contributed to socioenvironmental issues such as ground water depletion, monoculture, and soil pollution from fertilizer application, poor working conditions, the use of materials that are hazardous to health, and increasing environmental pollution (Jiang et al., 2022). The labor intensiveness and lack of sustainability in the coffee industry raise concerns among stakeholders and affect productivity and income generation (Akenroye et al., 2021; Campos et al., 2021).

In this situation, the Indonesian ministries of industry and agriculture have made many steps to promote the industry's long-term development, such as improving access to financing and implementing I4.0 in the agriculture sector (Ministry of agriculture of Indonesia, 2019). However, there are variances in the integration and information timeliness that stakeholders can access and control due to the uncertainty and complexity in this industry (Ming et al., 2021). The industry is still acquainted with traditional supply chain processes, which result in low productivity and sustainability performance. Developing sustainable tactics and a technology-oriented approach that strives to decrease losses and waste throughout the supply chain process is required to obtain the maximum advantage in this market (da Silveira et al., 2021). Therefore, this study suggests enhancing coffee industry SSCMPs by utilizing I4.0 to maximize productivity while increasing social and environmental performance, thus achieving sustainability.

### 3.2. Fuzzy Delphi method

The FDM integrates fuzzy set theory and the Delphi method to overcome the limitations of expert preferences and to improve the quality of questionnaires (Ishikawa et al., 1993). The method is used to evaluate the proposed attribute set using the linguistic preferences of experts, and it provides an effective assessment of the evaluation process by reducing the survey time and expense while avoiding the need for a large respondent sample (Bui et al., 2020).

For instance, there are $n$ experts, and the analytical process begins by asking experts simultaneously to assess the level of importance of the y attribute as $p = \left(a_{xy}; b_{xy}; c_{xy}\right)$, $x = 1, 2, 3, \dots, n$; $y = 1, 2, 3, \dots, m$, as $p_y$ is the weight of $y$ presented as $p_y = \left(a_y; b_y; c_y\right)$ with $a_y = min\left(a_{xy}\right)$, $b_y = \left(\prod_1^n b_{xy}\right)^{1/n}$, and $c_y = max\left(c_{xy}\right)$. Next, the experts' linguistic preferences are interpreted into triangular fuzzy numbers (TFNs) (see Table 1).

Table 1. Transformation 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 convex combination values are obtained using a $\varepsilon$ cut as follows:

$$u_y = a_y - \varepsilon\left(c_y - b_y\right),$$
$$p_y = x_y - \varepsilon\left(b_y - \varepsilon a_y\right),$$
$$b = 1,2,3, \dots, m \qquad (1)$$

where $\varepsilon = [0,1]$ regarding experts' perceptions are negative or affirmative. $\varepsilon = 0.5$ is typically enquired as the overall perception state.

The fuzzy assessment is transformed into precise values $H_y$ as follows:

$$H_y = \int\left(u_y, p_y\right) = \sigma\left[u_y + (1 - \sigma)p_y\right] \qquad (2)$$

where $\sigma$ represents the experts' balance valuation.

Afterward, the threshold is obtained as $T = \left(\sum_{y=1}^{m} H_y\right)/m$ to sanitize the valid attributes from the initial set.

If $H_y \geq T$, attribute $b$ is valid. If not, it ought to be removed from the set.

### 3.3. Fuzzy decision-making trial and evaluation laboratory

In the FDEMATEL, defuzzification is used to transform qualitative information into fuzzy linguistic data. The fuzzy membership functions $\tilde{e}_{ij}^{k} = (\tilde{e}_{1ij}^{k}, \tilde{e}_{2ij}^{k}, \tilde{e}_{3ij}^{k})$ are used to acquire the total weighted scores. In particular, the right and left values are computed using the lowest and highest fuzzy numbers. The crisp values are then arranged in a total direct relation matrix for mapping a diagram as a simplification of the analytical results. Finally, the cause-and-effect groupings assign particular properties that represent structural interrelationships and critical consequences.

An attribute set $Q = \{q1, q2, q3, \cdots, qn\}$ is offered, and pairwise comparisons are utilized to create accurate associations. The examination obtains crisp values from TFNs using linguistic scales from VL (very low impact) to VH (very high impact) (see Table 2). Suppose that there are $k$ experts, and $\tilde{e}_{ij}^{k}$ represents the fuzzy weight of the $i^{th}$ attribute's impact on the $j^{th}$ attribute as expert $k^{th}$ evaluation.

Table 2. FDEMATEL's TFN linguistic scale

| Scale | Linguistic variable | Corresponding triangular fuzzy number (TFNs) |
|---|---|---|
| VH | Very high influence | (0.7, 0.9, 1.0) |
| H | High influence | (0.5, 0.7, 0.9) |
| M | Moderate influence | (0.3, 0.5, 0.7) |
| L | Low influence | (0.1, 0.3, 0.5) |
| VL | Very low influence | (0.0, 0.1, 0.3) |

The fuzzy numbers are abridged using the following:

$$Q = \left(q\tilde{e}_{1ij}^{k}, q\tilde{e}_{2ij}^{k}, q\tilde{e}_{3ij}^{k}\right) = \left[\frac{(e_{1ij}^{k} - min\ e_{1ij}^{k})}{\Delta}, \frac{(e_{2ij}^{k} - min\ e_{2ij}^{k})}{\Delta}, \frac{(e_{3ij}^{k} - min\ e_{3ij}^{k})}{\Delta}\right] \quad (3)$$

where $\Delta = \max e_{3ij}^{k} - \min e$.

The left $(l)$ and right $(r)$ normalized values are calculated as follows:

$$\left(l_{ij}^{n}, r_{ij}^{n}\right) = \left[\frac{(qe_{2ij}^{k}}{\left(1 + qe_{2ij}^{k} - qe_{1ij}^{k}\right)}, \frac{qe_{3ij}^{k}}{\left(1 + qe_{3ij}^{k} - qe_{2ij}^{k}\right)}\right]. \quad (4)$$

The individual normalized crisp values $(nc)$ are computed as: follows:

$$nc_{ij}^{k} = \frac{[l_{ij}^{k}\left(1 - l_{ij}^{k}\right) + (r_{ij}^{k})^{2}]}{(1 - l_{ij}^{k} + r_{ij}^{k})}. \quad (5)$$

The synthetic crisp values for all respondents are obtained as follows:

$$\tilde{e}_{ij}^{k} = \frac{(nc_{ij}^{1} + nc_{ij}^{2} + nc_{ij}^{3} + \cdots + nc_{ij}^{3})}{k}. \quad (6)$$

The $n \times n$ initial direct relation matrix $(IM)$ is obtained in a pairwise comparison arrangement, wherein $\tilde{e}_{ij}^{k}$ signifies the impact level of attribute $i$ on attribute $j$:

$$IM = [\tilde{e}_{ij}^{k}]_{n \times n}. \quad (7)$$

The normalized direct relation matrix $(U)$ is created as follows:

$$U = \tau \otimes IM$$

$$\tau = \frac{1}{\max\limits_{1 \le i \le k} \sum_{j=1}^{k} \tilde{e}_{ij}^{k}}. \quad (8)$$

The interrelationship matrix $(W)$ is then obtained using the following:

$$W = U(I - U)^{-1}, \quad (9)$$

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

The driving value $(\vartheta)$ and dependence value $(\mu)$ are assimilated as total values of the row and column in the interrelationship matrix:

$$\vartheta = [\textstyle\sum_{i-1}^{n} w_{ij}]_{n \times n} \quad = [w_{i}]_{n \times 1} \quad (10)$$

$$\mu = [\textstyle\sum_{j-1}^{n} w_{ij}]_{n \times n} \quad = [w_{j}]_{1 \times n}. \quad (11)$$

Accordingly, the attributes are situated into the cause-and-effect diagram by deriving $[(\vartheta + \mu), (\vartheta - \mu)]$, which in turn are the horizontal and vertical vectors. On the one hand, $(\vartheta +$

$\mu$) denotes the attributes' critical scores. The larger the $(\vartheta + \mu)$ value is, the more critical the attribute is in the set. On the other hand, there are cause and effect areas in which the attributes are categorized based on their $(\vartheta\ \mu)$ scores, either positive or negative. If $(\vartheta - \mu)$ is positive, the attributes are categorized in the cause area; in contrast, they will be allocated to the effect area.

### 3.4. Analytic network process

The ANP incorporates the interrelationships among the attributes to illustrate the interdependence of the structure using a hierarchical supermatrix to calculate their convergent weights (Saaty, 2001). An unweighted supermatrix $D$ is obtained from the FDEMATEL and represents the correlation of interaction and feedback between aspects and criteria. Then, a weighted supermatrix $S$ is computed to conform to the column stochastic principle. Finally, the limited weighted supermatrix $S^*$ is obtained as the gradual convergence of the accurate interdependence weights of aspects and criteria. The limited weighted supermatrix $S^*$ is calculated as follows:

$$S^* = \lim_{n \to \infty} S^n \qquad (12)$$

### 3.5. Data analysis steps

This study is conducted to understand the attributes that improve SSCMPs for I4.0. This study was designed in two phases. In phase 1, the attributes were collected from the literature. In phase 2, this study collected data from a committee of 30 experts who have reasonable years of experience, including experts who are professional managers and faculty members (see Appendix B). The proposed analysis steps are as follows (see Figure 1):

1. The SSCMP attributes are collected from the literature.
2. The FDM refines the valid attributes and augments the robustness of the attribute set.
3. The FDEMATEL obtains the causal interrelationship among the attributes and determines the critical attributes for better performance.
4. The ANP critically validates the interdependent relationships between the aspects and criteria, thus confirming the consistency of the SSCMP hierarchical structure.

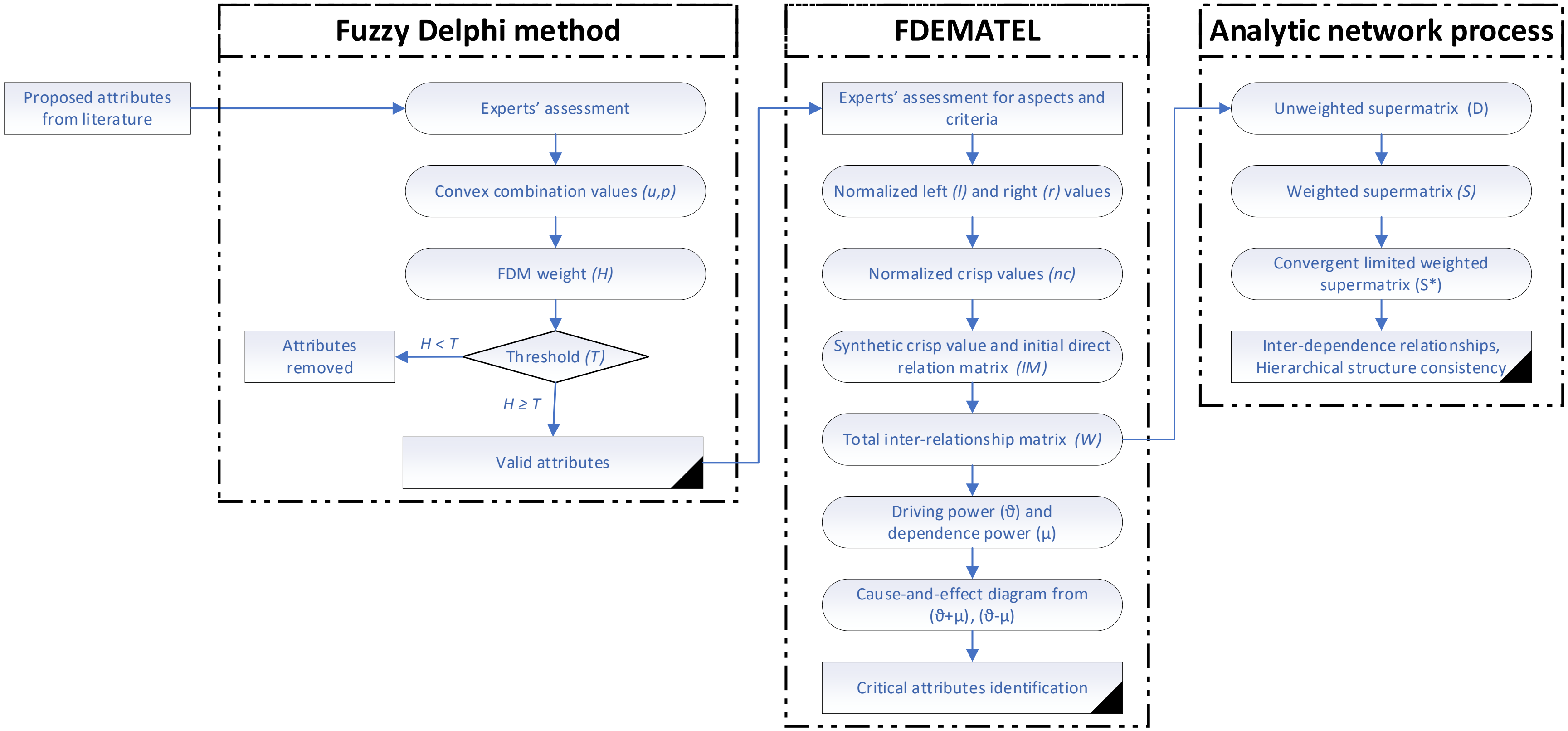


Figure 1. Proposed analysis step

## 4. Results

The results of the FDM, FDEMATEL, and ANP are presented in this section.

### 4.1. Fuzzy Delphi method results

A set of nine aspects and 33 criteria is recommended under four perspectives: the social dimension (P1), environmental dimension (p2), economic dimension (P3), and I4.0 (P4). The experts evaluated the initial set of SSCMP attributes using their judgment and expertise, and their linguistic preferences were transformed into TFNs (see Table 1). The FDM is used to purify the attributes into a valid SSCMP indicator set using equations (1)-(2). The results with the attribute weights are obtained, and the valid attributes are determined with the threshold $\gamma = 0.670$ (see Appendix C), under which eight out of nine aspects and 17 out of 33 criteria are accepted. Agricultural production technology is eliminated, and the valid SSCMP model retains eight aspects, including social responsibility (A1), labor conditions (A2), environmental management systems (A3), supplier management (A4), government policy (A5), economic performance (A6), supply chain finance accessibility (A7), and digitalization (A8) (see Table 3).

Table 3. Valid SSCMP structure

| Aspects | | Criteria | |
|---|---|---|---|
| A1 | Social responsibility | C1 | Fair trade |
| | | C2 | Job generation |
| A2 | Labour condition | C3 | Health and safety measures |
| | | C4 | Sufficient income |
| | | C5 | Good working condition |
| A3 | Environmental management system | C6 | Improving energy efficiency |
| | | C7 | Waste management |
| A4 | Supplier management | C8 | Supplier selection |
| | | C9 | Supplier integration |
| A5 | Government policy | C10 | Trade policy |
| A6 | Economic performance | C11 | Investment recovery |
| | | C12 | Revenue/profit |
| A7 | Supply chain finance accessibility | C13 | Access to capital |
| | | C14 | Collaborative efforts |
| A8 | Digitalization | C15 | Blockchain technology |
| | | C16 | Digital platform |
| | | C17 | Real time information |

### 4.2. Fuzzy decision-making trial and evaluation laboratory results

The TFNs are normalized to handle the uncertainty in linguistic preferences (see Table 2). The experts' evaluation of the set of valid indicators determines the interrelationships by transforming the linguistic scales provided into synthetic crisp value notation using equations (3)-(6); as a result, the initial direct relation matrix is generated using equation (7) (see Appendix D). Afterward, the normalized direct relation matrix is obtained using equation (8) (see Appendix E).

A complete interrelationship matrix is then processed to obtain the causal interrelationships among indicators using equation (9), and $\vartheta$ and $\mu$ are counted as the total value of rows and columns using equations (10)-(11) (see Table 4). Then, by mapping the dataset onto $[(\vartheta + \mu), (\vartheta - \mu)]$,, a causal interrelationship diagram of the aspects is generated.

Table 4. Interrelationship matrix and causal interrelationship among aspects

| | A1 | A2 | A3 | A4 | A5 | A6 | A7 | A8 | $\vartheta$ | $\mu$ | $(\vartheta+\mu)$ | $(\vartheta-\mu)$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A1 | 1.590 | 1.542 | 1.668 | 1.660 | 1.916 | 1.694 | 1.828 | 1.645 | 13.542 | 12.917 | 26.459 | 0.625 |
| A2 | 1.569 | 1.559 | 1.665 | 1.659 | 1.872 | 1.703 | 1.831 | 1.651 | 13.509 | 12.699 | 26.208 | 0.809 |
| A3 | 1.537 | 1.487 | 1.658 | 1.627 | 1.874 | 1.679 | 1.751 | 1.606 | 13.218 | 13.711 | 26.928 | -0.493 |
| A4 | 1.633 | 1.604 | 1.717 | 1.770 | 1.989 | 1.783 | 1.900 | 1.704 | 14.099 | 13.741 | 27.840 | 0.358 |
| A5 | 1.581 | 1.575 | 1.706 | 1.685 | 1.996 | 1.736 | 1.869 | 1.669 | 13.817 | 15.810 | 29.627 | -1.992 |
| A6 | 1.608 | 1.586 | 1.697 | 1.706 | 1.973 | 1.787 | 1.882 | 1.682 | 13.921 | 14.118 | 28.039 | -0.197 |
| A7 | 1.674 | 1.651 | 1.765 | 1.784 | 2.061 | 1.844 | 2.009 | 1.772 | 14.559 | 15.101 | 29.660 | -0.542 |
| A8 | 1.726 | 1.695 | 1.836 | 1.851 | 2.128 | 1.893 | 2.031 | 1.848 | 15.008 | 13.576 | 28.584 | 1.432 |

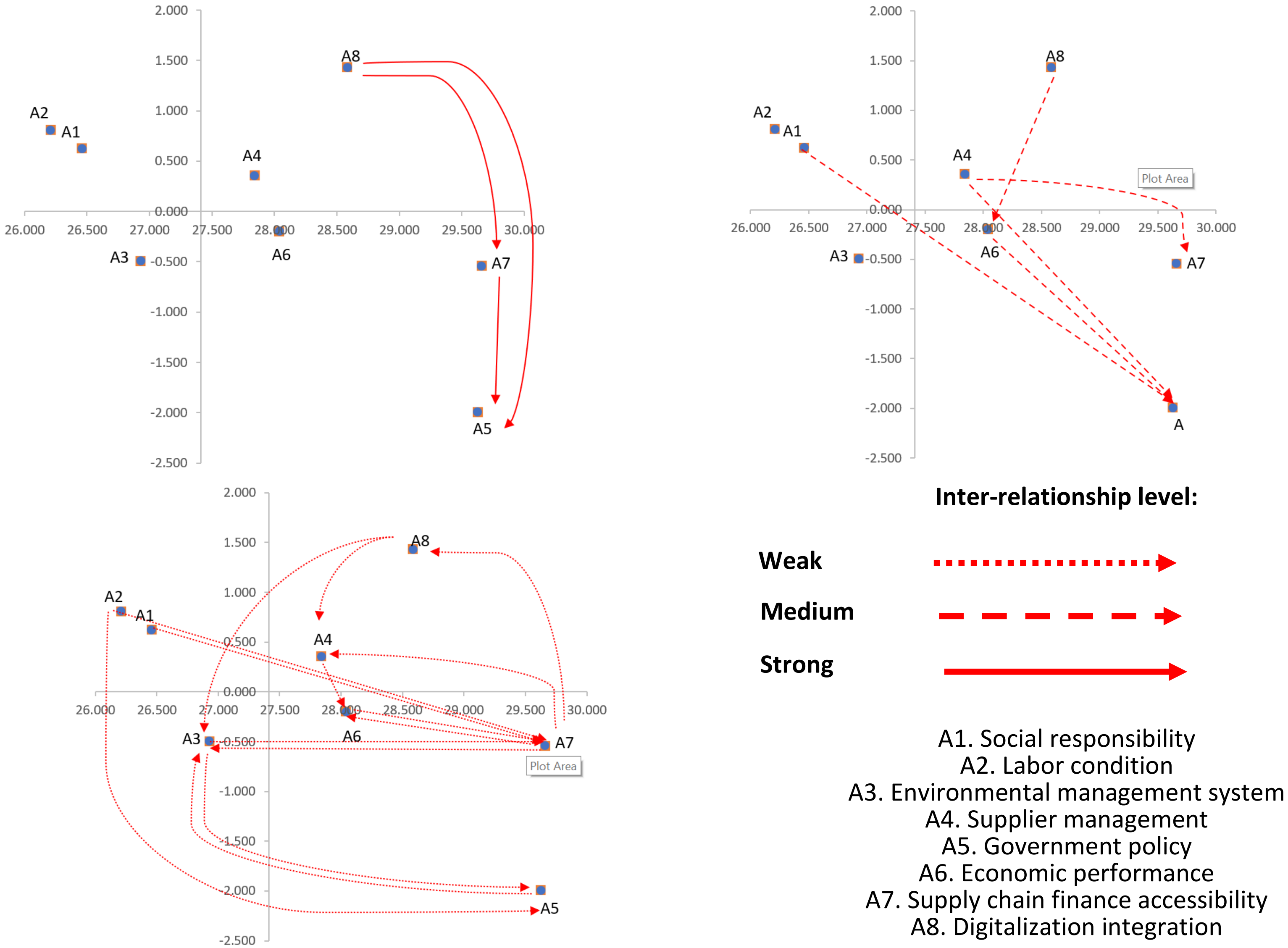
Table 5. Interrelationship matrix among criteria

| | C1 | C2 | C3 | C4 | C5 | C6 | C7 | C8 | C9 | C10 | C11 | C12 | C13 | C14 | C15 | C16 | C17 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| C1 | 1.486 | 0.477 | 0.519 | 0.492 | 0.517 | 0.533 | 0.527 | 0.530 | 0.540 | 0.517 | 0.513 | 0.520 | 0.501 | 0.541 | 0.486 | 0.491 | 0.493 |
| C2 | 0.403 | 1.466 | 0.486 | 0.453 | 0.476 | 0.494 | 0.488 | 0.481 | 0.485 | 0.468 | 0.478 | 0.479 | 0.469 | 0.493 | 0.452 | 0.451 | 0.453 |
| C3 | 0.431 | 0.454 | 1.506 | 0.456 | 0.488 | 0.506 | 0.487 | 0.496 | 0.487 | 0.462 | 0.466 | 0.470 | 0.460 | 0.485 | 0.461 | 0.464 | 0.465 |
| C4 | 0.404 | 0.415 | 0.475 | 1.465 | 0.469 | 0.482 | 0.475 | 0.462 | 0.493 | 0.451 | 0.451 | 0.453 | 0.441 | 0.490 | 0.463 | 0.467 | 0.466 |
| C5 | 0.470 | 0.481 | 0.540 | 0.493 | 1.548 | 0.544 | 0.550 | 0.534 | 0.544 | 0.522 | 0.529 | 0.539 | 0.498 | 0.551 | 0.520 | 0.515 | 0.523 |
| C6 | 0.447 | 0.464 | 0.523 | 0.491 | 0.524 | 1.564 | 0.545 | 0.530 | 0.542 | 0.523 | 0.519 | 0.526 | 0.514 | 0.538 | 0.527 | 0.527 | 0.529 |
| C7 | 0.451 | 0.486 | 0.529 | 0.507 | 0.526 | 0.556 | 1.566 | 0.536 | 0.545 | 0.516 | 0.526 | 0.529 | 0.529 | 0.550 | 0.533 | 0.531 | 0.535 |
| C8 | 0.515 | 0.520 | 0.564 | 0.529 | 0.556 | 0.594 | 0.591 | 1.596 | 0.593 | 0.556 | 0.574 | 0.575 | 0.552 | 0.595 | 0.567 | 0.567 | 0.569 |
| C9 | 0.519 | 0.539 | 0.593 | 0.542 | 0.589 | 0.610 | 0.605 | 0.600 | 1.620 | 0.581 | 0.589 | 0.592 | 0.567 | 0.608 | 0.584 | 0.582 | 0.586 |
| C10 | 0.513 | 0.523 | 0.574 | 0.524 | 0.566 | 0.592 | 0.586 | 0.581 | 0.589 | 1.577 | 0.572 | 0.573 | 0.553 | 0.591 | 0.557 | 0.556 | 0.553 |
| C11 | 0.474 | 0.505 | 0.551 | 0.513 | 0.544 | 0.574 | 0.570 | 0.557 | 0.565 | 0.534 | 1.568 | 0.557 | 0.545 | 0.567 | 0.545 | 0.547 | 0.554 |
| C12 | 0.520 | 0.537 | 0.582 | 0.545 | 0.579 | 0.609 | 0.605 | 0.600 | 0.607 | 0.570 | 0.588 | 1.604 | 0.580 | 0.607 | 0.580 | 0.582 | 0.582 |
| C13 | 0.442 | 0.463 | 0.502 | 0.444 | 0.497 | 0.510 | 0.510 | 0.503 | 0.512 | 0.492 | 0.496 | 0.496 | 1.511 | 0.510 | 0.491 | 0.492 | 0.491 |
| C14 | 0.514 | 0.535 | 0.586 | 0.541 | 0.583 | 0.606 | 0.598 | 0.591 | 0.602 | 0.573 | 0.586 | 0.588 | 0.567 | 1.617 | 0.577 | 0.579 | 0.579 |
| C15 | 0.533 | 0.539 | 0.595 | 0.541 | 0.595 | 0.613 | 0.607 | 0.601 | 0.612 | 0.586 | 0.591 | 0.595 | 0.578 | 0.615 | 1.600 | 0.586 | 0.587 |
| C16 | 0.538 | 0.561 | 0.607 | 0.556 | 0.606 | 0.621 | 0.622 | 0.612 | 0.621 | 0.593 | 0.602 | 0.604 | 0.590 | 0.621 | 0.595 | 1.610 | 0.595 |
| C17 | 0.545 | 0.563 | 0.605 | 0.564 | 0.607 | 0.627 | 0.621 | 0.612 | 0.624 | 0.595 | 0.603 | 0.605 | 0.591 | 0.628 | 0.597 | 0.595 | 1.613 |

Table 6. Causal interrelationship among criteria

| | $\boldsymbol{\vartheta}$ | $\boldsymbol{\mu}$ | $(\boldsymbol{\vartheta} + \boldsymbol{\mu})$ | $(\boldsymbol{\vartheta} - \boldsymbol{\mu})$ |
|---|---|---|---|---|
| C1 | 8.684 | 8.205 | 16.888 | 0.479 |
| C2 | 7.974 | 8.528 | 16.502 | -0.554 |
| C3 | 8.045 | 9.337 | 17.382 | -1.291 |
| C4 | 7.821 | 8.656 | 16.477 | -0.835 |
| C5 | 8.900 | 9.270 | 18.170 | -0.370 |
| C6 | 8.833 | 9.634 | 18.467 | -0.801 |
| C7 | 8.951 | 9.553 | 18.504 | -0.602 |
| C8 | 9.614 | 9.422 | 19.036 | 0.191 |
| C9 | 9.907 | 9.580 | 19.488 | 0.327 |
| C10 | 9.580 | 9.116 | 18.696 | 0.464 |
| C11 | 9.270 | 9.251 | 18.521 | 0.019 |
| C12 | 9.877 | 9.305 | 19.182 | 0.572 |
| C13 | 8.362 | 9.046 | 17.408 | -0.684 |
| C14 | 9.821 | 9.608 | 19.429 | 0.213 |
| C15 | 9.975 | 9.136 | 19.111 | 0.839 |
| C16 | 10.154 | 9.142 | 19.296 | 1.012 |
| C17 | 10.193 | 9.175 | 19.368 | 1.018 |

The classification of aspects is determined by the result of $(\vartheta - \mu)$. The causal interrelationship between aspects in which social responsibility (A1), labor conditions (A2), supplier management (A4), and digitalization integration (A8) are allocated to the cause area, while the effect area consists of environmental management systems (A3), government policy (A5), economic performance (A6), and supply chain finance accessibility (A7) (see Figure 2). Specifically, digitalization integration is the main aspect affecting SSCMPs, as it has a strong and moderate influence on other aspects in the matrix. This aspect strongly influences government policy and supply chain accessibility and moderates the influence on economic performance, confirming the role of I4.0 in SSCMPs.



A1. Social responsibility
A2. Labor condition
A3. Environmental management system
A4. Supplier management
A5. Government policy
A6. Economic performance
A7. Supply chain finance accessibility
A8. Digitalization integration

Figure 2. Causal inter-relationship diagram for aspects

Similarly, the initial direct relation matrix and normalized direct relation matrix for the criteria are obtained (see Appendixes F and G). The causal interrelationships among criteria are computed (Table 5), and $\vartheta$ and $\mu$ are calculated (see Table 6). The cause-and-effect diagram is drawn, and the results show that C1, C8, C9, C10, C11, C12, C14, C15, C16, and C17 are the cause criteria, whereas the effect area consists of C2, C3, C4, C5, C6, C7, and C13 (see Figure 3). Among these attributes, the most critical criteria in the cause area are supplier integration (C9), revenue/profit (C12), collaborative effort (C14), digital platforms (C16), and real-time information (C17).

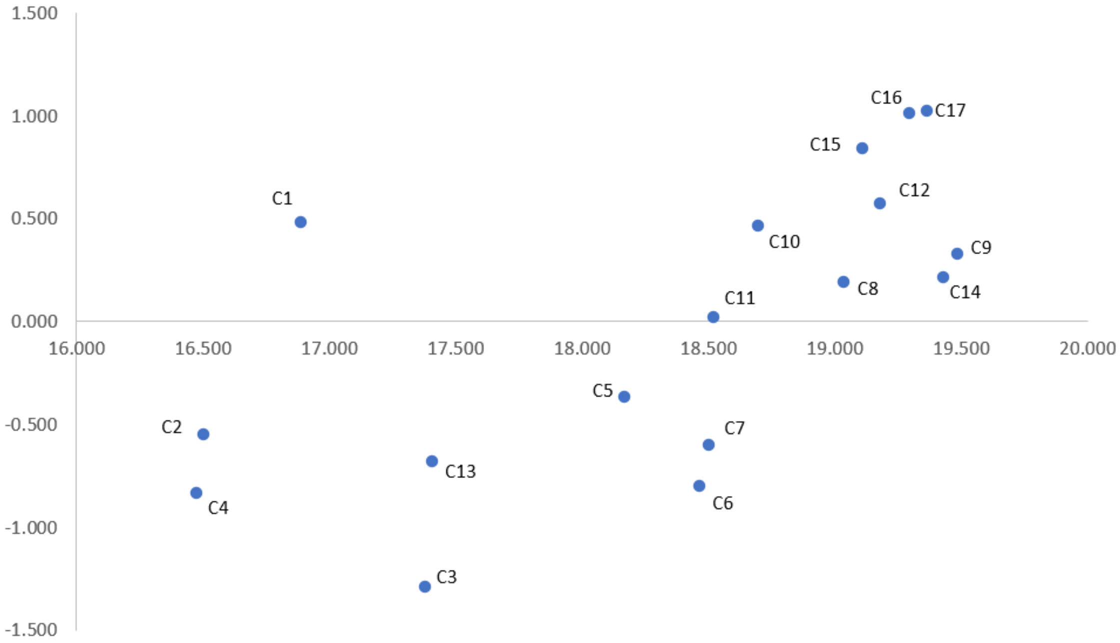


Figure 3. Cause-and-effect diagram for criteria

### 4.3. Analytic network process results

The total interrelationship matrix of the aspects and the criteria and the dependency comparison between aspects and criteria and between criteria and aspects are integrated into an unlimited supermatrix (see Table 7). The weighted supermatrix is computed as the self-response and interdependence in the hierarchical associations (see table 8). Then, the convergent limited weighted supermatrix is formed to display the ranking of the aspect and criteria weights using equation (12) (shown in Table 9). The results show that the causative aspects rank the highest within the results, as digitalization (A8), which belongs to the I4.0 perspective, is the top priority, followed by supplier management (A4), which ranks second. Labor conditions (A2) and social responsibility (A1) rank third and fourth, respectively. The bottom ranks belong to the affected aspects of the structure, including (A3), (A5), (A6), and (A7). Meanwhile, the top-ranking criteria are (C9), (C12), (C14), (C16), and (C17), which are also consistent with the FDEMATEL analysis result. This process addresses the consistency of the FDEMATEL results and confirms the validity of the interdependency of the SSCMP hierarchical structures.

## Table 7. Unlimited supermatrix

| | A1 | A2 | A3 | A4 | A5 | A6 | A7 | A8 | C1 | C2 | C3 | C4 | C5 | C6 | C7 | C8 | C9 | C10 | C11 | C12 | C13 | C14 | C15 | C16 | C17 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A1 | 1.5896 | 1.5423 | 1.6675 | 1.6595 | 1.9163 | 1.6941 | 1.8277 | 1.6445 | 0.4466 | 0.4639 | 0.5230 | 0.4911 | 0.5238 | 0.5639 | 0.5451 | 0.5301 | 0.5415 | 0.5231 | 0.5189 | 0.5262 | 0.5139 | 0.5382 | 0.5270 | 0.5272 | 0.5295 |
| A2 | 1.5686 | 1.5592 | 1.6654 | 1.6586 | 1.8723 | 1.7033 | 1.8308 | 1.6506 | 0.4701 | 0.4807 | 0.5396 | 0.4928 | 0.5485 | 0.5436 | 0.5497 | 0.5339 | 0.5437 | 0.5221 | 0.5288 | 0.5393 | 0.4980 | 0.5512 | 0.5204 | 0.5153 | 0.5225 |
| A3 | 1.5366 | 1.4870 | 1.6577 | 1.6271 | 1.8745 | 1.6785 | 1.7506 | 1.6056 | 0.4313 | 0.4537 | 0.5062 | 0.4556 | 0.4883 | 0.5058 | 0.4869 | 0.4959 | 0.4875 | 0.4618 | 0.4664 | 0.4705 | 0.4601 | 0.4853 | 0.4610 | 0.4640 | 0.4650 |
| A4 | 1.6327 | 1.6041 | 1.7168 | 1.7698 | 1.9886 | 1.7825 | 1.9004 | 1.7036 | 0.4515 | 0.4862 | 0.5291 | 0.5066 | 0.5261 | 0.5559 | 0.5663 | 0.5362 | 0.5446 | 0.5159 | 0.5262 | 0.5287 | 0.5288 | 0.5499 | 0.5329 | 0.5307 | 0.5353 |
| A5 | 1.5813 | 1.5749 | 1.7060 | 1.6854 | 1.9959 | 1.7358 | 1.8694 | 1.6686 | 0.4859 | 0.4771 | 0.4185 | 0.4922 | 0.4168 | 0.5330 | 0.5274 | 0.4297 | 0.5401 | 0.5172 | 0.5132 | 0.5200 | 0.5013 | 0.5414 | 0.4860 | 0.4913 | 0.4928 |
| A6 | 1.6077 | 1.5864 | 1.6967 | 1.7062 | 1.9726 | 1.7867 | 1.8823 | 1.6823 | 0.4029 | 0.4661 | 0.4860 | 0.4532 | 0.4756 | 0.4937 | 0.4875 | 0.4808 | 0.4853 | 0.4676 | 0.4781 | 0.4792 | 0.4687 | 0.4930 | 0.4523 | 0.4506 | 0.4534 |
| A7 | 1.6743 | 1.6507 | 1.7646 | 1.7835 | 2.0611 | 1.8439 | 2.0086 | 1.7723 | 0.4040 | 0.4154 | 0.4746 | 0.4646 | 0.4687 | 0.4820 | 0.4752 | 0.4621 | 0.4926 | 0.4511 | 0.4507 | 0.4532 | 0.4411 | 0.4898 | 0.4626 | 0.4669 | 0.4663 |
| A8 | 1.7260 | 1.6946 | 1.8361 | 1.8510 | 2.1282 | 1.8934 | 2.0308 | 1.8483 | 0.5149 | 0.5204 | 0.5642 | 0.5294 | 0.5565 | 0.5942 | 0.5909 | 0.5957 | 0.5930 | 0.5562 | 0.5737 | 0.5748 | 0.5520 | 0.5951 | 0.5669 | 0.5667 | 0.5691 |
| C1 | 0.4200 | 0.4092 | 0.4205 | 0.3481 | 0.3733 | 0.3304 | 0.3255 | 0.3894 | 0.4859 | 0.4771 | 0.5185 | 0.4922 | 0.5168 | 0.5330 | 0.5274 | 0.5297 | 0.5401 | 0.5172 | 0.5132 | 0.5200 | 0.5013 | 0.5414 | 0.4860 | 0.4913 | 0.4928 |
| C2 | 0.4281 | 0.4038 | 0.4505 | 0.3414 | 0.3552 | 0.3671 | 0.3915 | 0.3122 | 0.4029 | 0.4661 | 0.4860 | 0.4532 | 0.4756 | 0.4937 | 0.4875 | 0.4808 | 0.4853 | 0.4676 | 0.4781 | 0.4792 | 0.4687 | 0.4930 | 0.4523 | 0.4506 | 0.4534 |
| C3 | 0.3459 | 0.3208 | 0.3450 | 0.3271 | 0.4444 | 0.4035 | 0.4192 | 0.3539 | 0.4313 | 0.4537 | 0.5062 | 0.4556 | 0.4883 | 0.5058 | 0.4869 | 0.4959 | 0.4875 | 0.4618 | 0.4664 | 0.4705 | 0.4601 | 0.4853 | 0.4610 | 0.4640 | 0.4650 |
| C4 | 0.4077 | 0.3837 | 0.4031 | 0.3231 | 0.3847 | 0.4208 | 0.4094 | 0.3420 | 0.4040 | 0.4154 | 0.4746 | 0.4646 | 0.4687 | 0.4820 | 0.4752 | 0.4621 | 0.4926 | 0.4511 | 0.4507 | 0.4532 | 0.4411 | 0.4898 | 0.4626 | 0.4669 | 0.4663 |
| C5 | 0.3734 | 0.3456 | 0.3677 | 0.3352 | 0.3880 | 0.3334 | 0.3213 | 0.3942 | 0.4701 | 0.4807 | 0.5396 | 0.4928 | 0.5485 | 0.5436 | 0.5497 | 0.5339 | 0.5437 | 0.5221 | 0.5288 | 0.5393 | 0.4980 | 0.5512 | 0.5204 | 0.5153 | 0.5225 |
| C6 | 0.3814 | 0.3950 | 0.3748 | 0.2709 | 0.3318 | 0.3311 | 0.3519 | 0.2927 | 0.4466 | 0.4639 | 0.5230 | 0.4911 | 0.5238 | 0.5639 | 0.5451 | 0.5301 | 0.5415 | 0.5231 | 0.5189 | 0.5262 | 0.5139 | 0.5382 | 0.5270 | 0.5272 | 0.5295 |
| C7 | 0.3780 | 0.3622 | 0.3788 | 0.3291 | 0.3574 | 0.3196 | 0.3098 | 0.3748 | 0.4515 | 0.4862 | 0.5291 | 0.5066 | 0.5261 | 0.5559 | 0.5663 | 0.5362 | 0.5446 | 0.5159 | 0.5262 | 0.5287 | 0.5288 | 0.5499 | 0.5329 | 0.5307 | 0.5353 |
| C8 | 0.3729 | 0.3627 | 0.3823 | 0.3112 | 0.3087 | 0.3908 | 0.4119 | 0.3352 | 0.5149 | 0.5204 | 0.5642 | 0.5294 | 0.5565 | 0.5942 | 0.5909 | 0.5957 | 0.5930 | 0.5562 | 0.5737 | 0.5748 | 0.5520 | 0.5951 | 0.5669 | 0.5667 | 0.5691 |
| C9 | 0.4466 | 0.4248 | 0.4448 | 0.3831 | 0.3037 | 0.3841 | 0.4028 | 0.3481 | 0.5191 | 0.5385 | 0.5932 | 0.5419 | 0.5889 | 0.6099 | 0.6054 | 0.6002 | 0.6201 | 0.5813 | 0.5893 | 0.5924 | 0.5671 | 0.6082 | 0.5840 | 0.5819 | 0.5856 |
| C10 | 0.3750 | 0.2930 | 0.3621 | 0.3812 | 0.2930 | 0.3621 | 0.3812 | 0.3291 | 0.5131 | 0.5229 | 0.5737 | 0.5244 | 0.5664 | 0.5922 | 0.5865 | 0.5812 | 0.5890 | 0.5767 | 0.5717 | 0.5729 | 0.5526 | 0.5911 | 0.5568 | 0.5564 | 0.5527 |
| C11 | 0.3876 | 0.3092 | 0.3808 | 0.4026 | 0.3092 | 0.3808 | 0.4026 | 0.3397 | 0.4735 | 0.5048 | 0.5509 | 0.5132 | 0.5445 | 0.5738 | 0.5695 | 0.5568 | 0.5648 | 0.5342 | 0.5682 | 0.5572 | 0.5451 | 0.5673 | 0.5448 | 0.5475 | 0.5540 |
| C12 | 0.3865 | 0.3029 | 0.3765 | 0.4013 | 0.3225 | 0.3699 | 0.3355 | 0.3949 | 0.5202 | 0.5371 | 0.5824 | 0.5450 | 0.5786 | 0.6093 | 0.6053 | 0.5996 | 0.6068 | 0.5701 | 0.5876 | 0.6040 | 0.5803 | 0.6065 | 0.5802 | 0.5817 | 0.5823 |
| C13 | 0.3622 | 0.3421 | 0.3570 | 0.4118 | 0.3421 | 0.3892 | 0.3548 | 0.3846 | 0.4420 | 0.4632 | 0.5022 | 0.4439 | 0.4968 | 0.5102 | 0.5101 | 0.5034 | 0.5118 | 0.4922 | 0.4964 | 0.4956 | 0.5106 | 0.5099 | 0.4911 | 0.4918 | 0.4912 |
| C14 | 0.3532 | 0.3291 | 0.3595 | 0.4054 | 0.3381 | 0.3772 | 0.3552 | 0.3795 | 0.5136 | 0.5347 | 0.5862 | 0.5408 | 0.5831 | 0.6056 | 0.5976 | 0.5913 | 0.6024 | 0.5726 | 0.5858 | 0.5876 | 0.5671 | 0.6169 | 0.5771 | 0.5792 | 0.5793 |
| C15 | 0.3979 | 0.4155 | 0.3528 | 0.3818 | 0.2837 | 0.3220 | 0.3008 | 0.3153 | 0.5330 | 0.5389 | 0.5951 | 0.5413 | 0.5950 | 0.6130 | 0.6073 | 0.6011 | 0.6122 | 0.5857 | 0.5912 | 0.5949 | 0.5780 | 0.6150 | 0.6003 | 0.5859 | 0.5872 |
| C16 | 0.3713 | 0.3934 | 0.3300 | 0.3585 | 0.3186 | 0.3696 | 0.3517 | 0.3704 | 0.5379 | 0.5612 | 0.6065 | 0.5562 | 0.6056 | 0.6210 | 0.6217 | 0.6123 | 0.6207 | 0.5931 | 0.6024 | 0.6037 | 0.5903 | 0.6212 | 0.5954 | 0.6096 | 0.5953 |
| C17 | 0.4261 | 0.3914 | 0.4162 | 0.4787 | 0.3376 | 0.3766 | 0.3519 | 0.3771 | 0.5451 | 0.5629 | 0.6051 | 0.5638 | 0.6065 | 0.6267 | 0.6208 | 0.6120 | 0.6242 | 0.5952 | 0.6026 | 0.6046 | 0.5910 | 0.6276 | 0.5968 | 0.5953 | 0.6129 |

## Table 8. Weighted supermatrix

| | A1 | A2 | A3 | A4 | A5 | A6 | A7 | A8 | C1 | C2 | C3 | C4 | C5 | C6 | C7 | C8 | C9 | C10 | C11 | C12 | C13 | C14 | C15 | C16 | C17 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A1 | 0.0615 | 0.0607 | 0.0608 | 0.0604 | 0.0606 | 0.0600 | 0.0605 | 0.0606 | 0.0619 | 0.0616 | 0.0647 | 0.0632 | 0.0654 | 0.0660 | 0.0644 | 0.0652 | 0.0640 | 0.0651 | 0.0640 | 0.0643 | 0.0648 | 0.0634 | 0.0657 | 0.0657 | 0.0656 |
| A2 | 0.0607 | 0.0614 | 0.0607 | 0.0604 | 0.0592 | 0.0603 | 0.0606 | 0.0608 | 0.0652 | 0.0639 | 0.0668 | 0.0634 | 0.0685 | 0.0636 | 0.0650 | 0.0657 | 0.0643 | 0.0650 | 0.0652 | 0.0659 | 0.0628 | 0.0649 | 0.0649 | 0.0642 | 0.0648 |
| A3 | 0.0595 | 0.0585 | 0.0605 | 0.0592 | 0.0593 | 0.0594 | 0.0580 | 0.0591 | 0.0598 | 0.0603 | 0.0626 | 0.0586 | 0.0610 | 0.0592 | 0.0576 | 0.0610 | 0.0576 | 0.0575 | 0.0575 | 0.0575 | 0.0580 | 0.0572 | 0.0575 | 0.0578 | 0.0576 |
| A4 | 0.0632 | 0.0632 | 0.0626 | 0.0644 | 0.0629 | 0.0631 | 0.0629 | 0.0627 | 0.0626 | 0.0646 | 0.0655 | 0.0652 | 0.0657 | 0.0651 | 0.0670 | 0.0660 | 0.0644 | 0.0643 | 0.0649 | 0.0646 | 0.0667 | 0.0648 | 0.0665 | 0.0661 | 0.0664 |
| A5 | 0.0612 | 0.0620 | 0.0622 | 0.0613 | 0.0631 | 0.0615 | 0.0619 | 0.0615 | 0.0673 | 0.0634 | 0.0518 | 0.0633 | 0.0520 | 0.0624 | 0.0624 | 0.0529 | 0.0639 | 0.0644 | 0.0633 | 0.0635 | 0.0632 | 0.0638 | 0.0606 | 0.0612 | 0.0611 |
| A6 | 0.0622 | 0.0625 | 0.0619 | 0.0621 | 0.0624 | 0.0633 | 0.0623 | 0.0620 | 0.0558 | 0.0619 | 0.0601 | 0.0583 | 0.0594 | 0.0578 | 0.0576 | 0.0591 | 0.0574 | 0.0582 | 0.0589 | 0.0586 | 0.0591 | 0.0581 | 0.0564 | 0.0561 | 0.0562 |
| A7 | 0.0648 | 0.0650 | 0.0644 | 0.0649 | 0.0652 | 0.0653 | 0.0665 | 0.0653 | 0.0560 | 0.0552 | 0.0587 | 0.0598 | 0.0585 | 0.0564 | 0.0562 | 0.0568 | 0.0582 | 0.0562 | 0.0556 | 0.0554 | 0.0556 | 0.0577 | 0.0577 | 0.0582 | 0.0578 |
| A8 | 0.0668 | 0.0667 | 0.0670 | 0.0674 | 0.0673 | 0.0671 | 0.0672 | 0.0681 | 0.0714 | 0.0691 | 0.0698 | 0.0681 | 0.0695 | 0.0695 | 0.0699 | 0.0733 | 0.0701 | 0.0693 | 0.0707 | 0.0702 | 0.0696 | 0.0701 | 0.0707 | 0.0706 | 0.0705 |
| C1 | 0.0318 | 0.0331 | 0.0323 | 0.0281 | 0.0322 | 0.0265 | 0.0263 | 0.0323 | 0.0296 | 0.0280 | 0.0278 | 0.0284 | 0.0279 | 0.0277 | 0.0276 | 0.0281 | 0.0282 | 0.0284 | 0.0277 | 0.0279 | 0.0277 | 0.0282 | 0.0266 | 0.0269 | 0.0269 |
| C2 | 0.0324 | 0.0326 | 0.0346 | 0.0276 | 0.0307 | 0.0295 | 0.0317 | 0.0259 | 0.0246 | 0.0273 | 0.0260 | 0.0262 | 0.0257 | 0.0256 | 0.0255 | 0.0255 | 0.0253 | 0.0256 | 0.0258 | 0.0257 | 0.0259 | 0.0257 | 0.0248 | 0.0246 | 0.0247 |
| C3 | 0.0262 | 0.0259 | 0.0265 | 0.0264 | 0.0384 | 0.0324 | 0.0339 | 0.0293 | 0.0263 | 0.0266 | 0.0271 | 0.0263 | 0.0263 | 0.0263 | 0.0255 | 0.0263 | 0.0254 | 0.0253 | 0.0252 | 0.0253 | 0.0254 | 0.0253 | 0.0252 | 0.0254 | 0.0253 |
| C4 | 0.0308 | 0.0310 | 0.0310 | 0.0261 | 0.0332 | 0.0338 | 0.0331 | 0.0283 | 0.0246 | 0.0244 | 0.0254 | 0.0268 | 0.0253 | 0.0250 | 0.0249 | 0.0245 | 0.0257 | 0.0247 | 0.0244 | 0.0244 | 0.0244 | 0.0255 | 0.0253 | 0.0255 | 0.0254 |
| C5 | 0.0282 | 0.0279 | 0.0283 | 0.0271 | 0.0335 | 0.0268 | 0.0260 | 0.0327 | 0.0286 | 0.0282 | 0.0289 | 0.0285 | 0.0296 | 0.0282 | 0.0288 | 0.0283 | 0.0284 | 0.0286 | 0.0286 | 0.0290 | 0.0275 | 0.0287 | 0.0285 | 0.0282 | 0.0285 |
| C6 | 0.0288 | 0.0319 | 0.0288 | 0.0219 | 0.0286 | 0.0266 | 0.0285 | 0.0243 | 0.0272 | 0.0272 | 0.0280 | 0.0284 | 0.0283 | 0.0293 | 0.0285 | 0.0281 | 0.0283 | 0.0287 | 0.0280 | 0.0283 | 0.0284 | 0.0280 | 0.0288 | 0.0288 | 0.0289 |
| C7 | 0.0286 | 0.0293 | 0.0291 | 0.0266 | 0.0309 | 0.0257 | 0.0251 | 0.0311 | 0.0275 | 0.0285 | 0.0283 | 0.0293 | 0.0284 | 0.0289 | 0.0296 | 0.0285 | 0.0284 | 0.0283 | 0.0284 | 0.0284 | 0.0292 | 0.0286 | 0.0292 | 0.0290 | 0.0292 |
| C8 | 0.0282 | 0.0293 | 0.0294 | 0.0251 | 0.0266 | 0.0314 | 0.0333 | 0.0278 | 0.0314 | 0.0305 | 0.0302 | 0.0306 | 0.0300 | 0.0308 | 0.0309 | 0.0316 | 0.0310 | 0.0305 | 0.0310 | 0.0309 | 0.0305 | 0.0310 | 0.0310 | 0.0310 | 0.0310 |
| C9 | 0.0338 | 0.0343 | 0.0342 | 0.0309 | 0.0262 | 0.0308 | 0.0326 | 0.0289 | 0.0316 | 0.0316 | 0.0318 | 0.0313 | 0.0318 | 0.0317 | 0.0317 | 0.0319 | 0.0324 | 0.0319 | 0.0319 | 0.0318 | 0.0313 | 0.0317 | 0.0320 | 0.0318 | 0.0319 |
| C10 | 0.0284 | 0.0237 | 0.0278 | 0.0308 | 0.0253 | 0.0291 | 0.0309 | 0.0273 | 0.0313 | 0.0307 | 0.0307 | 0.0303 | 0.0306 | 0.0307 | 0.0307 | 0.0308 | 0.0307 | 0.0316 | 0.0309 | 0.0308 | 0.0305 | 0.0308 | 0.0305 | 0.0304 | 0.0301 |
| C11 | 0.0293 | 0.0250 | 0.0293 | 0.0325 | 0.0267 | 0.0306 | 0.0326 | 0.0282 | 0.0289 | 0.0296 | 0.0295 | 0.0296 | 0.0294 | 0.0298 | 0.0298 | 0.0295 | 0.0295 | 0.0293 | 0.0307 | 0.0299 | 0.0301 | 0.0295 | 0.0298 | 0.0299 | 0.0302 |
| C12 | 0.0292 | 0.0245 | 0.0290 | 0.0324 | 0.0278 | 0.0297 | 0.0272 | 0.0327 | 0.0317 | 0.0315 | 0.0312 | 0.0315 | 0.0312 | 0.0316 | 0.0317 | 0.0318 | 0.0317 | 0.0313 | 0.0318 | 0.0325 | 0.0321 | 0.0316 | 0.0318 | 0.0318 | 0.0317 |
| C13 | 0.0274 | 0.0277 | 0.0275 | 0.0333 | 0.0295 | 0.0312 | 0.0287 | 0.0319 | 0.0269 | 0.0272 | 0.0269 | 0.0256 | 0.0268 | 0.0265 | 0.0267 | 0.0267 | 0.0267 | 0.0270 | 0.0268 | 0.0266 | 0.0282 | 0.0265 | 0.0269 | 0.0269 | 0.0268 |
| C14 | 0.0267 | 0.0266 | 0.0276 | 0.0327 | 0.0292 | 0.0303 | 0.0288 | 0.0315 | 0.0313 | 0.0314 | 0.0314 | 0.0312 | 0.0315 | 0.0314 | 0.0313 | 0.0314 | 0.0314 | 0.0314 | 0.0317 | 0.0316 | 0.0313 | 0.0321 | 0.0316 | 0.0317 | 0.0316 |
| C15 | 0.0301 | 0.0336 | 0.0271 | 0.0308 | 0.0245 | 0.0259 | 0.0244 | 0.0261 | 0.0325 | 0.0316 | 0.0319 | 0.0313 | 0.0321 | 0.0318 | 0.0318 | 0.0319 | 0.0320 | 0.0321 | 0.0320 | 0.0320 | 0.0319 | 0.0320 | 0.0329 | 0.0320 | 0.0320 |
| C16 | 0.0281 | 0.0318 | 0.0254 | 0.0290 | 0.0275 | 0.0297 | 0.0285 | 0.0307 | 0.0328 | 0.0329 | 0.0325 | 0.0321 | 0.0327 | 0.0322 | 0.0325 | 0.0325 | 0.0324 | 0.0325 | 0.0326 | 0.0324 | 0.0326 | 0.0323 | 0.0326 | 0.0333 | 0.0324 |
| C17 | 0.0322 | 0.0316 | 0.0320 | 0.0387 | 0.0291 | 0.0302 | 0.0285 | 0.0312 | 0.0332 | 0.0330 | 0.0324 | 0.0326 | 0.0327 | 0.0325 | 0.0325 | 0.0325 | 0.0326 | 0.0326 | 0.0326 | 0.0325 | 0.0327 | 0.0327 | 0.0327 | 0.0326 | 0.0334 |

## Table 9. Limited weighted supermatrix

| | A1 | A2 | A3 | A4 | A5 | A6 | A7 | A8 | C1 | C2 | C3 | C4 | C5 | C6 | C7 | C8 | C9 | C10 | C11 | C12 | C13 | C14 | C15 | C16 | C17 | Rank |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A1 | 0.0625 | 0.0625 | 0.0625 | 0.0625 | 0.0625 | 0.0625 | 0.0625 | 0.0625 | 0.0625 | 0.0625 | 0.0625 | 0.0625 | 0.0625 | 0.0625 | 0.0625 | 0.0625 | 0.0625 | 0.0625 | 0.0625 | 0.0625 | 0.0625 | 0.0625 | 0.0625 | 0.0625 | 0.0625 | 4 |
| A2 | 0.0627 | 0.0627 | 0.0627 | 0.0627 | 0.0627 | 0.0627 | 0.0627 | 0.0627 | 0.0627 | 0.0627 | 0.0627 | 0.0627 | 0.0627 | 0.0627 | 0.0627 | 0.0627 | 0.0627 | 0.0627 | 0.0627 | 0.0627 | 0.0627 | 0.0627 | 0.0627 | 0.0627 | 0.0627 | 3 |
| A3 | 0.0589 | 0.0589 | 0.0589 | 0.0589 | 0.0589 | 0.0589 | 0.0589 | 0.0589 | 0.0589 | 0.0589 | 0.0589 | 0.0589 | 0.0589 | 0.0589 | 0.0589 | 0.0589 | 0.0589 | 0.0589 | 0.0589 | 0.0589 | 0.0589 | 0.0589 | 0.0589 | 0.0589 | 0.0589 | 8 |
| A4 | 0.0642 | 0.0642 | 0.0642 | 0.0642 | 0.0642 | 0.0642 | 0.0642 | 0.0642 | 0.0642 | 0.0642 | 0.0642 | 0.0642 | 0.0642 | 0.0642 | 0.0642 | 0.0642 | 0.0642 | 0.0642 | 0.0642 | 0.0642 | 0.0642 | 0.0642 | 0.0642 | 0.0642 | 0.0642 | 2 |
| A5 | 0.0615 | 0.0615 | 0.0615 | 0.0615 | 0.0615 | 0.0615 | 0.0615 | 0.0615 | 0.0615 | 0.0615 | 0.0615 | 0.0615 | 0.0615 | 0.0615 | 0.0615 | 0.0615 | 0.0615 | 0.0615 | 0.0615 | 0.0615 | 0.0615 | 0.0615 | 0.0615 | 0.0615 | 0.0615 | 5 |
| A6 | 0.0602 | 0.0602 | 0.0602 | 0.0602 | 0.0602 | 0.0602 | 0.0602 | 0.0602 | 0.0602 | 0.0602 | 0.0602 | 0.0602 | 0.0602 | 0.0602 | 0.0602 | 0.0602 | 0.0602 | 0.0602 | 0.0602 | 0.0602 | 0.0602 | 0.0602 | 0.0602 | 0.0602 | 0.0602 | 7 |
| A7 | 0.0611 | 0.0611 | 0.0611 | 0.0611 | 0.0611 | 0.0611 | 0.0611 | 0.0611 | 0.0611 | 0.0611 | 0.0611 | 0.0611 | 0.0611 | 0.0611 | 0.0611 | 0.0611 | 0.0611 | 0.0611 | 0.0611 | 0.0611 | 0.0611 | 0.0611 | 0.0611 | 0.0611 | 0.0611 | 6 |
| A8 | 0.0687 | 0.0687 | 0.0687 | 0.0687 | 0.0687 | 0.0687 | 0.0687 | 0.0687 | 0.0687 | 0.0687 | 0.0687 | 0.0687 | 0.0687 | 0.0687 | 0.0687 | 0.0687 | 0.0687 | 0.0687 | 0.0687 | 0.0687 | 0.0687 | 0.0687 | 0.0687 | 0.0687 | 0.0687 | 1 |
| C1 | 0.0291 | 0.0291 | 0.0291 | 0.0291 | 0.0291 | 0.0291 | 0.0291 | 0.0291 | 0.0291 | 0.0291 | 0.0291 | 0.0291 | 0.0291 | 0.0291 | 0.0291 | 0.0291 | 0.0291 | 0.0291 | 0.0291 | 0.0291 | 0.0291 | 0.0291 | 0.0291 | 0.0291 | 0.0291 | 10 |
| C2 | 0.0280 | 0.0280 | 0.0280 | 0.0280 | 0.0280 | 0.0280 | 0.0280 | 0.0280 | 0.0280 | 0.0280 | 0.0280 | 0.0280 | 0.0280 | 0.0280 | 0.0280 | 0.0280 | 0.0280 | 0.0280 | 0.0280 | 0.0280 | 0.0280 | 0.0280 | 0.0280 | 0.0280 | 0.0280 | 14 |
| C3 | 0.0278 | 0.0278 | 0.0278 | 0.0278 | 0.0278 | 0.0278 | 0.0278 | 0.0278 | 0.0278 | 0.0278 | 0.0278 | 0.0278 | 0.0278 | 0.0278 | 0.0278 | 0.0278 | 0.0278 | 0.0278 | 0.0278 | 0.0278 | 0.0278 | 0.0278 | 0.0278 | 0.0278 | 0.0278 | 17 |
| C4 | 0.0280 | 0.0280 | 0.0280 | 0.0280 | 0.0280 | 0.0280 | 0.0280 | 0.0280 | 0.0280 | 0.0280 | 0.0280 | 0.0280 | 0.0280 | 0.0280 | 0.0280 | 0.0280 | 0.0280 | 0.0280 | 0.0280 | 0.0280 | 0.0280 | 0.0280 | 0.0280 | 0.0280 | 0.0280 | 15 |
| C5 | 0.0287 | 0.0287 | 0.0287 | 0.0287 | 0.0287 | 0.0287 | 0.0287 | 0.0287 | 0.0287 | 0.0287 | 0.0287 | 0.0287 | 0.0287 | 0.0287 | 0.0287 | 0.0287 | 0.0287 | 0.0287 | 0.0287 | 0.0287 | 0.0287 | 0.0287 | 0.0287 | 0.0287 | 0.0287 | 11 |
| C6 | 0.0278 | 0.0278 | 0.0278 | 0.0278 | 0.0278 | 0.0278 | 0.0278 | 0.0278 | 0.0278 | 0.0278 | 0.0278 | 0.0278 | 0.0278 | 0.0278 | 0.0278 | 0.0278 | 0.0278 | 0.0278 | 0.0278 | 0.0278 | 0.0278 | 0.0278 | 0.0278 | 0.0278 | 0.0278 | 16 |
| C7 | 0.0285 | 0.0285 | 0.0285 | 0.0285 | 0.0285 | 0.0285 | 0.0285 | 0.0285 | 0.0285 | 0.0285 | 0.0285 | 0.0285 | 0.0285 | 0.0285 | 0.0285 | 0.0285 | 0.0285 | 0.0285 | 0.0285 | 0.0285 | 0.0285 | 0.0285 | 0.0285 | 0.0285 | 0.0285 | 12 |
| C8 | 0.0298 | 0.0298 | 0.0298 | 0.0298 | 0.0298 | 0.0298 | 0.0298 | 0.0298 | 0.0298 | 0.0298 | 0.0298 | 0.0298 | 0.0298 | 0.0298 | 0.0298 | 0.0298 | 0.0298 | 0.0298 | 0.0298 | 0.0298 | 0.0298 | 0.0298 | 0.0298 | 0.0298 | 0.0298 | 7 |
| C9 | 0.0316 | 0.0316 | 0.0316 | 0.0316 | 0.0316 | 0.0316 | 0.0316 | 0.0316 | 0.0316 | 0.0316 | 0.0316 | 0.0316 | 0.0316 | 0.0316 | 0.0316 | 0.0316 | 0.0316 | 0.0316 | 0.0316 | 0.0316 | 0.0316 | 0.0316 | 0.0316 | 0.0316 | 0.0316 | 2 |
| C10 | 0.0293 | 0.0293 | 0.0293 | 0.0293 | 0.0293 | 0.0293 | 0.0293 | 0.0293 | 0.0293 | 0.0293 | 0.0293 | 0.0293 | 0.0293 | 0.0293 | 0.0293 | 0.0293 | 0.0293 | 0.0293 | 0.0293 | 0.0293 | 0.0293 | 0.0293 | 0.0293 | 0.0293 | 0.0293 | 9 |
| C11 | 0.0295 | 0.0295 | 0.0295 | 0.0295 | 0.0295 | 0.0295 | 0.0295 | 0.0295 | 0.0295 | 0.0295 | 0.0295 | 0.0295 | 0.0295 | 0.0295 | 0.0295 | 0.0295 | 0.0295 | 0.0295 | 0.0295 | 0.0295 | 0.0295 | 0.0295 | 0.0295 | 0.0295 | 0.0295 | 8 |
| C12 | 0.0304 | 0.0304 | 0.0304 | 0.0304 | 0.0304 | 0.0304 | 0.0304 | 0.0304 | 0.0304 | 0.0304 | 0.0304 | 0.0304 | 0.0304 | 0.0304 | 0.0304 | 0.0304 | 0.0304 | 0.0304 | 0.0304 | 0.0304 | 0.0304 | 0.0304 | 0.0304 | 0.0304 | 0.0304 | 4 |
| C13 | 0.0283 | 0.0283 | 0.0283 | 0.0283 | 0.0283 | 0.0283 | 0.0283 | 0.0283 | 0.0283 | 0.0283 | 0.0283 | 0.0283 | 0.0283 | 0.0283 | 0.0283 | 0.0283 | 0.0283 | 0.0283 | 0.0283 | 0.0283 | 0.0283 | 0.0283 | 0.0283 | 0.0283 | 0.0283 | 13 |
| C14 | 0.0304 | 0.0304 | 0.0304 | 0.0304 | 0.0304 | 0.0304 | 0.0304 | 0.0304 | 0.0304 | 0.0304 | 0.0304 | 0.0304 | 0.0304 | 0.0304 | 0.0304 | 0.0304 | 0.0304 | 0.0304 | 0.0304 | 0.0304 | 0.0304 | 0.0304 | 0.0304 | 0.0304 | 0.0304 | 5 |
| C15 | 0.0299 | 0.0299 | 0.0299 | 0.0299 | 0.0299 | 0.0299 | 0.0299 | 0.0299 | 0.0299 | 0.0299 | 0.0299 | 0.0299 | 0.0299 | 0.0299 | 0.0299 | 0.0299 | 0.0299 | 0.0299 | 0.0299 | 0.0299 | 0.0299 | 0.0299 | 0.0299 | 0.0299 | 0.0299 | 6 |
| C16 | 0.0307 | 0.0307 | 0.0307 | 0.0307 | 0.0307 | 0.0307 | 0.0307 | 0.0307 | 0.0307 | 0.0307 | 0.0307 | 0.0307 | 0.0307 | 0.0307 | 0.0307 | 0.0307 | 0.0307 | 0.0307 | 0.0307 | 0.0307 | 0.0307 | 0.0307 | 0.0307 | 0.0307 | 0.0307 | 3 |
| C17 | 0.0322 | 0.0322 | 0.0322 | 0.0322 | 0.0322 | 0.0322 | 0.0322 | 0.0322 | 0.0322 | 0.0322 | 0.0322 | 0.0322 | 0.0322 | 0.0322 | 0.0322 | 0.0322 | 0.0322 | 0.0322 | 0.0322 | 0.0322 | 0.0322 | 0.0322 | 0.0322 | 0.0322 | 0.0322 | 1 |

## 5. Implications

In this section, the theoretical and managerial implications of SSCMPs are discussed.

### 5.1. Theoretical implications

Theoretical insights into the causative features of SSCMPs are provided in this study. The findings show that digitalization, supplier management, social responsibility, and labor conditions are the most important aspects that must be prioritized to improve SSCMPs.

Digitalization in I4.0 is the most critical causal aspect in the SSCMP cause-effect model. This aspect strongly influences supply chain finance accessibility and government policy and has a moderating influence on economic performance. This study confirms the importance of digitalization, as it supports the level of interaction across supply chains and between stakeholders and then drives sustainability (Esmaeilian et al., 2020). This aspect complies with government policy while also giving supply chain stakeholders better access to financial sources. Digitalization offers advantages to SSCMPs to better synchronize interaction, thus resulting in better integration throughout the process. In particular, SSCMPs complicate the processes and information from different stages, and actors need to be integrated and coordinated efficiently. This aspect ensures the ability to manage and process information to gain valuable insights. Moreover, is contributes to sustainability in SSCMPs. Valuable information from digitalization and enhanced integration throughout the SSCMP process results in reduced resource usage and improved product quality.

From the environmental perspective, supplier management refers to the evaluation and integration of suppliers. This study shows that this aspect moderately influences government policy and supply chain finance accessibility and confirms that supplier management improves the SSCMP process (Watteyn et al., 2022; Zhu et al., 2022). This aspect is important for closely maintaining SSCMP processes since firms need to comply with environmental and social standards, as do their suppliers, by evaluating which suppliers adhere to sustainability standards and integrating available information and knowledge. Through integration, agricultural firms and their suppliers can enhance their transparency and efficiency, which improves sustainable performance. Therefore, supplier management offers beneficial measures to SSCMPs, makes sustainable initiatives more feasible, and improves economic and socioenvironmental performance (Luthra et al., 2017; Seuring et al., 2019).

From the social perspective, social responsibility is one of the causal aspects and influences aspects from the economic and environmental perspectives, and it has been confirmed that this aspect is beneficial for SSCMP performance. In particular, SSCMP attempt to include social responsibility have the potential to change the behavior and attitudes of society. The willingness to engage in more eco-friendly activities will be reflected in attitudes, thus affecting the carbon sink throughout the process (Jiang et al., 2022). Moreover, social sustainability offers great potential to reduce unemployment and underemployment, especially in developing countries. The increasing population and trend of consuming coffee will increase demand, which in turn will generate job opportunities. This aspect can set standards and practices for social justice in agricultural sustainability, encouraging firms to connect to their workers and farmers. Therefore, social sustainability can balance environmental, social, and economic performance, which promote the SSCMP process.

Although labor conditions have weak effects only on policy government policy and supply chain finance accessibility, they are also one of the causes of the SSCMP structure. Labor conditions are a vital aspect of SSCMPs and provide basic attributes of sustainable development (Bubicz et al., 2019). Health and safety measures, sufficient income, and good working conditions are the validated combination of labor conditions in this study. Labor is a valuable asset and can become key to the long-term sustainability development of a firm. However, common harvesting processes include highly dangerous risks to the health and safety of workers due to the widespread use of pesticides, which are also the main cause of pollution problems that need to be addressed through this aspect. The failure to establish good labor conditions can also lessen workers' commitment to carry out sustainable practices. Therefore, this aspect offers benefits to SSCMPs, such as enhancing productivity and efficiency, which results in economic and socioenvironmental performance.

Supply chain finance accessibility is classified in the effect group; however, this aspect has a strong influence on government policy. The economic dimension, which includes the supply chain finance accessibility aspect in this study, is still a critical factor in sustainable development. Supply chain finance accessibility has an important role in enabling SSCMPs, as this aspect aims to improve efficiency and lower transaction costs, having the potential to improve economic performance not only for purchasers but also for providers, in turn impacting their fiscal costs and operational choices by providing access to credit and liquidity to both parties (van Bergen et al., 2019). Meanwhile, a lack of sufficient credit leads to lower productivity and an increased likelihood of using cheap and hazardous materials that can result in low sustainability. Thus, this aspect offers an advantage to SSCMPs for better economic performance, which then affects sustainable development.

## 5.2. Managerial implications

This study contributes to practice by giving managers insight into the SSCMP causative criteria. The findings show that in this study, supplier integration, revenue/profit, collaborative effort, digital platform, and real-time information have the highest importance, which means that these criteria must be prioritized to improve SSCMPs.

Coffee processing firms and their suppliers should collaborate to apply various methods, such as quality management, to limit the negative environmental impact of goods and services through a supplier integration network. Supplier integration has a large impact on how inputs and equipment such as seeds, fertilizers, tractors, and irrigation systems are made, distributed, and sold in SSCMPs. Supplier integration connects participants from all parts of the value chain, including government agencies, multinational manufacturers, and exporters. In other words, the diffusion of processes in pricing, distribution networks, marketing, and end-user feedback are all in the hands of the suppliers. Through their activities, capacities, and networks, the objective here is to give information, produce and distribute knowledge, mobilize funding, and participate in agricultural innovations. As a result, managers should establish supplier integration between firms and their suppliers to improve sustainability performance because supplier integration is important not only for meeting enterprise requirements but also for ensuring SSCMPs.

Revenue/profit and the overall sales value of the product minus the expenses of variable inputs and hired labor equals net income from coffee production and processing. Having such a high revenue/profit ratio can help a firm and coffee farmer realize SSCMPs. The coffee industry's revenue/profit efficiency has important consequences for the types of development strategies. Understanding revenue/profit efficiency and its relationship from farm-level characteristics to end users substantially assists policymakers in developing SSCMP maize efficiency-enhancing measures. Managers should improve their economic performance to raise revenue/profit so that firms may invest more in research and development to increase SSCMPs in the coffee sector. This type of investment can be employed for I4.0 or technology so that investors can examine firms and spend more on coffee production. This type of investment can be extremely beneficial for the coffee business in terms of increasing production and processing efficiency.

Ultimately, firms' collaborative efforts, whether via cooperative supply chain scheduling and implementation or win–win arrangements, still produce good results. Collaborative effort and collaboration across firms can help suppliers boost their order volume and better follow the growth patterns of customers. Managers should examine how diverse schemes (such as asset-based loans or shared financing determinations) might help increase the entire value of a coffee production supply chain, allowing suppliers to obtain higher order volumes and buyers to meet increased demand. The more evolved the stream of supply chain collaboration is, the higher the possibility of expanding SSCMPs. In addition, joint efforts between businesses have the potential to boost profits not only for buyers but also for sellers.

Digitalization integration is the integration of the technical adaptation of analog data into a digital formula. A digital platform helps coffee production extend the functionality of technology and enhance the mediation between service providers and service recipients in agriculture that uses digital equipment. Managers should use a digital platform to assemble a spectrum of activities and encompass digitalization. A new digital platform also causes a significant shift in the old value proposition, business model, value generation, and value detention components to assist SSCMPs in anticipating market developments and taking a long-term view of a firm's future directions in light of new technologies. Advancements in digital platforms are changing the norms of business, especially in regard to disruptive technologies, which compel established businesses to significantly change their present business models. To bridge the performance gap, established businesses must increasingly develop new digital network business models.

The cyber-physical system, Internet of Things, big data, and other I4.0-related real-time information technologies have the ability to keep linked and offer important information during the coffee goods life cycle. Agricultural real-time data can help SSCMPs to improve the precise response to operational uncertainty and real-time data updates. Real-time information uses developing technologies to accomplish and organize farming activities, and it creates a new culture of growth that inspires coffee farmers to modernize their production strategies and practices for a more efficient supply chain. Furthermore, the definition of real-time agricultural information is linked to four key requirements: increased productivity, proper resource allocation, reduced food waste, and climate change adaptation. Real-time agricultural data also reveal the coffee industry's possible environmental, ethical, and social impacts. Managers should employ real-time information technology to improve the relationship between what happens on the farm and what decisions management should make, and this is also beneficial for decision-makers on the farm, allowing them to complete tasks faster.

## 6. Conclusion

Global population growth, rising coffee consumption and the significant demand placed on the coffee supply have led to increasing concerns about sustainability. However, despite the wide trade and high level of consumption, coffee industry SSCMPs receive less attention and remain scientifically unexplored. Furthermore, the effects of I4.0 have been discussed in the literature; however, little attention has been paid to how this digitalization integration can handle the transition of the ASC to sustainability. This study aims to propose a valid hierarchical structure of SSCMPs for I4.0 and to indicate the important attributes for Indonesia's coffee ASC practices to realize sustainability. This study employs the FDM to validate and remove excessive attributes. The FDEMATEL is implemented to investigate the cause-and-effect group of those attributes and to allocate their structural interrelationship to achieve SSCMPs. The ANP is adopted to determine the consistency of the interdependent relationships and the hierarchical structure of SSCMPs for I4.0.

This study identified 17 valid indicators that are set to eight aspects capable of improving SSCMPs: social responsibility, labor conditions, environmental management systems, supplier management, government policy, economic performance, supply chain finance accessibility, and digitalization integration. The results show that digitalization integration leads to social responsibility, labor conditions, and supply chain finance accessibility as causal aspects. The most important criteria are supplier integration, revenue/profit, collaborative effort, digital platforms, and real-time information, as they can help to enhance SSCMP performance.

This study enriches the literature on SSCMPs and managerial implications for the coffee industry by providing insights into the integrated model and causal attributes for better sustainability performance. The results indicate that (1) I4.0, especially digitalization integration, strongly leads SSCMPs through supply chain finance accessibility and government policy, as well as economic performance. (2) Supplier integration is important for closely maintaining SSCMPs throughout industry processes because firms need to ensure not only that they comply with environmental and social standards but also that their suppliers do so by evaluating which suppliers adhere to sustainability standards and integrate available information and knowledge. (3) Social responsibility contributes to setting standards and practices for social justice in agricultural sustainability, including encouraging firms to connect to their workers and farmers. (4) Labor conditions offer benefits to SSCMPs, such as enhancing productivity and efficiency, which results in economic and socioenvironmental performance. In addition, the managerial implications are helpful for the Indonesian coffee sector. This study contributes to coffee SSCMPs in Indonesia by providing managerial insights based on the causal criteria. Firms must recognize the importance of these criteria in helping them achieve SSCMPs. Systematic and comprehensive efficiency leads to large benefits and a positive influence on firms, consumers, and investors.

This study has certain limitations. First, because this study primarily focuses on the TBL and I4.0 digitalization as an aspect of constructing a framework, other key components of SSCMPs may be ignored. Future research could investigate additional aspects to provide a more comprehensive view. Second, the focus of the study is limited to the Indonesian coffee sector. To extend the SSCMP model, future studies could expand to different geographical locations and industries to obtain more generalized results. Third, because the sample consisted of 30 expert respondents, the results may be severely impacted by objective evaluations. To minimize such issues, future studies should seek to increase the number of participants to prevent these problems.

## Data Availability Statement

The data that support the findings of this study are available from the corresponding author, Kuo-Jui Wu (garykjwu@gmail.com), upon reasonable request.

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## Appendix A. Proposed measures

| Perspectives | Aspects | Criteria | Description | References |
|---|---|---|---|---|
| Social perspectives | Social responsibility | Fair trade | Fair-trade coffee movement is the most recognised form of ethical consumption, and is focused on empowering coffee farmers while positively impact the living conditions | Nematollahi & Tajbakhsh, 2020; Akenroye et al., 2021; Jiang et al., 2022 |
| | | Job generation | One of the most important key indicators for social assessment is the employment generated | |
| | | Supporting smallholder coffee farmers | Sustainable agriculture can help farmers to cope with challenges imposed on them | |
| | | Product quality | The safety of consumers is also an important part of social sustainability. | |
| | Labor condition/ farmer condition | Health and safety measures | Farmers' health is often endangered by the many chemicals used during growing and weeding limited access to basic or affordable healthcare services | Bubicz et al., 2019; Akenroye et al., 2021 |
| | | Sufficient income | Smallholders have a low level of education and literacy skills and therefore might not recognize the appropriate incentive systems to use to motivate laborer in making an ethically conscious decision, because average coffee wages are far below average country wages and lower than the averages wages paid in the agricultural sector | |
| | | Good working condition | Good working condition such as providing first aid kits with personal protective equipment, could prevent injuries, disease, and irritation | |
| Environmental perspective | Environmental management system | Improving energy efficiency / energy consumption | Conventional methods in agriculture industry typically depend on energy-intensive inputs which should be deduced and reduce the impact on the environment | Akenroye et al., 2021; Luthra et al., 2017 |
| | | Preventing pollution | Air contamination in terms of co2 emissions through the supply chain facilities, including suppliers and emissions generated by transport operations. | |
| | | Soil sustainability | Intensive use of cheap inorganic inputs have gradually resulted in soil degradation | |
| | | Water use and contamination | There is increasing importance of agricultural commodity trade to efficiently use of water and the irrigation water to preserve water quality | |
| | | Waste management | Integrated waste management hierarchy ascertains agricultural recycling of organic wastes to be more sustainable and eco-friendly approach than traditional methods of waste disposal and energy recovery | |
| | Supplier management | Supplier selection | Supplier selection based on sustainability criteria represents a strategic decision and is regarded as a crucial concern in the implementation of sustainable agriculture | Luthra et al., 2017; Seuring et al., 2019; Watteyn et al., 2022; Nematollahi and Tajbakhsh; 2020 |
| | | Supplier integration | Firms and suppliers would work together to implement various practices, such as quality management to reduce the adverse impact of goods or services on the environment. | |
| | Government policy | Land use policy | Land use policy seeks the promotion of sustainable farming practices to cope with land degradation and environmental problems caused by the intensification of agricultural production | Liu et al., 2021; Jiang et al., 2022; Akenroye et al.. 2021 |
| | | Trade policy | Trade policy could be used as an instrument to improve environmental quality in the long-run even though in the short-run, it deteriorates the environment. | |
| | | Climate policy | Climate change and sectoral policy objectives, indicate that mainstreaming is critical to support sustainability, highlight the distinct nature of timing of mitigation and adaptation, and the lack of linkages between the two climate change objectives in certain sectors | |
| | | Food safety or standard | Food safety is the most important factors that determine consumer acceptance of food products | |

| | | | | |
|---|---|---|---|---|
| Economic perspective | Economic performance | Investment recovery | Investment recovery refers to the process of recovering the value of unused or end of life assets through effective reuse or surplus sales. | Esfahbodi et al., 2017<br>Jezeer et al., 2018 |
| | | Labor productivity | Net income from coffee production per person-day of family labor in coffee production, processing and marketing, and expressed per person-day | |
| | | Revenue/profit | Income is net income in from coffee production and processing, and derived as total sales value of coffee minus the costs of variable inputs and hired labor | |
| | Supply chain finance assessability | Access to capital | In developing countries access to capital for farmers might even be nonexistent | Esfahbodi et al., 2017; van Bergen et al., 2019 |
| | | Funding cost | Capital costs for agricultural businesses differ widely. However, the interest rate spread between SMEs and large firms has increased | |
| | | Collaborative efforts | Collaborative efforts of companies, either through joint supply chain planning and execution or through win-win agreements, ultimately yield higher profits | |
| | | Credit constraints | The structure of capital constraints in the chain may influence the manufacturer's choice. | |
| Industry 4.0 perspective | Digitalization integrity | Information and communication technology | These activities are to exchange information, knowledge, technology in agricultural productions. | Esmaeilian et al., 2020; Amaral & Peças, 2021; Benyam et al., 2021; Amaral & Peças, 2021 |
| | | Machine learning | The knowledge base of the learning system decides the use of an appropriate ml algorithm, considering the decisions to be taken by the organization. | |
| | | Blockchain technology | Blockchain technology can play a key role by eliminating the concept of trust among the entities and providing a platform to share information such as products' origin, cost and financial issues throughout the chain | |
| | | Digital platform | A digital artefact comprising an extensible codebase to which complementary third-party modules can be added to extend functionality and to enhance mediation between service providers and service recipients in agriculture that uses digital equipment | |
| | | Real time information | Technology related to I4.0, like the cyber-physical system, internet-of-things, bigdata, etc. Have the capabilities to stay connected and provide critical information throughout the life cycle of agricultural products | |
| | Agricultural production technology | Agricultural automation | Agricultural automation will play a role in improving agricultural productivity, quality and economic growth also promote the development of agriculture towards improved the yield, efficiency, quality, ecology, safety and intelligence | Mao et al., 2021; Benyam et al., 2021; Ghobakhloo, 2020 |
| | | Robotic technology | By imitating human skills or expanding them, robots overcome critical human constraints; including an ability to operate in difficult agricultural environments (e.g., Outdoors, hazardous conditions), help mitigate labor shortages, provide high potential for increased agricultural productivity | |
| | | Mobile device | Devices such as mobile phones, computers, satellites, and sensors to solve challenges in agriculture. | |

Appendix B. Respondents' demographic

| Expert | Position | Education levels | Years of experience | Organization type (academia/ practice |
|---|---|---|---|---|
| 1 | Café Owner | Bachelor | 5 | Practitioner |
| 2 | Café Owner | Bachelor | 4 | Practitioner |
| 3 | Café Owner | Bachelor | 4 | Practitioner |
| 4 | Café Owner | Bachelor | 9 | Practitioner |
| 5 | Café Owner | Master | 8 | Practitioner |
| 6 | Coffee processing company manager | Master | 10 | Practitioner |
| 7 | Coffee processing company manager | Master | 14 | Practitioner |
| 8 | Coffee processing company manager | Bachelor | 8 | Practitioner |
| 9 | Coffee processing company manager | Master | 9 | Practitioner |
| 10 | Coffee Barista | Master | 5 | Practitioner |
| 11 | Coffee Barista | Bachelor | 9 | Practitioner |
| 12 | Coffee Barista | Bachelor | 9 | Practitioner |
| 13 | Coffee Barista | Bachelor | 5 | Practitioner |
| 14 | Café Owner | Bachelor | 8 | Practitioner |
| 15 | Café Owner | Bachelor | 9 | Practitioner |
| 16 | Café Owner | Bachelor | 8 | Practitioner |
| 17 | Coffee Farmer | High School | 15 | Practitioner |
| 18 | Coffee Farmer | High School | 9 | Practitioner |
| 19 | Coffee Farmer | High School | 21 | Practitioner |
| 20 | Café Owner | Bachelor | 12 | Practitioner |
| 21 | Café Owner | Bachelor | 14 | Practitioner |
| 22 | Coffee Farmer | High School | 25 | Practitioner |
| 23 | Coffee Farmer | High School | 17 | Practitioner |
| 24 | Coffee Farmer | High School | 20 | Practitioner |
| 25 | Lecturer | Ph.D r | 5 | Faculty member |
| 26 | Lecturer | Master | 4 | Faculty member |
| 27 | Lecturer | Ph.D. | 11 | Faculty member |
| 28 | Lecturer | Master | 7 | Faculty member |
| 29 | Lecturer | Ph.D | 7 | Faculty member |
| 30 | Lecturer | Master | 2 | Faculty member |

Appendix C. FDM results

| Criteria | $u_y$ | $p_y$ | $H_y$ | Decision |
|---|---|---|---|---|
| Fair trade | (0.074) | 0.949 | 0.456 | Accepted |
| Job generation | (0.067) | 0.942 | 0.454 | Accepted |
| Supporting smallholder coffee farmers | (0.435) | 0.935 | 0.359 | Unaccepted |
| Product quality | (0.455) | 0.955 | 0.364 | Unaccepted |
| Health and safety measures | 0.287 | 0.963 | 0.553 | Accepted |
| Sufficient income | 0.299 | 0.951 | 0.550 | Accepted |
| Good working condition | 0.303 | 0.947 | 0.549 | Accepted |
| Improving energy efficiency | (0.013) | 0.888 | 0.441 | Accepted |
| Preventing pollution | (0.365) | 0.865 | 0.341 | Unaccepted |
| Soil sustainability | (0.452) | 0.952 | 0.363 | Unaccepted |
| Water use and contamination | (0.425) | 0.925 | 0.356 | Unaccepted |
| Waste management | (0.038) | 0.913 | 0.447 | Accepted |
| Supplier selection | (0.043) | 0.918 | 0.448 | Accepted |
| Supplier integration | (0.046) | 0.921 | 0.449 | Accepted |
| Land use policy | (0.403) | 0.903 | 0.351 | Unaccepted |
| Trade policy | (0.049) | 0.924 | 0.450 | Accepted |
| Climate policy | (0.395) | 0.895 | 0.349 | Unaccepted |
| Food safety or standard | (0.416) | 0.916 | 0.354 | Unaccepted |
| Investment recovery | (0.033) | 0.908 | 0.446 | Accepted |
| Labor productivity | (0.450) | 0.950 | 0.362 | Unaccepted |
| Revenue/profit | 0.303 | 0.947 | 0.549 | Accepted |
| Access to capital | (0.086) | 0.961 | 0.459 | Accepted |
| Funding cost | 0.000 | 0.500 | 0.250 | Unaccepted |
| Collaborative efforts | (0.067) | 0.942 | 0.454 | Accepted |
| Credit constraints | (0.330) | 0.830 | 0.333 | Unaccepted |
| Information and communication technology | (0.440) | 0.940 | 0.360 | Unaccepted |
| Machine learning | (0.406) | 0.906 | 0.352 | Unaccepted |
| Blockchain technology | (0.013) | 0.888 | 0.441 | Accepted |
| Digital platform | (0.057) | 0.932 | 0.452 | Accepted |
| Real time information | (0.038) | 0.913 | 0.447 | Accepted |
| Agricultural automation | (0.357) | 0.857 | 0.339 | Unaccepted |
| Robotic technology | (0.268) | 0.768 | 0.317 | Unaccepted |
| Mobile device | (0.017) | 0.892 | 0.442 | Accepted |
| Threshold $T$ | | | 0.424 | |

## Appendix D. Initial direct relation matrix for aspects

| | A1 | A2 | A3 | A4 | A5 | A6 | A7 | A8 |
|---|---|---|---|---|---|---|---|---|
| A1 | 0.6898 | 0.5689 | 0.6236 | 0.5672 | 0.6823 | 0.5248 | 0.6414 | 0.5848 |
| A2 | 0.5938 | 0.6773 | 0.6353 | 0.5788 | 0.4800 | 0.5891 | 0.6780 | 0.6331 |
| A3 | 0.5936 | 0.4608 | 0.7658 | 0.5913 | 0.6840 | 0.6422 | 0.4600 | 0.5774 |
| A4 | 0.5995 | 0.5808 | 0.5524 | 0.8080 | 0.6770 | 0.6420 | 0.6514 | 0.5657 |
| A5 | 0.4929 | 0.5865 | 0.6590 | 0.5396 | 0.9066 | 0.5715 | 0.6771 | 0.5492 |
| A6 | 0.5705 | 0.5865 | 0.5524 | 0.5845 | 0.7146 | 0.7742 | 0.6725 | 0.5592 |
| A7 | 0.5600 | 0.5689 | 0.5283 | 0.6045 | 0.7330 | 0.6768 | 0.9066 | 0.6485 |
| A8 | 0.5761 | 0.5513 | 0.6300 | 0.6860 | 0.7729 | 0.6595 | 0.7322 | 0.7827 |

## Appendix E. Normalized direct relation matrix for aspects

| | A1 | A2 | A3 | A4 | A5 | A6 | A7 | A8 |
|---|---|---|---|---|---|---|---|---|
| A1 | 2.5896 | 1.5423 | 1.6675 | 1.6595 | 1.9163 | 1.6941 | 1.8277 | 1.6445 |
| A2 | 1.5686 | 2.5592 | 1.6654 | 1.6586 | 1.8723 | 1.7033 | 1.8308 | 1.6506 |
| A3 | 1.5366 | 1.4870 | 2.6577 | 1.6271 | 1.8745 | 1.6785 | 1.7506 | 1.6056 |
| A4 | 1.6327 | 1.6041 | 1.7168 | 2.7698 | 1.9886 | 1.7825 | 1.9004 | 1.7036 |
| A5 | 1.5813 | 1.5749 | 1.7060 | 1.6854 | 2.9959 | 1.7358 | 1.8694 | 1.6686 |
| A6 | 1.6077 | 1.5864 | 1.6967 | 1.7062 | 1.9726 | 2.7867 | 1.8823 | 1.6823 |
| A7 | 1.6743 | 1.6507 | 1.7646 | 1.7835 | 2.0611 | 1.8439 | 3.0086 | 1.7723 |
| A8 | 1.7260 | 1.6946 | 1.8361 | 1.8510 | 2.1282 | 1.8934 | 2.0308 | 2.8483 |

## Appendix F. Initial direct relation matrix for criteria

| | C1 | C2 | C3 | C4 | C5 | C6 | C7 | C8 | C9 | C10 | C11 | C12 | C13 | C14 | C15 | C16 | C17 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| C1 | 0.742 | 0.497 | 0.503 | 0.575 | 0.521 | 0.498 | 0.484 | 0.570 | 0.592 | 0.598 | 0.493 | 0.533 | 0.481 | 0.593 | 0.287 | 0.333 | 0.333 |
| C2 | 0.267 | 0.732 | 0.558 | 0.544 | 0.490 | 0.500 | 0.478 | 0.472 | 0.446 | 0.484 | 0.523 | 0.510 | 0.522 | 0.510 | 0.320 | 0.300 | 0.313 |
| C3 | 0.504 | 0.575 | 0.720 | 0.528 | 0.575 | 0.581 | 0.434 | 0.581 | 0.427 | 0.387 | 0.373 | 0.387 | 0.407 | 0.393 | 0.373 | 0.400 | 0.393 |
| C4 | 0.333 | 0.307 | 0.523 | 0.729 | 0.492 | 0.466 | 0.436 | 0.367 | 0.592 | 0.393 | 0.333 | 0.333 | 0.333 | 0.554 | 0.492 | 0.531 | 0.511 |
| C5 | 0.481 | 0.424 | 0.592 | 0.473 | 0.715 | 0.479 | 0.581 | 0.492 | 0.510 | 0.534 | 0.529 | 0.604 | 0.333 | 0.569 | 0.504 | 0.452 | 0.505 |
| C6 | 0.280 | 0.293 | 0.465 | 0.497 | 0.505 | 0.716 | 0.569 | 0.491 | 0.523 | 0.575 | 0.466 | 0.511 | 0.518 | 0.478 | 0.593 | 0.593 | 0.599 |
| C7 | 0.280 | 0.455 | 0.464 | 0.590 | 0.467 | 0.575 | 0.718 | 0.492 | 0.492 | 0.447 | 0.479 | 0.478 | 0.605 | 0.530 | 0.593 | 0.570 | 0.598 |
| C8 | 0.588 | 0.468 | 0.459 | 0.486 | 0.418 | 0.587 | 0.598 | 0.718 | 0.604 | 0.496 | 0.593 | 0.575 | 0.491 | 0.610 | 0.587 | 0.581 | 0.587 |
| C9 | 0.492 | 0.503 | 0.587 | 0.466 | 0.581 | 0.581 | 0.581 | 0.604 | 0.715 | 0.592 | 0.593 | 0.592 | 0.491 | 0.581 | 0.605 | 0.581 | 0.599 |
| C10 | 0.588 | 0.509 | 0.569 | 0.454 | 0.535 | 0.587 | 0.575 | 0.593 | 0.587 | 0.718 | 0.593 | 0.575 | 0.518 | 0.592 | 0.511 | 0.504 | 0.449 |
| C11 | 0.347 | 0.481 | 0.509 | 0.499 | 0.481 | 0.575 | 0.575 | 0.521 | 0.517 | 0.461 | 0.723 | 0.587 | 0.599 | 0.528 | 0.547 | 0.570 | 0.616 |
| C12 | 0.519 | 0.505 | 0.499 | 0.513 | 0.497 | 0.593 | 0.598 | 0.616 | 0.598 | 0.499 | 0.593 | 0.726 | 0.634 | 0.581 | 0.582 | 0.593 | 0.581 |
| C13 | 0.453 | 0.506 | 0.510 | 0.267 | 0.489 | 0.448 | 0.484 | 0.479 | 0.492 | 0.515 | 0.490 | 0.458 | 0.727 | 0.460 | 0.497 | 0.502 | 0.481 |
| C14 | 0.480 | 0.508 | 0.563 | 0.498 | 0.569 | 0.587 | 0.552 | 0.564 | 0.587 | 0.552 | 0.604 | 0.593 | 0.535 | 0.715 | 0.581 | 0.599 | 0.581 |
| C15 | 0.594 | 0.473 | 0.569 | 0.428 | 0.604 | 0.575 | 0.564 | 0.575 | 0.598 | 0.598 | 0.576 | 0.581 | 0.564 | 0.610 | 0.732 | 0.587 | 0.581 |
| C16 | 0.564 | 0.605 | 0.587 | 0.486 | 0.616 | 0.558 | 0.610 | 0.593 | 0.587 | 0.581 | 0.593 | 0.575 | 0.593 | 0.575 | 0.593 | 0.731 | 0.570 |
| C17 | 0.617 | 0.605 | 0.552 | 0.540 | 0.604 | 0.592 | 0.581 | 0.570 | 0.598 | 0.581 | 0.575 | 0.564 | 0.581 | 0.616 | 0.587 | 0.570 | 0.725 |

## Appendix G. Normalized direct relation matrix for criteria

| | C1 | C2 | C3 | C4 | C5 | C6 | C7 | C8 | C9 | C10 | C11 | C12 | C13 | C14 | C15 | C16 | C17 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| C1 | 1.486 | 0.477 | 0.519 | 0.492 | 0.517 | 0.533 | 0.527 | 0.530 | 0.540 | 0.517 | 0.513 | 0.520 | 0.501 | 0.541 | 0.486 | 0.491 | 0.493 |
| C2 | 0.403 | 1.466 | 0.486 | 0.453 | 0.476 | 0.494 | 0.488 | 0.481 | 0.485 | 0.468 | 0.478 | 0.479 | 0.469 | 0.493 | 0.452 | 0.451 | 0.453 |
| C3 | 0.431 | 0.454 | 1.506 | 0.456 | 0.488 | 0.506 | 0.487 | 0.496 | 0.487 | 0.462 | 0.466 | 0.470 | 0.460 | 0.485 | 0.461 | 0.464 | 0.465 |
| C4 | 0.404 | 0.415 | 0.475 | 1.465 | 0.469 | 0.482 | 0.475 | 0.462 | 0.493 | 0.451 | 0.451 | 0.453 | 0.441 | 0.490 | 0.463 | 0.467 | 0.466 |
| C5 | 0.470 | 0.481 | 0.540 | 0.493 | 1.548 | 0.544 | 0.550 | 0.534 | 0.544 | 0.522 | 0.529 | 0.539 | 0.498 | 0.551 | 0.520 | 0.515 | 0.523 |
| C6 | 0.447 | 0.464 | 0.523 | 0.491 | 0.524 | 1.564 | 0.545 | 0.530 | 0.542 | 0.523 | 0.519 | 0.526 | 0.514 | 0.538 | 0.527 | 0.527 | 0.529 |
| C7 | 0.451 | 0.486 | 0.529 | 0.507 | 0.526 | 0.556 | 1.566 | 0.536 | 0.545 | 0.516 | 0.526 | 0.529 | 0.529 | 0.550 | 0.533 | 0.531 | 0.535 |
| C8 | 0.515 | 0.520 | 0.564 | 0.529 | 0.556 | 0.594 | 0.591 | 1.596 | 0.593 | 0.556 | 0.574 | 0.575 | 0.552 | 0.595 | 0.567 | 0.567 | 0.569 |
| C9 | 0.519 | 0.539 | 0.593 | 0.542 | 0.589 | 0.610 | 0.605 | 0.600 | 1.620 | 0.581 | 0.589 | 0.592 | 0.567 | 0.608 | 0.584 | 0.582 | 0.586 |
| C10 | 0.513 | 0.523 | 0.574 | 0.524 | 0.566 | 0.592 | 0.586 | 0.581 | 0.589 | 1.577 | 0.572 | 0.573 | 0.553 | 0.591 | 0.557 | 0.556 | 0.553 |
| C11 | 0.474 | 0.505 | 0.551 | 0.513 | 0.544 | 0.574 | 0.570 | 0.557 | 0.565 | 0.534 | 1.568 | 0.557 | 0.545 | 0.567 | 0.545 | 0.547 | 0.554 |
| C12 | 0.520 | 0.537 | 0.582 | 0.545 | 0.579 | 0.609 | 0.605 | 0.600 | 0.607 | 0.570 | 0.588 | 1.604 | 0.580 | 0.607 | 0.580 | 0.582 | 0.582 |
| C13 | 0.442 | 0.463 | 0.502 | 0.444 | 0.497 | 0.510 | 0.510 | 0.503 | 0.512 | 0.492 | 0.496 | 0.496 | 1.511 | 0.510 | 0.491 | 0.492 | 0.491 |
| C14 | 0.514 | 0.535 | 0.586 | 0.541 | 0.583 | 0.606 | 0.598 | 0.591 | 0.602 | 0.573 | 0.586 | 0.588 | 0.567 | 1.617 | 0.577 | 0.579 | 0.579 |
| C15 | 0.533 | 0.539 | 0.595 | 0.541 | 0.595 | 0.613 | 0.607 | 0.601 | 0.612 | 0.586 | 0.591 | 0.595 | 0.578 | 0.615 | 1.600 | 0.586 | 0.587 |
| C16 | 0.538 | 0.561 | 0.607 | 0.556 | 0.606 | 0.621 | 0.622 | 0.612 | 0.621 | 0.593 | 0.602 | 0.604 | 0.590 | 0.621 | 0.595 | 1.610 | 0.595 |
| C17 | 0.545 | 0.563 | 0.605 | 0.564 | 0.607 | 0.627 | 0.621 | 0.612 | 0.624 | 0.595 | 0.603 | 0.605 | 0.591 | 0.628 | 0.597 | 0.595 | 1.613 |