Sustainable Production and Consumption 39 (2023) 203–215

Contents lists available at ScienceDirect

Sustainable Production and Consumption

journal homepage: www.elsevier.com/locate/spc

Overcoming barriers to implement digital technologies to achieve sustainable production and consumption in the food sector: A circular economy perspective

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ARTICLE INFO

Editor: Prof Konstantinos Tsagarakis

Keywords:
Sustainable production and consumption
Digital technologies
Food supply chains
Circular economy

ABSTRACT

Food security and waste minimisation are the main concerns for the management of food supply chains (FSC), as >33 % of global food production is wasted or lost due to mismanagement. Stakeholders must address the ongoing issues, such as resource scarcity, climate change, waste creation etc. to create an environment conducive to sustainable production and consumption (SPC) and to promote economic sustainability. Resource efficiency and waste minimization are necessary for SPC in the FSC. Technologies from the Industry 4.0 era have demonstrated their ability to address these problems effectively. However, there are barriers to the adoption of digital technology because of internal or external issues. Therefore, it is necessary to examine the challenges faced by the food industry while applying digital technology to attain SPC. The current study has adopted an integrated methodology of Best-Worst-Method (BWM)-Level Based Weight Assessment (LBWA) and Combined Compromise Solution (CoCoSo) methods to analyse the barriers in implementing digital technologies to achieve SPC in FSC. Strategic measures to overcome these barriers are suggested. The BWM-LBWA-CoCoSo technique is used for the first time in this study to evaluate the barriers and determine the most effective strategies. According to the BWM-LBWA research, "organisational barriers" are the main impediment to the adoption of digital technology for SPC in the FSC. According to CoCoSo findings, the best way to overcome the major barriers is to "focus on improving commitment from senior management towards SPC." The study gives decision-makers information about the major barriers in utilizing advanced digital technology to achieve SPC in FSC.

1. Introduction

Sustainable production and consumption (SPC) is regarded as the main driving force behind economic reform and sustainable growth. Its importance is highlighted by Sustainable Development Goal-12 (SDG) of the United Nations, which aims to promote sustainable development and responsible production (Beier et al., 2018; Guo et al., 2022). Recently, reverse logistics, closed-loop supply chains, circular economy acts as an environemnetal and sustainability tool in various supply chain applications (Kannan et al., 2023; Butt et al., 2023; Aryee and Adaku, 2023; Mondal et al., 2022). A new era in which the integration of triple bottom line dimensions, including environmental, social and economic progress, is required for the expansion of the economy in a sustainable manner. National policies and strategies assist stakeholders in managing tradeoffs and fostering synergy between SPC and SDGs (Obersteiner et al., 2016). Data management, real-time decision-making, creative approaches for extending the end-of-life and shelf life of perishable items etc. have changed throughout the present Industry 4.0 era; this has unquestionably enhanced SPC in FSC (Gölzer and Fritzsche, 2017; Ekren

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https://doi.org/10.1016/j.spc.2023.04.002
Received 23 August 2022; Received in revised form 27 March 2023; Accepted 3 April 2023
Available online 18 April 2023

Nomenclature

A_B	Best-to-Others vector
Aw	Others-to-Worst vector
BWM	Best Worst Method
CoCoSo	Combined Compromise Solution
CI	Consistency Index
CR	Consistency Ratio
CE	Circular Economy
LBWA	Level Based Weight Assessment
w	Weights
SDG	Sustainable Development Goals
ξ^*	Consistency index
r_0	the elasticity coefficient
K_{ia}	arithmetic mean of WSM and WPM scores
K_{ib}	sum of WSM and WPM scores
K_{ic}	balanced compromise score of WSM and WPM

et al., 2021). It is clear that digitalization has the potential to improve the SPC in FSC, but it still faces challenges including a conservative perception, a risk-averse culture, lack of technical expertise etc. (Mathews and Tan, 2016; Lezoche et al., 2020; Diaz-Ruiz et al., 2019). Some research papers have looked at environmental studies on SPC but there are few empirical studies on how digital technologies are being used in FSC to study SPC patterns (Berkhout and Hertin, 2004; Li et al., 2020; Heidenstrøm and Hebrok, 2022). Beier et al. (2018) explored how the industry might achieve sustainable production growth, transparency and resource efficiency through digitization. The dynamic changes in society production and consumption requirements have been addressed by the Sustainable Development Agenda of the United Nations. Additionally, UN-SDG-12 guarantees SPC in all economies (Bengtsson et al., 2018; Gjorgievski et al., 2022). SPC barriers have not been thoroughly researched, and it is yet unknown which barriers prevent the deployment of digital technologies. Additionally, the path towards a circular economy (is less explored to achieve SPC in FSC. In emerging economies, the use of digital technology is still in its early stages, necessitating prompt evaluation (Kurniawan et al., 2022).

SPC focuses primarily on efficient resource mobilisation and catering to the basic needs of every household. It aims to bring about systemic changes such as minimising the dependence on scarce resources, changing practices and processes for reducing food waste, and enhancing food security (O'Rourke and Lollo, 2015; Deka and Goswami, 2022). SPC is based on three significant objectives:

(a) Decoupling the environmental dilapidation caused by economic growth at the expense of environmental degradation and non-recycled waste;
(b) Building the circularity approach across production and consumption processes from cradle to gate to a cradle to cradle life cycle;
(c) Building support systems for new developing countries to become self-reliant and eradicate poverty through low-cost, new and highly competitive technologies.

Using modern digital technology, food waste management in a circular economy can accomplish the SDGs (Mak et al., 2020). Moreover, food waste circularity will improve the value chain to minimize global greenhouse gas emissions (Latka et al., 2022). The SPC patterns of food products are responsible for numerous environmental and climate changes which have a negative impact on human lifestyles and threaten future generations. As part of the compliance with the Paris Climate Agreement (2015), the SPC pattern is regarded as a strategic method of addressing these issues. As an integral aspect of the SDGs is aimed at achieving sustainable food systems, the European Union suggested a farm-to-fork strategy that ensures an SPC path towards sufficient and healthy food value chains (UN, 2015; Von der Leyen, 2019; Kaufmann et al., 2022).

Previous research indicates that digital technologies are essential for performance improvements (Govindan et al., 2014) and the transition to sustainable food systems (Joshi and Sharma, 2021; Marvin et al., 2022). It is noted that utilizing innovative technologies for pre- and post-harvest operations within agri-food value chains is a common aspect of digitalizing agricultural systems. Digital technologies encompass a broader array of tools and technologies, such as big data analytics (BDA), blockchain technology, the Internet of Things (IoT) and others. These technologies together reconfigure, realign and relink processes across organisational processes through continuously innovating business models that aim to increase the value chain and firm-level profitability (Cane and Parra, 2020; Chauhan et al., 2021). Digital technologies provide advantages such as the assurance of inter-firm information exchange throughout supply chains to address lead time, in-transit losses and damages, end-user consumption habits, and overall food safety and security (Strotmann et al., 2022). Additionally, digitally enabled supply chains generate downstream integration to fulfil the needs of the end client (Annosi et al., 2021; Kurniawan et al., 2022). Multiple technologies, including BDA, machine learning and deep learning, are used to facilitate connectivity, information gathering and distribution, and data-driven decision-making (Jun et al., 2021).

Farooque et al. (2019) studied challenges to the circular food supply chain. Kamble et al. (2019) developed the modelling of IoT adoption hurdles in FSC; Annosi et al. (2019) highlighted the potential of digital technologies to prevent food waste. While earlier studies have addressed the challenges associated with building circular supply chains in the food industry, less attention has been dedicated to the barriers associated with applying digital technology to achieve SPC. In addition, strategic options to improve SPC in FSC have not been investigated in previous research. Consequently, the purpose of this study is to address the following two significant research questions:

RQ1: What barriers exist in the implementation of digital technology to achieve SPC in the FSC?
RQ2: What are the potential strategic solutions for overcoming barriers in the FSC's deployment of digital technology to attain SPC?

The current study proposes a framework for investigating and assessing the most significant barriers to the use of digital technologies in FSC in order to achieve SPC. Integrated BWM-LBWA-CoCoSo methodologies have been utilised in this work. Based on the food sector decision-makers' responses, the proposed framework has been evaluated. The study's most significant implications are the analysis of barriers to the application of digital technologies in FSC from a CE perspective. The study provides the following significant contributions:

- Critical barriers to implementing digital technologies in FSC to achieve SPC are identified, assessed and ranked.
- Strategic solutions for mitigating the adverse effect of barriers in implementing digital technologies for SPC in FSC are offered.

The order of the subsequent sections of the paper is as follows. Section 2 discusses the literature review on the existing barriers to digitization in FSC in order to attain SPC. The third section describes the study's research methodology. In Section 4, the achieved results are discussed. Strategy mapping is presented in Section 5. Section 6 concludes the study.

2. Literature review

Prior studies have evaluated sustainability of the FSC. Govindan and Hasanagic (2018) demonstrated the barriers and possible solutions for coordination of a circular economy. Mangla et al. (2018) identified the most significant roadblocks hindering the circular FSC whereas Gaitán-Cremaschi et al. (2019) emphasised agent-based modelling for sustainability transition. Torkayesh et al. (2021) evaluated Eastern European healthcare sectors using the BWM-LBWA-CoCoSo framework. The compelling arguments made by researchers underscore the need to build a more comprehensive SPC framework for food chains (Lehtokunnas et al., 2022). FSC have several challenges as a result of complicated internal and external indicators, such as pre-harvesting seasonality, high regularity, perishability, warehousing, in-transit losses and damages, adulteration, recycling and reuse (Matzembacher et al., 2020; Papargyropoulou et al., 2014; Yadav et al., 2022). The other issue is the increase in food production due to a shift in food consumption patterns (Matzembacher et al., 2021). Consequently, SPC in the FSC is an absolute necessity for future generations (Matzembacher et al., 2021).

A thorough examination of prior relevant works has scrutinized the literature on SPC. The SLR timeline chosen was between 2010 and 2022. This involved “Sustainable production and consumption” AND “food supply chain” OR “Sustainable Supply Chain Management” AND “Agri-food” OR “Digitalisation” AND “Sustainable Production and Consumption” OR “Information technology” AND “Agri-food” AND “sustainability” OR “Digitalisation” AND “Agri-food” AND “sustainability.” In the initial round of searches, 214 articles were discovered. All conference proceedings' papers, non-English papers and duplicate papers were eliminated in the second round. In the third and final round, 49 papers were chosen after examining the abstracts and eliminating articles irrelevant to the current study.

2.1. Sustainable production and consumption, food supply chains and digital technologies

During the Rio summit in 1992, world leaders generally agreed that unsystematic patterns were causing ongoing degradation of the biological environment. Sustainable practices are relevant to economic shifts and long-term economic prosperity (European Commission, 2012). Numerous highlighted theories, such as the theories of social practice and resource-based view, demonstrate that SPC actions stimulate the needs of individuals, groups, communities and society as a whole (Takacs et al., 2022). The United Nations Environmental Program (UNEP, 2020) described SPC as a sustainable approach that assures a dignified and quality existence for all, cautious and optimum utilisation of products and linked services to meet fundamental needs through limiting the usage and waste of natural resources.

Global food waste amounts to around one-third of annual production (Singh et al., 2022). According to previous studies, the magnitude of food waste is a major concern for both developing and developed nations (Gustavsson et al., 2011; Singh et al., 2022). However, there are numerous reasons for this waste (Luo et al., 2021). Due to structural differences, only a few types of food waste are unfit for human consumption and must be reprocessed for value recovery (Sonnino and McWilliam, 2011; Lee and Stuckey, 2022). On the other hand, environmental hazards and hygiene difficulties are associated with food waste management (Aguilar et al., 2022). In light of the worrisome socio-ecological problems in the ecosystem, short-term improvements or adjustments are insufficient to tackle the challenges to sustainability. Instead, a technology-driven systematic strategy is needed to address the issue (Fuchs and Lorek, 2005; Lorek and Fuchs (2013); Annosi et al., 2021; Sharma et al., 2022). Advanced technologies have the ability to aid businesses in tackling difficulties and creating value (Eshghali et al., 2023). There is a need for strong policy frameworks to encourage the general population's consumption patterns that are sustainable (Goyal et al., 2022).

The circular economy (CE) gives a new perspective on SPC for FSC by treating food waste as a vital source for co-creating value (Kumar et al., 2022). According to the Ellen MacArthur Foundation (2013), extraction of organic food waste from landfills can generate economic and environmental benefits. Santagata et al. (2021) outlined various opportunities for the recovery of food waste in the CE. To focus on the transition to CE is very relevant to FSC and waste management literature; however studies have emphasised the importance of consumers and consumption patterns as well (Lehtokunnas et al., 2022).

2.2. Barriers to digitalisation technologies in the food industry

21 barriers preventing the deployment of digital technologies in FSC to achieve SPC were identified from previous studies. Table 1 provides a description of these barriers.

Thirty experts were contacted to analyse the barriers by questionnaire, but only 18 responded. The experts were from the firms' middle and upper management. These experts were divided into three categories: retailers, food processors and distribution channels, which included supermarkets. Table 2 gives information on the experts.

72.2 % of the experts were men, while 27.7 % were women. The age distribution of experts is as follows: >30 years (55.5 %), 30–40 years (27.7 %) and > 40 years (16.5 %). The experts carefully examined the barriers' descriptions in the survey instrument and evaluated them based on their significance for achieving SPC in FSC. Each expert has more than a decade of industrial experience and is familiar with digital technology implementation, either partially or in supply chain procedures. In a variety of businesses, experts are recognised as production planners, global operations managers, distribution managers, food control managers, analysts, consultants or supervisors. Previous studies based on expert judgement have considered 2–20 experts as an appropriate sample; there is no limitation of sample size population (Li et al., 2019; Yavas and Ozkan-Ozen, 2020).

3. Research methodology

The present investigation was conducted in two phases. The questionnaire was shared with the experts (Supplementary File). All of the experts were in senior managerial roles in the food sector in North Indian companies. During the initial phase, barriers were identified, validated and evaluated using BWM and LBWA techniques. These techniques helped determine the aggregate weight of the barriers to identify the most significant. During the second phase, the strategies were investigated through a literature review, examined by the decision-makers and evaluated using the CoCoSo method. The flow chart for the research methodology is shown in Fig. 1.

3.1. Best worst method

Razeai developed the Best Worst Method (BWM) in 2015; it is a pairwise comparison-based method. This method has an advantage over other pairwise comparison techniques due to its capacity to handle discrepancies. This is a reliable method for determining pairwise comparisons between criteria and determining their optimal weight. (Moktadir et al., 2019; Orji et al., 2020). BWM has been successfully implemented in a variety of fields, such as manufacturing, sustainability, waste management, selection of supply chain partners, green performance etc.

Using a questionnaire containing a 1-to-9 linguistic scale, each expert determines the pairwise comparisons between the best criterion and the other criteria. Each expert is asked to comment on the degree to which a particular criterion is considered superior to the others. The score is ‘1’ if an expert believes the best criterion is ‘equally significant to other criteria,’ and ‘9’ if the pairwise comparison is ‘very important to’. The following steps are included in this procedure:

Step1. The experts identify and define a set of criteria as $\{c_1, c_2, \dots\dots\dots c_n\}$

Step 2. Determination of the best (B) and worst (W) criteria by the experts.

Table 1
Barriers to digital technologies for SPC in FSC.

Code	Criteria (C_1-C5)	Barriers to Digital Technologies for Sustainable Production and Consumption	Implied Meaning	Reference
BSPC1	Regulations and policy barriers (C_1) REG	Weak environmental regulations	Environmental regulations are not stringent for SPC in FSC.	Farooque et al. (2019)
BSPC2		Lack of global standard processes, rules and frameworks	Organisations face problems in adopting digital technologies due to the absence of global standard processes.	Kumar et al. (2021).
BSPC3		Lack of stringent national policy for sustainable production and consumption /or CE policy	Absence of a policy for CE and also for technology adoption. Most economies are still hesitant towards adoption due to the dynamic environment.	Lorek and Spangenberg (2014); Blok et al. (2015)
BSPC4	Financial barriers (C_2)	Limited funds	Digital technologies are expensive and thus need funds in the initial phase. Also, there is less awareness related to long-run payback and investment opportunities.	Köhler and Pizzol (2020)
BSPC5		High operational cost	The cost is very high to develop digital technology enabled sustainable supply chains.	Kamble et al. (2020).
BSPC6	Organisational barriers (C_3)	Lack of experts	Selection of the right personnel to use and develop SPC strategies for food systems is a significant task.	Annosi et al. (2021)
BSPC7		Lack of change management capabilities	Organisational culture sometimes has resistance to adopting any change and hence is hesitant towards implementing digital technologies.	Annosi et al. (2021)
BSPC8		Less skilled workforce	Lack of technical, sound and knowledgeable workforce for SPC implementation in food supply chains	Lezoche et al. (2020)
BSPC9		Benchmarking/standards	There is less clarity in set standards to measure the performance of firms.	Mathews and Tan (2016)
BSPC10		Risk-averse culture	Perception towards potential risk may adversely affect the stakeholder in the FSC.	Diaz-Ruiz et al. (2019)
BSPC11		Lack of physical and IT infrastructure/ technical competency	Lack of infrastructure, interface platform, standardization and compatibility issues.	Kamble et al. (2019).
BSPC12	Supply chain related barriers (C_4)	Lack of cross-sector collaboration/ inability to work across silos	Collaboration across industries is limited, and therefore digital technology implementation is limited for sharing of information and data.	Behnke and Janssen (2020)
BSPC13		Low motivation towards information exchange among SC actors	The fear of information loss due to shared information.	Carter and Rogers (2008)
BS5C14		Lack of support from supply chain actors	Food sector stakeholders are skeptical about using digital technologies, especially in agri-food supply chains.	Mahdad et al. (2022).
BSPC15	Behavioral barriers (C_5)	Less priority of firms	Digital transformation is not a top priority for many businesses.	Annosi et al. (2021)
BPSC16		Low-level commitment among top-level management	Top-level management are less interested in changing the firm's processes and thus avoid implementing digital technologies.	Dubey et al. (2015)
BSPC17	Strategic barriers (C_6)	Low technological know-how for implementation	Lack of knowledge about digitalization of supply chain processes.	Saberi (2018); Kamilaris et al. (2019)
BSPC18		Lack of training to develop skilled workers	Due to budgetary constraints, small food cooperatives lack the resources to invest in the skill development of their employees.	Carter and Rogers (2008) and Govindan et al. (2014)
BPSC19		Meager environmental education and absence of environmental consciousness	There is a lack of environmental education and its links to SPC orientation in food systems.	Tian and Wang (2016)
BPSC20		Lack of circular design aspect	The circular design focusing on closed loops using digital technologies like Industry 4.0 is still lacking in many firms.	Ranta et al. (2021)
BPSC21		Lack of agility	Firms are not agile in embracing digital technology implementation; there is insufficient encouragement towards innovation.	Aiyar and Pingali (2020)

Step 3. A pairwise comparison was made for each criterion using a 9-point scale to determine which criterion is preferred over others. The comparison results are represented as a vector from best to others vectors. $A_B = \{a_{B1}, a_{B2}, \ldots\ldots a_{Bj} \ldots a_{Bn}\}$

where a_{Bj} represents the preferences of the best criterion B over the criterion j.

Step 4. The preferences for the other criteria over the worst criterion are determined using the 1 to 9 scale

Vector $A_W = \{a_{1W}, a_{2W}, \ldots\ldots a_{jW}, ..a_{nW}\}$

where a_{jW} represents the preference of the criterion j over the worst criterion W.

Step 5. The mathematical model 1 is used to compute the weights of the criteria ($w_1^*, w_2^*, \ldots . w_n^*$)

Model 1

$$\min_j \max\{|W_B - a_{Bj}W_j|, |W_j - a_{jW}W_W|\} \tag{1}$$

s.t:

$\sum_j W_j = 1, W_j \geq 0$ for all j

To determine the weigts of the criteria ($w_1^*, w_2^*, \ldots . w_n^*$), model 1 can be converted into model 2,

Min ξ

s.t.

$$\left|\frac{w_B}{w_j} - a_{Bj}\right| \leq \xi \text{ for all j} \tag{2}$$

$$\left|\frac{w_j}{w_W} - a_j\right| \leq \xi \text{ for all j}$$

$$\sum_j W_j = 1, W_j \geq 0 \text{ for all j}$$

The consistency ratio (CR) of BWM is represented by ξ^* and the corresponding consistency index (CI) values are computed by Eq. (3). Table 3 presents the CI for BWM models with different numbers of criteria.

Table 2
Expert details.

Experts	Designation	Technologies	Experience
E1	Production Planner	ERP, SAP, Big Data Analytics, CRM	>10 years
E2	Global Operations	Big Data Analytics, Cloud Computing, EDI	>15 years
E3	Distribution Manager	Big Data Analytics, ERP systems for reordering and order fulfilment.	>10 years
E4	Production Planner	Big Data Analytics	>10 years
E5	Food Control	Food control systems that support international standards, including and FSSAI, Supplier Quality Management (SQM)	>10 years
E6	Global Operations	Power BI, ERP, APO system, Inventory Tool, VMI	>10 years
E7	Supply Chain Partner	Big Data Analytics, Power BI, ERP	>10 years
E8	Food Control	Big Data Analytics, Power BI, ERP	>10 years
E9	Production Planner	Power BI, ERP	>15 years
E10	Food Control	Big Data Analytics	>10 years
E11	Global Operations	Power BI, Google Studio and Tableau	>10 years
E12	Supply Chain Partner	Big Data Analytics	>10 years
E13	Distribution Manager	Big Data Analytics,	>10 years
E14	Supervisor	Big Data Analytics	>15 years
E15	Project Manager	Big Data Analytics, AMI, APO system	<10 years
E16	Analyst/ Consultant	Cloud computing	>10 years
E17	Supervisor	Power BI, ERP	<10 years
E18	Global Operations	Power BI, ERP	>15 years

$$CR = \frac{\xi^*}{CI} \tag{3}$$

The smaller the ξ^*, the smaller is the CR value, and the more consistent the vectors are.

3.2. Level-Based Weight Assessment (LBWA)

The LBWA method was proposed by Žižović and Pamucar (2019). This method is one of the pairwise comparison-based subjective methods. It uses an algorithm that groups criteria according to their levels of significance. According to the expert's preferences, the relevance of the grouped criteria is then specified. This method has been used in sustainable practices, transportation, operations etc. For its application, the following steps are taken:

Step 1. The most important criterion from the set of predefined criteria is identified.

$$s = \{c_1, c_2, \ldots..c_n\}.$$

Step 2. The remaining criteria are categorised into different levels (mentioned below) on the basis of their significance
Level S_1: Criteria that are as important or up to twice as important as the most important criterion are placed in this level.
Level S_2: Criteria whose significance level is exactly twice or up to three times less significant than the most significant criterion are placed in this level.
Level S_3: Criteria with significance levels exactly k times or up to k + 1 times less significant than the most significant criterion are placed in this level.

The significance of criterion is represented as $S(c_j)$ for each $j \in \{1, 2, \ldots..,n\}$; the following equation is formed for each level $i \in \{1, 2, \ldots..,k\}$:

$$S = S_1 \cup S_2 \ldots \cup S_k \tag{4}$$

where for each p, q $\in \{1, 2, \ldots, k\}$; p and q are not equal, $S_1 \cap S_2 = \emptyset$ holds.

Step 3. As the expert categorises criteria according to their relative weights, each criterion $C_{jp} \in S_i$ in the subset of $S_j = \{C_j, C_{j_2}, \ldots.,C_{j_s}\}$ is assigned with an integer value that is denoted by I_{j_p}. I_{j_p} contains integer values from 0 to a constant called r where r is equal to

$$r = max\{|S_1|, |S_2|, \ldots.,|S_k|\} \tag{5}$$

It is essential to note that $I_1 = 0$, represents the most important criterion. If one criterion is more significant than another, its assigned value will be greater than this for the remaining criteria.

Step 4. The obtained value of r should satisfy $r_0 > r$ where r_0 is defined as the elasticity coefficient.
Step 5. The influence function of each criterion is computed using Eq. (6)

$$f\left(c_{j_p}\right) = \frac{r_0}{j(r_0) + I_{j_p}} \tag{6}$$

where I signifies the number of the level where the criterion is placed.

Step 6. The optimal values for the weight coefficient of the most important criterion are calculated using Eq. (7).

$$w_j = \frac{1}{1 + f(C_j) + \ldots + f(C_n)} \tag{7}$$

The remainder of the criteria's weight coefficients are calculated based on Eq. (8).

$$w_j = f(c_j) w_j \tag{8}$$

An aggregation operator is utilised to compute optimal criterion weights. The BWM and LBWA criterion weights are represented as y_j and z_j, respectively; the final weights are calculated using Eq. (9) (Yazdani et al., 2019).

$$w_j = \frac{y_i z_j}{\Sigma_{j=1}^{m} y_i z_j} \tag{9}$$

3.3. CoCoSo method

By combining the ideas of simple additive weighting (SAW), weighted aggregated sum product assessment (WASPAS) and multiplicative exponential weighting (MEW), Yazdani et al. (2019) developed the CoCoSo method. In the current study, strategies are ranked using the CoCoSo method, a combination of the SAW, WASPAS and MEW methods, as this yields more reliable results. It comprises the steps outlined below.

Step 1. Developing the initial decision matrix

$$x_{ij} = \begin{bmatrix} x_{11} & x_{12} & \ldots & x_{1n} \\ x_{21} & x_{22} & \ldots & x_{2n} \\ \ldots & \ldots & \ldots & \ldots \\ x_{m1} & x_{m2} & \ldots & x_{mn} \end{bmatrix}; i = 1, 2, \ldots., m; i = 1, 2, \ldots., n. \tag{10}$$

Step 2. Normalization of the initial decision matrix using Eqs. (11) and (12) based on the nature of the criteria.

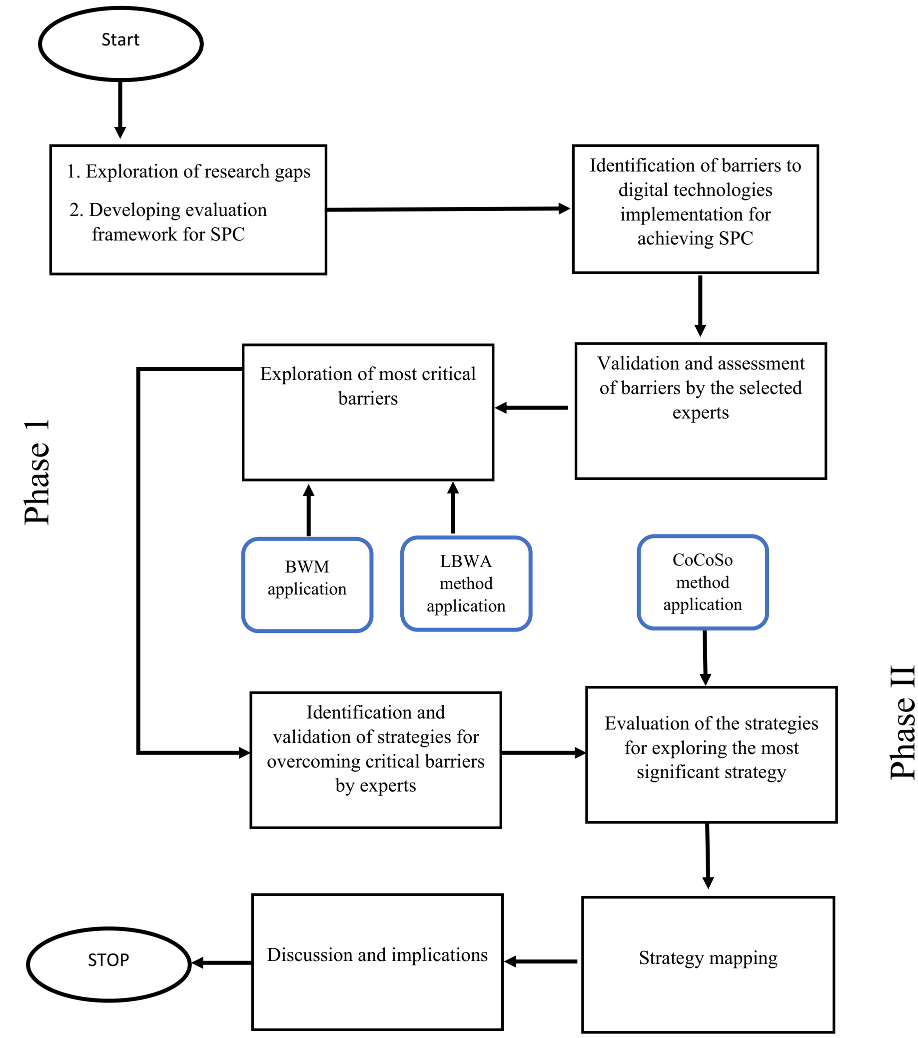

Fig. 1. Proposed framework.

Table 3
BWM consistency index.

a_{Bw}	1	2	3	4	5	6	7	8	9
	0	0.44	1.00	1.63	2.30	3.00	3.73	4.47	5.23

$$r_{ij} = \frac{x_{ij} - \min_i x_{ij}}{\max_i x_{ij} - \min_i x_{ij}} \text{ For benefit criteria} \quad (11)$$

$$rij = \frac{\max_i x_{ij} - x_{ij}}{\max_i x_{ij} - \max_i x_{ij}} \text{ for cost criteria} \quad (12)$$

Step 3. Calculation of the sum of the weighted comparability (Si) and power weighted comparability (Pi) sequences for each alternative using Eqs. (13) and (14):

$$S_i = \Sigma_{j=1}^{n} \left(w_j r_{ij}\right) \quad (13)$$

$$P_i = \Sigma_{j=1}^{n} \left(w_j\right)^{r_{ij}} \quad (14)$$

Step 4. Calculation of relative weights on the basis of three aggregated scores.

$$K_{ia} = \frac{P_i + S_i}{\Sigma_{i=1}^{m}(P_i + S_i)} \quad (15)$$

$$K_{ib} = \frac{S_i}{\min_i S_i} + \frac{P_i}{\min_i P_i} \quad (16)$$

$$K_{ic} = \frac{\lambda(Si) + (1-\lambda)(Pi)}{\lambda \max_i Si + (1-\lambda)\max_i Pi}; 1 \le \lambda \le 1 \quad (17)$$

Step 5. Determine the final ranking of the alternatives based on the cumulative score in descending order (K_i).

$$K_i = (K_{ia}K_{ib}K_{ic})^{\frac{1}{3}} + \frac{1}{3}(K_{ia} + K_{ib} + K_{ic}) \quad (18)$$

K_{ia} signifies the arithmetic mean of WSM and WPM scores;
K_{ib} indicates the sum of WSM and WPM scores;
K_{ic} indicates a balanced compromise score of WSM and WPM
The value of λ ranges from 0 to 1; the threshold value is usually undertaken as 0.50.

4. Results

The weights of the barriers (main criteria and sub criteria) are obtained by BWM and LBWA methods as shown in Tables 4 and 5. The assessment is based on best-to-others and others-to-worst vectors as per

Table 4
Best to others (main criteria).

Experts	Best to others	C_1	C_2	C_3	C_4	C_5	C_6
		REG	FIB	ORB	SCB	BEB	STB
E1	STB	6	3	3	4	5	1
E2	STB	3	6	4	4	3	1
E3	ORB	4	6	1	4	3	4
E4	ORB	3	5	1	4	6	4
E5	STB	4	3	2	3	6	1
E6	REG	1	4	4	4	6	3
E7	ORB	2	3	1	3	6	4
E8	ORG	3	3	1	6	4	4
E9	ORG	4	2	1	6	3	4
E10	STB	4	3	2	4	6	1
E11	STB	4	7	2	4	4	1
E12	ORB	2	5	1	8	3	4
E13	STB	3	4	5	4	7	1
E14	REG	1	6	2	3	8	4
E15	ORB	3	4	1	8	3	3
E16	STB	4	4	2	5	7	1
E17	ORB	3	4	1	8	4	3
E18	STB	4	8	3	5	5	1

Experts: E1-E18; Regulations and policies Barriers, REG (C_1); Financial Barriers, FIB (C_2) Organisational Barriers, ORB (C_3); Supply chain related Barriers, SCB (C_4); Behavioral Barriers (BEB) (C_5); Strategic Barriers (STB) (C_6)

Table 5
Others to the worst (main criteria) (experts E1-E18).

Experts	Others to the worst	C_1	C_2	C_3	C_4	C_5	C_6
		REG	FIB	ORB	SCB	BEB	STB
E1	REG	1	4	3	3	4	6
E2	FIB	4	1	3	4	4	6
E3	FIB	4	1	6	4	3	4
E4	BEB	5	3	6	3	1	3
E5	BEB	3	3	4	3	1	6
E6	BEB	6	3	3	5	1	3
E7	BEB	3	3	6	4	1	4
E8	SCB	2	4	6	1	3	3
E9	SCB	4	3	6	1	4	4
E10	BEB	3	2	4	4	1	6
E11	FIB	3	1	4	4	5	7
E12	SCB	2	4	7	1	4	3
E13	BEB	3	3	3	3	1	7
E14	BEB	8	5	3	4	1	4
E15	SCB	4	3	8	1	3	3
E16	BEB	2	3	4	3	1	7
E17	SCB	4	3	8	1	4	3
E18	FIB	4	1	3	4	4	8

Experts: E1-E18; Regulations and policies Barriers, REG (C_1); Financial Barriers, FIB (C_2) Organisational Barriers, ORB (C_3); Supply chain related Barriers, SCB (C_4); Behavioral Barriers (BEB) (C_5); Strategic Barriers (STB) (C_6)

the Eqs. (1)–(7) in Section 3.1.

4.1. BWM Results

Tables 4 and 5 show the best-to-others and worst-to-worst results. Weights and consistency rate are obtained using a non-linear mathematical model of BWM and are shown in Tables 4 and 5. According to the expert judgements, the results of BWM show that 'C3' is the most significant criterion. The ORB (C3) criterion was chosen by experts E3, E4, E7, E8, E9, E12, E15, and E17 as the 'best to others' criterion.

The 'others to the worst' for the main criteria preference is shown in Table 5. Experts E2, E3, E11, and E18 have selected FIB (C_2) as the 'others to the worst' criteria.

The consistency ratio was checked for all the values obtained by using Eq. (7). All the values were found to be <0.1 (Table 6); hence, this shows that there was no inconsistency issue in the results.

Similarly, the BWM solver was used to compute the weights for the sub-barriers. The global weights of the main criteria (barriers) were also calculated. The ranking was carried out using the global weights and is shown in Table 7.

Table 6
Consistency ratio and ξ^* for main criteria (all experts E1-E18).

Experts	ξ^*	CR
E1	0.0992	0.0331
E2	0.0852	0.0284
E3	0.0888	0.0296
E4	0.0962	0.0321
E5	0.0517	0.0172
E6	0.1117	0.0372
E7	0.0761	0.0254
E8	0.0667	0.0222
E9	0.0789	0.0263
E10	0.0789	0.0263
E11	0.0890	0.0297
E12	0.0840	0.0280
E13	0.0610	0.0203
E14	0.0995	0.0332
E15	0.0367	0.0122
E16	0.0563	0.0188
E17	0.0585	0.0195
E18	0.0781	0.0260

4.2. Level-Based Weight Assessment (LBWA) Results

Similarly, experts were asked to determine which criterion is the most important. The aggregate weights for the criteria were obtained using the step-by-step process described in Section 3.2. Based on the expert responses, criteria C3, C6, and C1 are grouped in Level 1, while criteria C2, C4, and C5 are grouped in Level 2. Table 8 shows the results of using the steps described in Section 3.2 and Eqs. (8), (9) and (10).

Based on the obtained weights, the ranking has been made. Organisational Barriers, ORB (C_3) are the most significant barriers for SPC in FSC; Strategic Barriers (C_6) are the second highest.

4.3. Weight aggregation results

The aggregated weights for the criteria are calculated using Eq. (9). The aggregated weights are shown in Table 9.

The BWM results show an organisational barriers (C3) weightage of 0.2742, an LBWA weightage of 0.2816 and an aggregate weightage of 0.414. Based on the above results, it is clear that organisational barriers (C3) are the most prominent, obtaining the highest weightage. Behavioral barriers (C5) have the least weightage based on BWM results and aggregated weightage; they are rated as the least significant barrier.

5. Discussion

This section expands on the research findings using an integrated BWM-LBWA-CoCoSo model. The study contributes to the investigation of existing issues concerning barriers to implementing digital technologies in the FSC to achieve SPC. The research investigates the barriers to digital technology implementation in the SPC food supply chain and proposes strategic solutions to each barrier using an integrated approach of BWM-LBWA-CoCoSo. The study's goal is to provide information to food industry decision-makers who are implementing digital technologies in their supply chains to achieve SPC. The obtained results for critical barriers were discussed with the experts in preparation for further strategic solution mapping.

The literature review identified barriers such as a lack of policy interventions, internal organisational structure, financial constraints and so on, demonstrating the need to improve transparency and traceability while fostering a culture of adaptability. A total of 21 barriers are classified as regulations and policies barriers (C1), financial barriers (C2), organisational barriers (C3), supply chain related barriers (C4),

Table 7
Global weights.

Main Criteria	Code	Sub-Criteria	Main criteria (Weights)	Sub-criteria (Weights)	Global weights	Rank
Regulations and policy barriers, REG (C_1)	BSPC1	Weak environmental regulations for FSC	0.1660	0.114	0.0189	15
	BSPC2	Lack of standardized framework and standards		0.133	0.0220	14
	BSPC3	Lack of stringent national policy for sustainable production and consumption / or CE policy		0.164	0.0271	13
Financial barriers, FIB (C_2)	BSPC4	Limited funds	0.1130	0.114	0.0129	16
	BSPC5	High operational cost		0.142	0.0161	17
Organisational barriers (C_3)	BSPC6	Lack of experts	0.2742	0.107	0.0293	12
	BSPC7	Lack of change management capabilities		0.318	0.0872	1
	BSPC8	Less skilled workforce		0.158	0.0433	3
	BSPC9	Benchmarking/Standards		0.152	0.0417	4
	BSPC10	Risk-averse culture		0.137	0.0376	7
	BSPC11	Lack of IT infrastructure/ technical incompetency		0.133	0.0365	9
Supply chain-related barriers, SCB (C_4)	BS5C12	Lack of cross-sector collaboration/ inability to work across silos	0.1028	0.318	0.0327	10
	BSPC13	Aversion of the supply chain members to exchange information		0.100	0.0103	18
	BPSC14	Lack of support from SC actors		0.085	0.0087	19
Behavioral barriers BAB (C_5)	BPSC15	Less priority of the firms	0.0955	0.065	0.0062	21
	BPSC16	Lack of interest and commitment by top-level management		0.089	0.0085	20
Strategic barriers, SAB (C_6)	BPSC17	Lack of technology know-how for implementation	0.2484	0.153	0.0380	6
	BPSC18	Lack of training to develop the skilled workforce		0.192	0.0477	2
	BPSC19	Absence of environmental education		0.122	0.0303	11
	BPSC20	Lack of circular design aspect		0.148	0.0368	8
	BPSC21	A lack of agility and insufficient encouragement towards innovation/lack of readiness		0.159	0.0395	5

Table 8
LBWA weightage of criteria.

Criteria	LBWA weightage	Ranking
C_1	0.1689	2
C_2	0.1206	4
C_3	0.2816	1
C_4	0.1299	3
C_5	0.1299	3
C_6	0.1689	2

Table 9
Aggregated weight calculations.

Criteria	LBWA weightage	BWM weightage	Aggregated weightage	Rank
C_1	0.1689	0.1660	0.150	3
C_2	0.1206	0.1130	0.073	4
C_3	0.2816	0.2742	0.414	1
C_4	0.1299	0.1028	0.072	5
C_5	0.1299	0.0955	0.066	6
C_6	0.1689	0.2484	0.225	2

behavioral barriers (C5) and strategic barriers (C6). The critical barriers were identified and assessed using BWM-LBWA methods. Section 4 presents the results obtained using both methods.

According to the findings, 'organisational barriers' are the most important in the FSC for achieving SPC. The organisational context includes internal focal firm concerns (Kouhizadeh et al. (2021). Interdisciplinary participation must be increased to instill sustainability into the processes. According to Kouhizadeh et al. (2021), one of the primary adoption barriers for sustainable supply chains is a lack of experts and limited knowledge of blockchain technology; this is classified as an 'organisational barrier'. A lack of commitment from top management is also a critical issue in blockchain implementation (Mangla et al., 2017).

According to the findings, the most significant barriers are 'organisational barriers,' followed by 'strategic barriers'. Organisations are challenged to adapt to changes due to internal weaknesses and mindsets; organisational barriers are the most significant barriers to environmental management. The current findings are consistent with previous research. An organisation may be uneasy about implementing new technology that would result in new sustainable practices that could have a negative impact on perceived ease of use (Kamble et al., 2019; Annosi et al., 2019). The current study lists the main criteria 'organisational barriers' containing six sub-barriers. 'Lack of change management capabilities' received the highest weight, followed by 'less skilled workforce.' This demonstrates that organisational culture has always acted as a barrier to change, causing businesses to be wary of digital technologies (Bellantuono et al., 2021). Because of a scarcity of experts in the field, organisations are sometimes unable to adapt to radical changes that are required in production (Mukhuty et al., 2022). Previous research has shown that technological advancements and upgrades are required to facilitate resource/material efficiency and to improve sustainable production and processes (Balachandra et al., 2010; Mangla et al., 2017). George et al. (2021) investigated innovative digital technologies that provide an effective means of addressing sustainability-related challenges. To achieve sustainable development, organisations must undergo fundamental and transformative change in their capabilities. A significant concern for organisations is the lack of a skilled workforce. This gap is widening as the pace of change quickens, resulting in stagnant growth for the organisation (Kumar et al., 2021). To achieve sustainable development, organisations must undergo fundamental and transformative change in their capabilities.

Strategic barriers are the second most important. 'Lack of training for developing skilled workers' received the second highest weight. According to previous literature, the sources of long-term challenges are a lack of a strategic approach by an organisation and its inability to implement technologies in their supply chains to improve SPC (Gunasekaran and Spalanzani, 2012; Dora et al., 2021). Strategic planning is inadequate for digital technology implementation in order to create a sustainable model for FSC production and consumption. This main barrier has five sub-barriers, the most important of which is 'lack of training support', highlighting the absence of a coordinated approach to implementation. 'Lack of agility and insufficient encouragement to innovate' is another barrier impeding the implementation of digital technologies. Dora et al. (2021) discovered that technology readiness, regulatory compliance, competitor pressure and information sharing among partners are the primary factors driving AI adoption in the FSC. Organisations must prioritise by responding quickly to the changing needs of stakeholders, particularly customers. To cope with the dynamic environment, supply chains must be made more agile (Farahani et al., 2014; Do et al., 2021). This is possible with the implementation of advanced technologies in supply chains.

The third most critical barrier is a lack of stringent national CE policy. According to Ludlow et al. (2021) policy-related barriers are significant. Currently, India lacks stringent laws, rules and regulations for dealing with end-of-life products or components. This indicates the need to develop stringent policies to reduce waste through the adoption of circular practices (Mangla et al., 2018).

6. Strategy mapping and its implications

Weights from the BWM-LBWA approach and expert judgements were used to identify and evaluate the strategies. Similarly, experts have identified and validated strategies as seen from previous literature. Table 10 shows a list of strategies.

The experts validated all of the identified strategies shown in Table 10. Experts were also asked to rate the strategies on a scale of 1 to 7 against each barrier. The weights for criteria (barriers) were taken from the BWM-LBWA results to measure the weightage. The CoCoSo method was used to rank strategies; final results are displayed in Table 11.

The results of the CoCoSo application indicate that the strategy alternative 'focus on enhancing commitment from top management towards sustainable production and consumption' (S12) is the most promising solution to address the issue. Based on these results, it is concluded that workforce training plays an important role in successfully implementing digital technologies in FSC to achieve SPC.

Significant changes that have positively impacted product end-of-life include Industry 4.0 technologies, data management, real-time decision-making and innovative practices. Organisations that implement digital technologies may improve SPC while decreasing food loss and waste (Gölzer and Fritzsche, 2017). Training and workshops aimed at developing a skilled workforce will aid efficient implementation of digital technologies. As technology advances, the skills gap between the existing workforce and the required skill set must be narrowed.

Today's ecosystem requires collaboration among supply chain partners; there must be high levels of coordination involving food producers, trading firms, corporations and other external parties. It will gradually strengthen the food supply chain to make it more agile and resilient. In addition, participation in the FSC helps stakeholders improve their financial performance by adding value and gaining a competitive advantage while maintaining ecological sustainability; overall sustainability leads to lower carbon footprints and a decrease in food waste (Zhao et al., 2021; Yadav et al., 2022).

Table 10
Strategies for enhancing SPC through digital technologies.

Code	Strategies	References
S1	Stringent CE policy for digital technology implementation to minimize food waste	Massaro et al. (2021)
S2	Enhancing traceability through digital technologies for control of waste and enhancing SPC	Feng et al. (2020).
S3	Monitoring the implementation of digital technologies	Kayikci et al. (2022)
S4	Standardizing the protocols for digital technology implementation	Tseng et al. (2021)
S5	Digital technologies for enhancing cross-sector collaboration through the CE model for SPC of FSC	Lopes de Sousa Jabbour et al. (2021)
S6	Digital technology implementation absorption in FSC vision and its strategic planning	Lopes de Sousa Jabbour et al. (2021)
S7	Training and workshops to develop a skilled workforce	Sachs et al. (2019)
S8	Financial support for technology upgradation for SPC of FSC	Alkhuzaim et al. (2021)
S9	Industry 4.0 based circular design model for SPC of FSC	Annosi et al. (2021)
S10	Government incentives for SPC of FSC through digital technologies	Roy et al. (2022)
S11	Connect to customers through digital technologies to enhance sustainable consumption measure	Kamble et al. (2020)
S12	Focus on enhancing commitment from top management towards SPC	Roy and Singh (2017)

The current study identifies 'digital technologies for cross-sector collaboration' as one of the effective strategies. Mensi and Udenigwe (2021) discussed how multi-sector collaboration could assist various food retail internet economies in making significant contributions to sustainable food waste recovery, reducing food waste and achieving SDG targets. Jagtap and Duong (2019) discussed the use of big data to improve the design of product networks. Irani et al. (2018) went on to explain how data modelling techniques can be used to manage inventory turnovers, improve the volume of sales, improve consumer food retailing experiences (product offerings and cash discounts) in superstores and improve food security. Data analytics has been extensively researched for predicting demand, selecting sustainable suppliers and engagement (Seyedan and Mafakheri, 2020). It has been demonstrated in a few empirical studies that big data contributes positively to the long-term viability of the FSC (Barbosa et al., 2018; Dubey et al., 2019). Customers are the most important stakeholders in bringing about change in sustainable consumption, so digital technologies should be used to communicate and interact with them directly. App-based communication will aid in the promotion of sustainable consumption education and can instill a sense of responsibility in consumers.

Based on the results, a strategic framework is developed on the level of digital technology implementation and organisational barriers as shown in Fig. 2.

The study sheds light on the barriers faced by firms to achieve SPC through digital technologies and how changes can boost circular performance in the current disruptive environment. Food waste is a massive problem in both developing and developed nations; the causes are diverse. Very few types of food waste are unfit for human consumption and must be reprocessed to recover their value. Additionally, environmental risks and hygiene issues are associated with managing food waste. Advanced technologies have the potential to aid businesses in addressing challenges and creating value. Using BDA, IoT and AI, food waste can be reduced through traceability, information sharing and decision-making support. This study suggests that firms should concentrate on their structural and strategic factors for implementation of digital technologies to improve SPC in FSC. It primarily contributes to the analysis of barriers identified and the strategies needed to overcome them, in order to improve the implementation of digital technologies for SPC of FSC. In the strategic vision and planning of an organisation, it is essential to have a digitally-enabled FSC with SPC. According to the results, the commitment of top management in undertaking initiatives to improve the efficiency of SPC implementation through digital technologies is significant. For long-term benefits, managers must acknowledge organisational barriers in the implementation of digital technologies for SPC initiatives and the economic benefits of SPC adoption. This study also indicates that digital technologies can assist in informing supply chain actors and the agricultural community to accept SPC initiatives in FSC. Apps and digital campaigns may augment FSC's SPC capacities. This study aims to raise stakeholder awareness about adopting sustainable consumption practices.

Integration of digital technologies has the potential to transform the FSC in rural and semi-urban areas. Before implementing digital technologies in the agriculture and food sector, certain conditions must be met; these include infrastructure, connectivity, network coverage, internet access, electricity supply, affordability and institutional support (fao.org). Digital technologies may offer significant benefits to farmers and other rural businesses through the provision of information, strategic partnerships, the provision of support services such as training, finance and legal services, and, most importantly, the ability to reach markets and customers (fao.org). This study provides insights to decision-makers, policymakers and industry decision-makers to encourage them to adopt strategies to mitigate the barriers that hinder

Table 11
Ranking of strategies for overcoming barriers to digital technologies for SPC.

Strategies	K_a	Rank	K_b	Rank	K_c	Rank	k	Final Rank
S1	0.094	4	6.552	6	0.800	5	3.27	5
S2	0.074	6	5.680	5	0.635	8	2.78	6
S3	0.085	5	5.185	7	0.728	6	2.69	7
S4	0.076	7	2.675	9	0.647	7	1.64	8
S5	0.108	3	6.842	3	0.920	4	3.50	4
S6	0.048	10	2.752	8	0.413	9	1.45	9
S7	0.111	2	7.185	2	0.947	2	3.66	2
S8	0.094	4	6.552	5	0.800	5	3.27	5
S9	0.094	4	6.552	6	0.800	5	3.27	5
S10	0.085	5	5.185	7	0.728	6	2.69	7
S11	0.108	3	6.856	4	0.923	3	3.51	3
S12	0.117	1	8.344	1	1.00	1	4.15	1

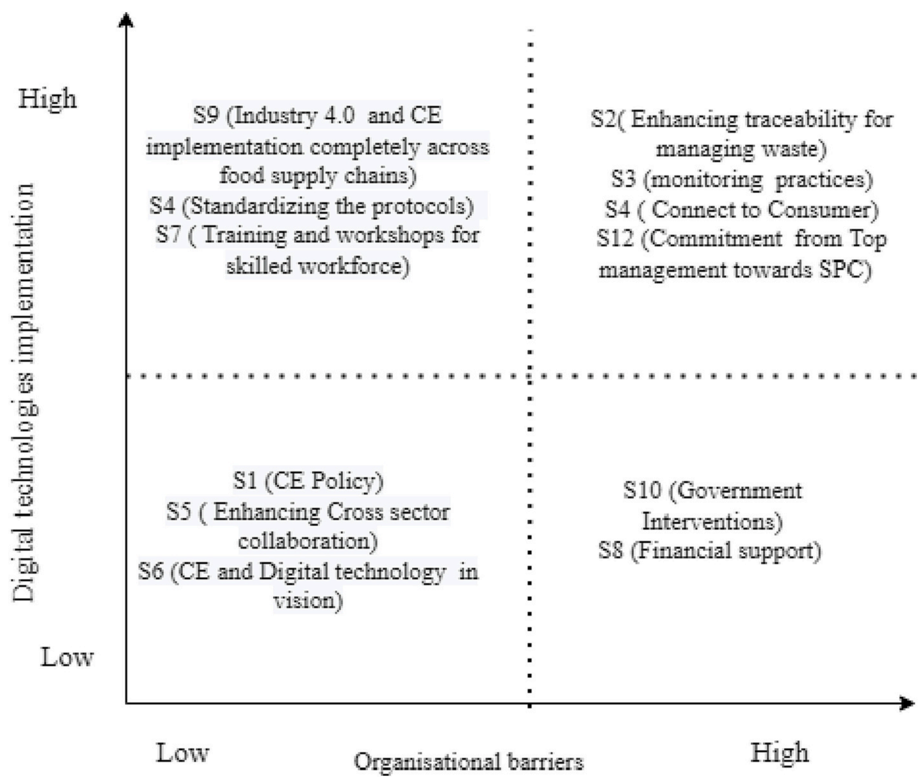

Fig. 2. Strategic framework.

the implementation of digital technologies for SPC in FSC.

There are some limitations, particularly concerning the analysed environment. This is restricted to a sample of firms operating in supply chain integration, food waste management, digitalization management and information sharing. To improve SPC and resource efficiency in other industries, such as manufacturing and services, the proposed model can be expanded. The work can also be extended to other developing countries where digital technology implementation in the FSC is in the initial phase. Also, other multicriteria decision making techniques under fuzzy environment could be explore in future (Xu et al., 2023).

7. Conclusion

The study has identified barriers and suggested solutions for implementing digital technologies in FSC to achieve SPC. The study has evaluated the barriers and mapped a strategy to overcome each barrier to efficiently implement digital technologies. The identified barriers include the need for policy interventions, organisational structure and financial constraints. In addition, a robust model is created to assess the existing barriers in implementing digital technologies for SPC of FSC. BWM-LBWA and CoCoSo methods were used to assess the identified and validated strategies. These barriers demonstrate the need to improve transparency and traceability, foster a culture of change adaptation and meet sustainability requirements. Unquestionably, in the pursuit of enhanced SPC for achieving sustainable development, the emphasis must be placed on shared action plans and product price-related information that directly influences the implementation of digital technologies that may prevent food waste. In the first phase, barriers were identified, validated and evaluated using BWM and LBWA methods; this was useful for exploring the aggregate weighting of the barriers and identifying the most significant. During the second phase, mitigating strategies were derived from previous research, validated by experts and evaluated using the CoCoSo application.

To achieve SDG-12, a more comprehensive approach to decision-making and behaviour modification is required, in which individuals are not targeted in isolation, but rather in conjunction with the larger systemic environment. In addition, the role of flexibility in supply chains is significant as it could facilitate the growth of a local FSC. To make business competitive on the global market, intelligent networks should be developed in which businesses share their resources.

This study has revealed that the internal environment, including organisational barriers such as aversion to change or a lack of priority from top management, imposes limitations on developing positive employee behaviour. This study provides insights to business decision-makers regarding the primary barriers to digital technologies that limit the SPC of FSC. The strategies were identified and evaluated using CoCoSo, and the results indicate that "focus on enhancing commitment from top management towards SPC processes in supply chains" is the most preferred strategy.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgment

This research was partially supported by a Grant from the Danida Fellowship Centre (Project no. 20- M11SDU).

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.spc.2023.04.002.

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