Critical success factors of food safety management for achieving climate neutrality: a multilevel moderated approach with industry revolution 4.0

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Abstract

Purpose – The growing awareness of climate risks associated with food safety issues has drawn the attention of stakeholders urging the food industry to carry out a sustainable food safety management system (FSMS). This study aims to investigate whether the critical success factors (CSFs) of sustainable FSMS can contribute to achieving climate neutrality, and how the adoption of FSMS 4.0 supported by the Industry Revolution 4.0 (IR 4.0) technologies moderates the impact of the CSFs on achieving climate neutrality.

Design/methodology/approach – Survey data from 255 food production firms in China and Vietnam were utilised for the empirical analysis. The research hypotheses were examined using structural equations modelling (SEM) with route analysis and bootstrapping techniques.

Findings – The results show that top management support, human resource management, infrastructure and integration appear as the significant CSFs that directly impact food production firms in achieving climate neutrality. Moreover, the results demonstrate that the adoption of FSMS 4.0 integrated with the three components (ecosystems, quality standards and robustness) significantly moderates the impact of the CSFs on achieving climate neutrality with lower inputs in human resources, infrastructure investment, integration and external assistance, and higher inputs in strengthening food safety administration.

Originality/value – This study provides empirical findings that fill the research gap in understanding the relationship between climate neutrality and the CSFs of sustainable FSMS while considering the moderating effects of the FSMS 4.0 components. The results provide theoretical and practical insights into how the food production sector can utilise IR 4.0 to attain sustainable FSMS for achieving climate neutrality.

Keywords Critical success factors, Food safety management system, Climate neutrality, Industry revolution 4.0, Sustainability, Vietnam, China

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1. Introduction

The growing and widespread awareness of climate risks associated with food safety issues has drawn the attention of stakeholders urging firms to carry out sustainable food safety management systems (FSMS) in food production (Duong *et al.*, 2023; FAO, 2020). As the world faces a dynamic shift towards a sustainable agricultural system and food production practices in the face of climate change, the consideration of food safety is imperative in ensuring safe food is available throughout the food supply chain (IPCC, 2018). Climate neutrality resonates with the goal of net-zero emissions which can be achieved by balancing the total amount of harmful gas emissions (Acampora *et al.*, 2023; Ngo *et al.*, 2023), such as carbon dioxide, methane, and nitrous oxide emissions produced directly or indirectly by a country, firm, product, activity, or individual over a certain period via carbon offset or removal initiatives (Mishra *et al.*, 2022; Torkayesh *et al.*, 2022). Food production with no carbon-neutralising practices can deteriorate climate neutrality by generating harmful gas emissions and feed waste (Abbas *et al.*, 2023a), and exacerbate the outbreak of food-borne diseases and pathogens in the food supply chain that worsen mass public health (Hassoun *et al.*, 2023).

Critical success factors (CSFs) can be viewed as a benchmarking instrument for assessing the efficient operations among the managerial or enterprise elements that impact the firm's performance toward accomplishing their strategic goals (Dora *et al.*, 2021; Kannan, 2018; Truong *et al.*, 2017). Without a deep understanding of the CSFs that impact the sustainability of FSMS, food supply chain management can be exposed to food safety risks. In the meantime, the emergence of the Fourth Industrial Revolution (IR 4.0) in recent years has raised the interests of food supply chain stakeholders and scholars in understanding how the FSMS can be enhanced with advanced IR 4.0 technologies in the global food supply chain (Bui *et al.*, 2022; Liu *et al.*, 2020). Recent studies showed that the efficacy of FSMS can be enhanced with advanced IR 4.0 technologies, such as smart sensor-equipped devices able for food hazard detection, data storage and control with cloud computing, smart devices for traceability (Hassoun *et al.*, 2022; Bui *et al.*, 2022), artificial intelligence (AI) information management system (Akbari *et al.*, 2023; Liu *et al.*, 2021a), and the farm-to-fork food traceability system with blockchain technology and Internet of Things (IoT) (Khan *et al.*, 2020).

Prior studies showed that there is a research gap in understanding the quantifiable relationship between CSFs, such as top management support, human resource management, infrastructure, integration, external assistance, and food safety administration with the firm's performance in achieving climate neutrality and sustainability (Abbas *et al.*, 2022, 2023a, b; Yontar, 2023; Nguyen and Li, 2022; King and King, 2020). While studies individually address aspects like the effectiveness of Food Safety Management Systems (FSMS) in global supply chains (Duong *et al.*, 2023; Nguyen and Li, 2021), the role of advanced digital technologies in agri-food supply chains (Yontar, 2023), and strategies for reducing waste (Abbas *et al.*, 2023a), they fall short in explicitly linking these CSFs to the specific goal of climate neutrality within firms. Particularly, the impact of these factors on a firm's carbon footprint, sustainable practices, and overall environmental impact remains underexplored. This suggests a need for more focused research on how internal and external factors within an organisation specifically contribute to or hinder the attainment of climate-neutral operations, especially in the context of the agri-food sector and supply chain management. Understanding this relationship is crucial for developing more effective strategies and policies that align business operations with climate neutrality goals.

Nonetheless, there is a dearth of literature that investigates what are the CSFs in FSMS that can foster climate neutrality and how the adoption of IR 4.0 in the FSMS can influence the impact of the CSFs on achieving climate neutrality. There are also calls for more research on how the adoption of IR 4.0 can play an important role in FSMS for achieving sustainable development goals (Yuan *et al.*, 2022; Liu *et al.*, 2021a; Wei *et al.*, 2021). Therefore, the research on the CSFs in the food production sector that foster the achievement of climate neutrality has taken on a new sense of urgency.

In this study, we define FSMS 4.0 as the food safety management system integrated with IR 4.0 technologies that enable sustainable integration of traceability, authentication, collaboration, and continuous improvement in food safety governance. We further define the initiative of firms in achieving climate neutrality as the ethical practice in food safety management such as reducing carbon emissions, methane and nitrous oxide, increasing renewable energy utilisation, reducing natural resources consumption, and implementing effective packaging waste management, and food preservation methods. Based on the arguments, this study proposes the following two research questions (RQs):

RQ1. Can the CSFs in the FSMS of food production firms impact the achievement of climate neutrality?

RQ2. How does the implementation of FSMS 4.0 moderate the impact of the CSFs on climate neutrality?

A novel combination of the CSF theory and FSMS is utilised in this study to construct the conceptual framework with hypotheses to address the research questions. Data gleaned from a survey of 255 food production firms in China and Vietnam were analysed using the partial least squares structural equation modelling (PLS-SEM) estimation method. Our study contributes to the extant literature by investigating whether the food production firms can align their CSFs in FSMS to respond to climate neutrality and whether the adoption of IR 4.0 technologies can moderate the impact of the CSFs on climate neutrality. Moreover, the results of this study can provide reference to the upstream and downstream food production firms in the global supply chains on how to revitalise their corporate social responsibility (CSR) to resonate with the growing awareness of achieving sustainable development goals in the era of the emerging IR 4.0 technologies.

The remainder of this paper is organised as follows. Section 2 reviews extant literature and presents the hypothesis development for this study. Section 3 outlines the research methodology of this study. Section 4 presents the analysis of the results and discusses the findings. Finally, Section 5 presents the conclusion with the theoretical and managerial implications, caveats and future research directions.

2. Theoretical background

2.1 Critical success factors theory

Critical success factors (CSFs) are defined as "those few things that should go well to ensure success" that apply to any type of industry (Dora *et al.*, 2021; Duong *et al.*, 2019). The CSFs theory suggests that if organisations intend to attain specific goals, the decision-making and operational management process toward the specific goals can become complicated due to the presence of heterogeneous elements to be considered. Hence, rather than examining all of the success factors, the organisation should concentrate on the CSFs that will contribute dominantly to the organisation's success or failure (Zhang *et al.*, 2022; Dora *et al.*, 2021). The CSFs theory has been extended to the studies on CSR (Dora *et al.*, 2021; Moktadir *et al.*, 2020), such as the studies on constructing sustainable supply chains (Ngo *et al.*, 2023; Ghobakhloo, 2020; Kannan, 2018), green supply chain management (Pham *et al.*, 2023; Moktadir *et al.*, 2020), and food safety governance (Lu *et al.*, 2021). These prior studies have emphasised that firms should emphasise the CSFs of their business performance that contribute to sustainable social and environmental ecosystems.

In this study, we derive the CSFs for the sustainable FSMS from the literature review. The literature review was conducted from the published journal research papers and industry review reports that related to food safety management and IR 4.0 technologies. Databases such as Web of Science and Scopus were used to collect strands of literature. The keywords such as "critical success factors", "food safety management system", "food quality standard", and "IR 4.0 technologies" were used to collect the relevant literature from the databases. The CSFs for sustainable FSMS can be categorised into three categories: organisational, market, and food safety administration CSFs. Table 1 presents the summary of the literature review.

2.1.1 Organisational CSFs. The three organisational CSFs consist of top management support, human resource management, and infrastructure. Top management support is an important organisational CSF that is accountable for developing and implementing food safety governance. Top management support is a CSF for achieving food safety priorities through the initiatives of delegating responsibilities and authority to food safety and food handlers within their organisation (De Boeck *et al.*, 2018; Truong *et al.*, 2017), assuring the requisite resources are accessible and the workforce for food safety management is adequately instructed (Kirezieva *et al.*, 2015b), and creating the organisational culture that emphasising high food safety standards (Isensee *et al.*, 2020). Besides, human resource management is the organisational CSF for the development, implementation, maintenance, and upgrading of FSMS (Nguyen and Li, 2021; Arvanitoyannis, 2009). Prior studies showed that human resource management in food safety governance can be enhanced in the forms of, such as employee engagement (Overbosch and Blanchard, 2023; Duong *et al.*, 2023), staff training programs for knowledge and expertise enhancement (Kumar *et al.*, 2022), and recognition of staff contributions for innovating a better food safety management (Oztemel and Gursev, 2020). Moreover, infrastructure is the organisational CSF that adds to the significance of infrastructure investment in improving the efficacy of FSMS (Mishra *et al.*, 2022), and enhancing the quality of the operational workplace that renders worker's health, safety, and better job performance in the food production operations (Xiong *et al.*, 2017).

2.1.2 Market CSFs. The two market CSFs comprise integration and external assistance. An interactive supply chain is characterised by stringent stakeholder expectations, robust supplier relationships, and extensive information sharing within the supply chains (Duong *et al.*, 2023; Schmelzle and Mukandwal, 2022; Kirezieva *et al.*, 2015b). Improved quality, lower costs, and consistent delivery are the competitive advantages primarily driven by the greater integration between multiple stakeholders in the food supply chain (Nguyen and Li, 2021). Moreover, external assistance is a market CSF that determines the effectiveness of FSMS. External assistance deficiency in the supply of essential facilities, equipment, and experienced labour often discouraged suppliers' adherence to food safety requirements. Food production firms often request external assistance for funds to upgrade infrastructure, provide professional training to staff (De Boeck *et al.*, 2018), and pursue food quality certification (Abbas *et al.*, 2023a).

2.1.3 Food safety administration CSF. Food safety administration CSF ensures the standards and legislation governance of controlling food safety (Kumar *et al.*, 2022). An effective food safety administration process is crucial to ensure food producers adhere to the standards set forth by local authorities. Food safety administration processes include assessments and site inspections, document tracking, arbitrary or periodic audits and inspections before or after the distribution of commodities at businesses, retail outlets, or exporting terminals (Lu *et al.*, 2021; FAO, 2020). Prior studies showed that the food safety administration CSF in food production firms that adhere to the Hazard Analysis and Critical Control Point (HACCP) system in their food safety assessment and benchmarking tool can foster higher HACCP effectiveness in improving food safety and render higher customer loyalty and trustworthiness in their business performance (Utz *et al.*, 2023; Duong *et al.*, 2023; Kafetzopoulos and Gotzamani, 2014).

2.2 Relationships between the CSFs and climate neutrality

2.2.1 Organisational CSFs and climate neutrality. Food safety is integral for all food production firms to fulfil their business values from a sustainable environmental and

References	Wilcock *et al.* (2011)	Mensah and Julien (2011)	Kafetzopoulos and Gotzamani (2014)	Kirezieva *et al.* (2015a)	Kirezieva *et al.* (2015b)	Xiong *et al.* (2017)	Lu *et al.* (2021)	Zhao *et al.* (2021)	Nguyen (2022)	Pincheira *et al.* (2022)
Sector	Food	Food	Agrifood	Leafy greens	Food	Pork	Food	Agri-food	Food	Agri-food
Country study	Canada	The UK	Greece	Spain, Belgium, Norway	Twelve developed and developing countries	China	Chile	China	Vietnam	Italy
Organisational CSFs										
Leadership	✓	✓							✓	
Human resource management	✓	✓	✓							
Infrastructure			✓							✓
Technology			✓							✓
Standardised process		✓	✓	✓		✓				✓
Market CSFs										
Integration									✓	
Cooperative and supportive		✓		✓			✓	✓	✓	
Domestic/Foreign						✓			✓	
External assistance	✓			✓					✓	
Food safety administration CSF										
Food safety		✓		✓	✓		✓		✓	
Agroclimatic					✓					
Public policy					✓		✓		✓	

Source(s): Authors' own work

Table 1.
Critical success factors (CSFs) of the food sector adapted from the literature review

socioeconomic development perspective (Jagtap and Duong, 2019). Top management support of firms with intrinsic sustainable environmental values plays a pivotal role in the initiation and progression towards carbon neutrality which can improve business legitimacy and reputation (De Boeck *et al.*, 2018). Top management support of firms can initiate leadership and cultivate the organisational culture that commits to transition towards carbon neutrality (Wang *et al.*, 2022). Employees are more likely to work for transitioning toward carbon neutrality based on the firm's sustainable enterprise business value and the operational direction of the top management (Zhang *et al.*, 2022). Besides, sufficient human resource capacity with people from different expertise is needed for firms to deploy the knowledge and skills in production, facilitate partnerships to reach unified climate change mitigation objectives (Acampora *et al.*, 2023), and attain equitable decisions and effective coordination between multiple stakeholders in achieving climate neutrality (IPCC, 2018). In addition, the infrastructure combined with advanced information technologies enables firms to analyse a vast volume of heterogeneous data to detect and prevent foodborne hazards (FDA, 2020), improve FSMS with low-cost and simple-to-implement algorithmic power (Agrawal *et al.*, 2018), and contributes to the energy efficiencies improvement of infrastructure in achieving climate neutrality (Torkayesh *et al.*, 2022).

2.2.2 Market CSFs and climate neutrality. The integrated surveillance approach with strengthened communication and cooperation among professionals is crucial for mitigating the adverse impact of climate change on foodborne disease (FAO, 2020). Firms can form long-term strategic alliances to achieve carbon neutrality via the collaborative, coordinated, and integrated supply chain (Dora *et al.*, 2021). Food supply chain integration can result in a cascade impact of collaboration and commitment to move towards carbon neutrality across multi-tier food supply chain operators (Nguyen and Li, 2021). Moreover, food production firms can foster wider external assistance among their public health authorities, counterparts auditors in veterinary, crop health, food safety offices, and research and development partners such as universities to work collectively in addressing climate change issues (De Boeck *et al.*, 2018).

2.2.3 Food safety administration CSF and climate neutrality. Food safety administration with periodic audits and inspections can provide valuable insights to the food safety professionals in the integrated network of the food supply chain, and thus reduce the time needed for risk assessment and prevention in the food production process (Overbosch and Blanchard, 2023). Access to food safety insights with data analytics enables food producers to identify, monitor, and prevent any increasing risks or incidents (Overbosch and Blanchard, 2023). Furthermore, the mitigation of food safety risks under climate change can be addressed through the design of an effective food safety governance process that involves risk assessment, risk management, and risk communication across different inspection parties in the food production process flow (Feliciano *et al.*, 2022).

In the realm of achieving climate neutrality, literature provides valuable insights into the role of Critical Success Factors (CSFs). These factors include top management support, human resource management, infrastructure, integration, external assistance, and food safety administration, each playing a pivotal role in enhancing a firm's performance towards this environmental goal.

Top management support emerges as a cornerstone in driving climate neutrality initiatives within organisations. The commitment and strategic orientation of top management towards sustainability are crucial for setting clear environmental goals and allocating necessary resources. This leadership is instrumental in embedding climate-conscious practices into the core business strategy, thereby steering the entire organisation towards reduced environmental impacts and enhanced sustainability (Nguyen and Li, 2021).

Human resource management is another key factor impacting a firm's journey towards climate neutrality. This entails nurturing a sustainability-centric culture within the workforce through training and engagement in environmentally friendly practices. When employees are well informed and involved in sustainability initiatives, they can significantly contribute to reducing the firm's carbon footprint and achieving broader environmental objectives (Wang and Zhao, 2023).

Infrastructure is also a critical aspect. Sustainable and energy-efficient infrastructure in a firm can substantially reduce its environmental impact. In the agri-food sector, for instance, sustainable infrastructure plays a vital role in minimising waste, optimising resource use, and thereby contributing significantly to climate neutrality (Yontar, 2023).

Integration of sustainability practices across all organisational levels further amplifies the impact on climate neutrality. This involves incorporating environmentally friendly practices in procurement, production, distribution, and waste management. Particularly, the integration of advanced digital technologies like blockchain enhances transparency and efficiency in supply chains, leading to reduced environmental impacts and moving closer to achieving climate neutrality (Abbas *et al.*, 2023a).

External assistance, including regulatory support, technological collaborations, and partnerships with environmental organisations, is essential in bolstering a firm's sustainability efforts. Access to external expertise and resources can facilitate the adoption of innovative technologies and practices that are crucial for environmental stewardship and achieving climate neutrality (Yontar, 2023).

Lastly, effective food safety administration is critical, especially in the agri-food sector, for achieving sustainability and climate goals. Efficient production and distribution practices that ensure food safety can help minimise waste and resource misuse, which are key elements in reducing the environmental impact and advancing towards climate neutrality (Nguyen and Li, 2021).

Taken together, these CSFs create a synergistic effect that propels firms towards reducing their environmental footprint and achieving climate neutrality. By integrating these factors into their operations, firms can make significant strides in their environmental performance, contributing to the global effort to combat climate change. In this study, we argue that the CSFs of food production firms in FSMS can positively impact their performance in achieving climate neutrality. Hence, based on the arguments, we propose the following hypothesis:

H1. The CSFs (top management support, human resource management, infrastructure, integration, external assistance, and food safety administration) are positively impact the firm's performance in achieving climate neutrality.

2.3 Food safety management system with IR 4.0 (FSMS 4.0)

The implementation of efficacy FSMS with high food safety standards and risk assessment is crucial for sustainable food business performance (Overbosch and Blanchard, 2023). Prior research showed that around 30% of edible foods are wasted at various stages of the food supply chain due to insufficient adoption of advanced technology (Rezaei and Liu, 2017). The enormous technological advancements in recent years have resulted in the birth of IR 4.0 with the key elements of automation and interconnection (Oztemel and Gursev, 2020). IR 4.0 is an interdisciplinary area that encompasses a broad range of knowledge from physics, biology, and digital realms (Chapman *et al.*, 2022). IR 4.0 has been characterised by its smart systems and higher intelligent manufacturing and production processes in increasing production efficiency, food safety and reducing food waste (Ghobakhloo, 2020; Oztemel and Gursev, 2020). Prior studies indicated that the adoption of IR 4.0 technologies at all stages of the food production process is shown to significantly improve food safety (Hassoun *et al.*, 2023), reduce food waste (Kumar *et al.*, 2022), and advance the future of the food supply chain (Hassoun *et al.*, 2022). Furthermore, the adoption of IR 4.0 is commensurate with the promotion of three aspects of sustainability, i.e. environmental, economic, and social domains in safeguarding food safety (Hassoun *et al.*, 2023). Among the IR 4.0 technologies such as smart sensors and IoT (Zhang *et al.*, 2022), robotics (Bader and Rahimifard, 2020), AI (Rahaman and Batcha, 2023), big data (Jin *et al.*, 2020), cybersecurity (Qian *et al.*, 2022), and augmented reality (Romanello and Veglio, 2022) have been widely discussed in the literature. In this study, we propose that the FSMS 4.0 should comprise three components for achieving climate neutrality, i.e. ecosystems, quality standards, and robustness, which are commensurate with the HACCP framework for the food supply chain (Arvanitoyannis, 2009).

2.3.1 Ecosystems. Ecosystems are the critical elements and activities mandated to retain a sanitary environment throughout the food chain that is conducive to safe food production, handling, and delivery (Shurson, 2020; Tirado *et al.*, 2010; Arvanitoyannis, 2009). Instead of relying on raw materials, products, and production processes, the ecosystems in FSMS 4.0 provide the networking that addresses the sanitary operating environment, and supports the quality assurance programs administered by professionals toward food safety (Nguyen and Li, 2021). Recent studies have demonstrated that the adoption of IR 4.0 technologies in the food production system can provide transparency, traceability, and predictive insights along the food production process to safeguard food safety, such as reduce food loss and waste (Misra *et al.*, 2022), monitoring and develop sampling procedures for food safety evaluation, and making real-time judgements in the food safety management process (Jin *et al.*, 2020).

2.3.2 Quality standards. Quality standards determine the specific threats and take precautionary measures against them to guarantee food safety and quality (Stoitsis and Manouselis, 2023; Arvanitoyannis, 2009). The quality standards highlight how to develop a standard quality scheme that facilitates each operation in minimising the likelihood of failure to maintain food safety (Nguyen and Li, 2021). Recent studies demonstrated that the adoption of IoT within food supply chains would elevate quality standards (Chapman *et al.*, 2022). For example, IoT has been used in conjunction with biosensors to detect food contamination (Zhang *et al.*, 2022), which can instantly reduce food safety risks to a minimum, ensure the food production is minimally disrupted, and save the use of resources for a food production batch that would have to be eliminated and wasted. The food-safety measurements that are mostly applied in combination with IoT technologies are such as temperature, humidity, location, and gas presence (Bouzembrak *et al.*, 2019; Popa *et al.*, 2019).

2.3.3 Robustness. Robustness in tracking and monitoring comprises food traceability, nonconformity management, corroboration, validation, and capability enhancement in FSMS 4.0. Traceability is one of the robustness technologies to track food, feed, food-producing animals, and substances throughout the supply chain (Overbosch and Blanchard, 2023; Arvanitoyannis, 2009). For instance, AI-driven biomimetic technologies such as chemical sensors can accurately track food quality (Sun *et al.*, 2019), and cloud computing technologies that track and monitor the lab-to-sample process in which food safety data is generated through portable devices and sensors, and transfer to a central cloud-based e-infrastructure for further data process and analysis (Hassoun *et al.*, 2023).

2.4 Relationship between the FSMS 4.0 and climate neutrality

Prior studies have shown that FSMS 4.0 can foster firms' initiatives in achieving climate neutrality. For example, FSMS 4.0 ecosystems with food safety controlled in a smart indoor closed-loop farming system can foster high productivity while achieving climate neutrality (Wang *et al.*, 2021). Besides, the adoption of risk assessment and life cycle assessment in food supply chains was shown to limit the adverse climate change impact on food safety (Feliciano *et al.*, 2022). Moreover, blockchain technology can provide support to climate change adaptation and mitigation strategies for agri-food stakeholders (Van Wassenaer *et al.*, 2021; FAO and ICTSD, 2020). However, there is a lack of empirical studies that identify the moderating effects of FSMS 4.0 components on the impact of the CSFs on achieving climate neutrality (Acampora *et al.*, 2023).

The ecosystem of an FSMS encompasses the network of processes, stakeholders, and technologies involved in ensuring food safety. This ecosystem can moderate the impact of CSFs by providing a comprehensive framework for aligning these factors with climate neutrality goals (Banihashemi *et al.*, 2017). For instance, top management support in a well-integrated FSMS ecosystem can lead to more effective implementation of sustainability initiatives (Nguyen and Li, 2021). Similarly, the ecosystem can facilitate better collaboration (integration) and external assistance by connecting various stakeholders within the food safety network and aligning their efforts towards environmental objectives (Journeault *et al.*, 2021).

Quality standards in FSMS, such as ISO 22000 or HACCP, set benchmarks for operational excellence and compliance. These standards ensure that the efforts towards food safety also consider environmental impact, thus moderating the influence of CSFs on climate neutrality (Nguyen and Li, 2021). For example, robust quality standards can guide human resource management to not only focus on food safety but also sustainable practices. Additionally, these standards can steer infrastructure development towards more environmentally friendly designs and processes.

The robustness of an FSMS refers to its strength and resilience in managing risks and ensuring consistent food safety. A robust FSMS can enhance the effectiveness of CSFs in achieving climate neutrality by ensuring that sustainability efforts are resilient to changes and challenges (Okpala, 2014). For example, a robust system can make better use of external assistance by quickly adapting to new technologies or practices that enhance sustainability (Garetti and Taisch, 2012). It can also ensure that the firm's infrastructure is capable of withstanding various challenges while maintaining its commitment to climate neutrality.

Based on these arguments, in this study, we argue that the FSMS 4.0 components (ecosystems, quality standards, and robustness) can positively moderate the impact of the CSFs on achieving climate neutrality, such that the CSFs positively and significantly influence the firm's performance in achieving climate neutrality when the moderating effects of FSMS 4.0 components are high than when it is low. Therefore, this study proposes the following hypothesis:

H2. The FSMS 4.0 components (ecosystems, quality standards, and robustness) are positively moderate the impacts of the CSFs on the firm's performance in achieving climate neutrality.

Figure 1 presents the conceptual framework of this study.

3. Research methodology

3.1 Sample and data collection

Our survey questionnaire is derived from the prior studies related to FSMS and IR 4.0, as shown in Table 1. The measurements of CSFs for sustainable FSMS are derived based on the organisational, market, and food safety administration CSFs. The selected CSFs for FSMS 4.0 fulfil the two criteria, i.e. the capabilities to reduce errors and foster the continuous advancement of FSMS 4.0 (De Boeck *et al.*, 2018). The questionnaire was divided into three parts: (1) respondent's perception of the CSFs of FSMS within their organisation; (2) respondent's evaluation of their food safety management practices within their organisation; and (3) respondent's commitment to supporting climate neutrality within their organisation. A five-point Likert scale was utilised in the questions accordingly, where the scales of 1–5 denote poor, fair, average, good, and excellent respectively.

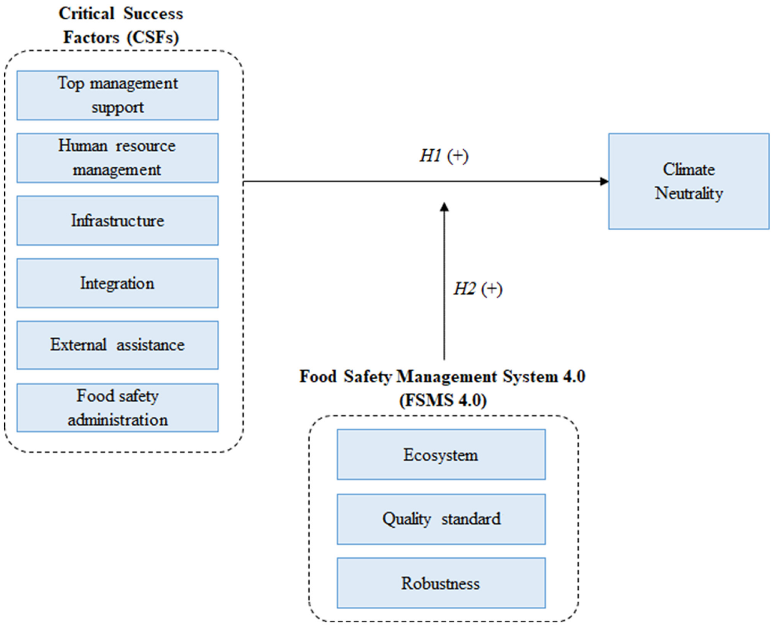


Figure 1.
The conceptual framework of this study

Source(s): Author's own work

Due to the exploratory nature of the research questions, a predefined and exhaustive questionnaire that fully covers all the factors in the paper from a single source does not exist. To address this, we initially defined the CSFs for the questionnaire based on our findings in the literature review. Subsequently, the items that contribute to the respective CSF were derived either from the questionnaire available in the prior studies or through the discussions among us and the industrial consultants for generating the questionnaire to address the research questions. The strand of literature used to extract the related CSFs is presented in Table 1. Besides, the Exploratory Factor Analysis (EFA) was conducted to examine the robustness of the questionnaire and assess whether the items measured the defined factors appropriately. The results of EFA indicate that all items in the questionnaire achieved the required level of reliability and validity as shown in Appendix 1.

We began our survey by shortlisting the food production firms through the directories of food production firms in China and Vietnam and also through the authors' professional networks. The sample data was collected through the hardcopy survey questionnaire delivered through postage mail delivery and door-to-door to the shortlisted food production firms. China is one of the world's largest agricultural food producers and exporters with a diverse variety of food goods exported, while Vietnam is a major agricultural food producer and exporter of a wide range of food products (FAO, 2022). Hence, the food production firms in China and Vietnam were targeted for the sample data collection owing to their food safety management practices and CSR performances on achieving climate neutrality that were expected to provide substantial evidence and implications in the context of global food markets for our research.

An online pilot test of the survey questionnaire was conducted with the 50 firm respondents randomly selected from our shortlisted firms in China and Vietnam, respectively, to ensure the reliability of our survey questionnaire. The questionnaire and informed consent form were distributed through postage mail delivery and door-to-door surveys to the selected food production firms in China and Vietnam from January to September 2022. Besides, the access link to the online version survey questionnaire was supplemented as another response channel to these firms via their email addresses. The survey was administered to a total of 910 business owners and managers of food production firms in China and Vietnam. There were four rounds of follow-up emails carried out to the firm respondents. As a result, there were 266 answered survey questionnaires reverted to us, which yielded a response rate of 28%. After excluding 11 incomplete or discarded surveys, we finally obtained a total sample data of 255 answered survey questionnaires for this study.

3.2 Estimation methods

We addressed the research hypotheses testing in this study by utilised the multilevel moderated regression analysis recommended by Hair *et al.* (2019b) to assess the presence and significance of the relationships between the six CSFs (top management support, human resource management, infrastructure, integration, external assistance, and food safety administration) and the firm's performance in achieving climate neutrality, and determines whether the relationships between the CSFs and climate neutrality achievement varies under the moderating effects of the three FSMS 4.0 components as the moderators (ecosystems, quality standards, and robustness). Equations (1), (2) and (3) were constructed for the multilevel moderated regression analysis to examine the direct effects and moderating effects between the variables. To eliminate multicollinearity and improve the interpretability of the results, the sample data of the variables of CSFs and FSMS 4.0 components were mean-centred before the multilevel moderated regression analysis.

In Equations (1) and (2), the parameters of the six CSFs and FSMS 4.0 are estimated to analyse the direct effects on the firm's performance in achieving climate neutrality. Equation (3) investigates the moderating effects of FSMS 4.0 components on the impacts of CSFs on the firm's performance in achieving climate neutrality via the approach devised by Hair *et al.* (2019b) and Becker *et al.* (2018), where the variables were normalised such that their respective means were zero before the model estimation (Cohen *et al.*, 2014; Jaccard *et al.*, 2003). Besides, to investigate the moderator implications of FSMS 4.0 components on the relationship between the CSFs and climate neutrality, Equation (3) was developed after mean-centring the variables and incorporating the three FSMS 4.0 components. The three equations are presented in the general forms as follows:

$$y_i = \alpha_i + \beta X_i + u_i \tag{1}$$

$$y_i = \alpha_i + \beta X_i + \gamma M_i + u_i \tag{2}$$

$$y_i = \alpha_i + \beta X_i + \gamma M_i + \tau(X_i \times M_i) + u_i \tag{3}$$

where y_i represents the vector of factor score of the firm's performance in achieving climate neutrality, X_i represents the vector of factor score of the six CSFs (top management support, human resource management, infrastructure, integration, external assistance, and food safety administration), M_i represents the vector of factor score of the three FSMS 4.0 components (ecosystems, quality standards, and robustness) as the moderators, and $(X_i \times M_i)$ is the interaction terms between the mean-centred CSFs and moderators, all of firm i, respectively.

The partial least squares structural equations modelling (PLS-SEM) method is applied for this empirical study via route analysis and the bootstrapping method using the statistical analysis software SPSS 26 AMOS version 20. The PLS-SEM method is applied for the empirical research of this study because it can examine complex and intricate relationships between the variables in a model (Astrachan *et al.*, 2014). We also utilised Exploratory Factor

Analysis (EFA) and Confirmatory Factor Analysis (CFA) to examine the reliability and validity of the variables. The analyses were conducted with consideration of the issues of multicollinearity, unidimensionality, scale precision, and concept validity (Hair *et al.*, 2019a).

4. Results analysis and discussion

4.1 Descriptive statistics

Table 2 provides the demographic profile of the firm respondents. The results report that the majority of our survey respondents are food production firms in the food category of the fishery (47.8%) and fresh fruit and vegetables (20%), while the minority of them are producing food products comprised of dairy, poultry, beverages, rice, and grains. Besides, the majority of our survey respondents are small and medium-sized enterprises (SMEs) (74.5%) followed by large-sized firms with over 250 employees (13.3%). Moreover, half of our survey respondents were firms engaged in the food export business with 500 or lesser tonnes of food exported per year, followed by 11.1% of them exported between 500 and 1,000 tonnes of food per year. Furthermore, the survey respondents from the food production firms are mainly quality control managers (29.3%) and supply chain managers (30.7%), followed by chief executive officers, directors, and food safety administration executives. Hence, the demographic profile of our survey respondents indicates that the food production firms have possessed substantial international operational experiences in the food supply chain and food safety management and therefore the survey respondents are appropriate to provide evidence and implications for our research.

Question	Options	Results (%)
The number of current workers at your business	1–10 staff	12.2
	11–50 staff	38.4
	51–250 staff	36.1
	More than 250 staff	13.3
Current positions held	Supply chain manager	31.8
	Quality control manager	29.8
	Director/CEO	7.1
	Food safety administration executive	2.4
	Others	29.0
Category of food processing	Fishery	47.8
	Fresh fruit and vegetables	20.0
	Dairy	9.8
	Poultry	9.4
	Beverages	7.8
	Rice and grains	2.0
	Others	3.1
Annual amount of food exports (tonnes)	Less than 500	51.0
	500–1,000	24.3
	1,000–2000	11.0
	2000–3,000	3.5
	More than 3,000	10.2
Certificates that the company is conforming to	HACCP	79.6
	ISO9001	48.2
	ISO22000	18.4
	BRC	11.0
	GlobalGAP	15.3
	SQF	7.5
	IFS	5.9

Source(s): Authors' own work

Table 2.
Descriptive statistics

4.2 Measurement scale assessment

We utilised the EFA method to assess the reliability and validity of the questionnaire items and the results are presented in Appendix. The selection of items for the questionnaire was initially based on their overall correlations with the anticipated factors which were measured by the item-total correlation. The items with an item-total correlation result below 0.350 were deemed unsuitable and therefore disqualified from further analysis. The remaining items were then subjected to a principal components analysis. Multiple rounds of rotation with varimax criteria were conducted on the original items. During this process, items with factor loadings below 0.500 or items exhibiting high values of cross-loading were excluded from the final set of items. The Cronbach's alpha values of all the factors are all above 0.750 indicating their reliability in measuring the anticipated factors.

Before conducting the regression analyses for hypotheses testing, we utilised the CFA method (Hair *et al.*, 1995) to assess the validity and statistical significance of the measurement scales. Appendix shows the statistical analysis results of EFA and CFA. All items remaining from EFA were found to load on their corresponding components in CFA with the standardised regression coefficients greater than 0.650 (more than two times the standard error) and R^2 values of at least 0.356. The results indicate that the measurement scales met the standards for convergent validity. Additionally, the average variance extracted was found to be greater than or equal to 50.3% and the composite reliability was determined to be at least 0.789. The findings suggest that the construct is reliable.

4.3 Structural model analysis

Table 3 delineates the outcomes of the regression analyses for Equations (1), (2), and (3), elucidating the relationships between various factors and a firm's performance in achieving climate neutrality. The regression results for Equation (1) reveal a positive and significant correlation between climate neutrality and several critical success factors: top management support (TMS) exhibits a coefficient of 0.203 with $p < 0.01$, human resource management (HRM) shows a coefficient of 0.14 with $p < 0.10$, infrastructure (IFR) has a coefficient of 0.221 with $p < 0.01$, and integration (ITG) presents a coefficient of 0.333 with $p < 0.01$. However, this analysis does not find a direct effect relationship between the firm's performance in achieving climate neutrality and factors such as food safety administration (FSA) and external assistance (EA). This leads to partial validation of Hypothesis 1.

Furthermore, the direct effect regression results of Equation (2) demonstrate that quality standards (QS) and robustness (RB) significantly enhance the firm's performance in achieving climate neutrality, with coefficients of 0.201 ($p < 0.01$) and 0.186 ($p < 0.01$), respectively. Conversely, no significant correlation is noted between ecosystems (ES) and the firm's performance in this regard. Intriguingly, the moderating effect analysis, as per Equation (3), indicates an increase in the explained variance (R^2) to 0.682, a significant rise from the R^2 values of Equation (1) at 0.523 and Equation (2) at 0.577. This increase suggests the presence of interaction effects among the CSFs, FSMS 4.0 components, and the firm's climate neutrality performance, in line with Jaccard *et al.* (2003).

The moderating effect analysis further reveals that FSMS 4.0 ecosystems exert a significant negative moderating effect on the influence of human resource management (−0.184, $p < 0.05$) and external assistance (−0.195, $p < 0.10$) on achieving climate neutrality. Additionally, the quality standards of FSMS 4.0 negatively moderate the impact of infrastructure (−0.154, $p < 0.10$) on climate neutrality. Meanwhile, the robustness of FSMS 4.0 negatively moderates the impact of integration (−0.184, $p < 0.05$) but positively influences the effect of food safety administration (0.153, $p < 0.10$) on achieving climate neutrality. These results offer partial support for Hypothesis 2. The study is further enriched by the simple

	Dependent variable: climate neutrality		
	(1)	(2)	(3)
Direct effects			
Top management support (*TMS*)	0.203***	0.125**	0.092*
Human resources management (*HRM*)	0.140**	0.100*	0.05
Infrastructure (*IFR*)	0.221***	0.156***	0.126***
Integration (*ITG*)	0.333***	0.277***	0.166***
External assistance (*EA*)	0.059	−0.012	−0.006
Food safety administration (*FSA*)	0.015	−0.008	0.027
Moderators			
Ecosystems (*ES*)		−0.036	0.087
Quality standards (*QS*)		0.201***	0.133*
Robustness (*RB*)		0.186***	0.085
Moderating effects			
ES × *TMS*			0.111
ES × *HRM*			−0.184**
ES × *IFR*			0.008
ES × *ITG*			−0.115
ES × *EA*			−0.195*
ES × *FSA*			0.054
QS × *TMS*			−0.025
QS × *HRM*			0.077
QS × *IFR*			−0.154*
QS × *ITG*			0.102
QS × *EA*			−0.04
QS × *FSA*			−0.054
RB × *TMS*			−0.097
RB × *HRM*			−0.142
RB × *IFR*			−0.015
RB × *ITG*			−0.184**
RB × *EA*			0.111
RB × *FSA*			0.153*
R^2	0.523	0.577	0.682

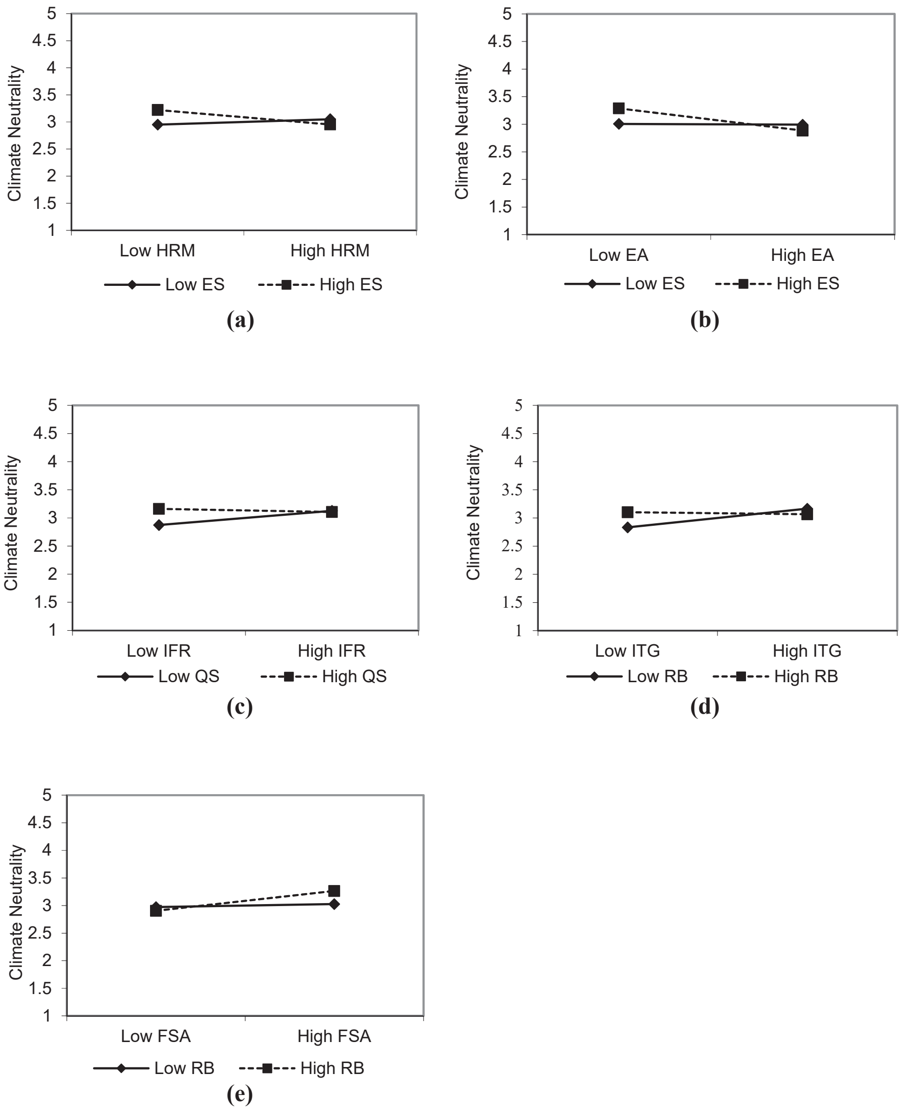
Note(s): ***p < 0.01, **p < 0.05, *p < 0.10
Source(s): Authors' own work

Table 3.
Parameter estimation results of the regression models

slope analysis, which details the significant moderating effects of FSMS 4.0 components on the CSFs' impact on climate neutrality performance, as depicted in Figure 2.

4.4 Discussion

The first research objective of this study is to utilise the theoretical framework to investigate whether the CSFs of sustainable FSMS can foster the food production firms' performances in achieving climate neutrality. Our direct effect results present that top management support, human resource management, infrastructure, and integration are the CSFs that contribute to achieving climate neutrality in the food safety management process. Our results provide evidence that assimilates with the prior findings, such as firms are more likely to perform their commitment to achieving climate neutrality with top management support (Zhang *et al.*, 2022), firms that expertise in food safety management can drive climate neutrality (Kumar *et al.*, 2022), firms equipped with the infrastructure combined with advanced IR 4.0 technologies can enhance food safety management and contribute in achieving climate neutrality (Liu *et al.*, 2021b), and higher integration across multi-tier food supply chain operators contributes to climate neutrality (Nguyen and Li, 2021).



Source(s): Author's own work

Figure 2. Simple slope plots for the moderating effects of respective FSMS 4.0's component on the impact of CSFs on climate neutrality

Meanwhile, the second research objective of this study is to utilise the theoretical framework to investigate whether the adoption of FSMS 4.0 can moderate the impacts of the CSFs on the firm's performance in achieving climate neutrality. First, our moderating effect results present that when the ecosystems of FSMS 4.0, such as the sanitary operating environment and professional quality assurance programs, are established at a low level of development, the firms should increase resource allocation in the human resource management and expand external assistance networks in food safety management for achieving climate neutrality. The results corroborate the prior findings that demonstrated the design principles and adoption of IR 4.0 technologies in the business ecosystems can minimise production wastes and non-value-added activities and thus contribute to climate risk mitigation (Ghobakhloo, 2020).

Besides, our results show that when the food quality standards of FSMS 4.0, such as the quality standards for reducing the food hazard likelihood, are established at a low level of development, more infrastructure investment in food safety management is needed for achieving climate neutrality. Our results imply that when the food quality standards of FSMS 4.0 are insufficiently implemented, more infrastructure investment is needed to facilitate the implementation of the CSFs at all stages of the food safety management process to achieve climate neutrality. The results assimilate with the prior findings that demonstrated the adoption of IR 4.0 technologies integrated with the food production infrastructure enables the achievement of rapid, reliable, and objective assessment of food quality control to address the climate change risk (Hassoun *et al.*, 2023).

Moreover, our findings depict that when the robustness of FSMS 4.0 is established at a high level of development, the strengthening of food safety administration with minimal efforts of integrating multiple stakeholders in the food supply chain can elevate the firm's performance in achieving climate neutrality. The results resemble the prior studies, for example, Liu *et al.* (2021b) showed that the combination of IR 4.0 technologies with data fusion promotes robustness in accuracy, transparency and traceability of food products to mitigate the adverse impact of climate change. Furthermore, the results also elucidate that although FSMS 4.0 enables safeguarding food safety while contributing to climate neutrality achievement, the strengthening of food safety administration remains necessary to ensure the food safety standards can be strictly implemented in FSMS 4.0. These results are in line with the prior findings of Misra *et al.* (2022) and Kumar *et al.* (2022) indicated that the supply chain performance supported with IR 4.0 technologies depends upon the implementation of strict food safety administration and high food safety standards.

Taken together, our moderating effect results imply that when the optimal facilitation of FSMS 4.0 components (ecosystems, quality standards, and robustness) are fulfilled, the adoption of FSMS 4.0 enables firms to improve climate neutrality achievement with lower inputs in human resource management, infrastructure investment, external assistance, and multiple stakeholder integration while continuously strengthening the food safety administration in the food production activities. Our findings also further highlight the significant moderating effects of the FSMS 4.0 components on optimising the firm's resource allocation efficacy in the CSFs of food safety management that can significantly improve the firm's performance in achieving climate neutrality.

5. Conclusion

Underlining the crucial role of FSMS in achieving the sustainable goal of climate neutrality, this study aims to investigate whether the CSFs of sustainable FSMS can contribute to achieving climate neutrality, and how the adoption of FSMS 4.0 that empowered with IR 4.0 technologies can moderate the impact of the CSFs on achieving climate neutrality. The survey data of 255 food production firms in China and Vietnam are used to address the research questions. Our empirical results provide theoretical and practical insights into how food production firms can utilise the CSFs of sustainable FSMS with the deployment of FSMS 4.0 for achieving climate neutrality, as we interpreted below.

5.1 Theoretical implications

There is a dearth of literature on whether and how the adoption of IR 4.0 can influence the CSR performance of firms in achieving climate neutrality. Embarked from the research questions, our study provides empirical evidence that conforms to the CSFs theory. Our results provide theoretical implications that elucidating the CSFs of sustainable FSMS can contribute to a firm's progression to achieving climate neutrality with the adoption of FSMS 4.0. Our findings support prior research that highlights the important roles of the CSFs of sustainable FSMS and the adoption of IR 4.0 in contributing to achieving climate neutrality (Rahaman and Batcha, 2023; Hassoun *et al.*, 2023; Romanello and Veglio, 2022). Besides, our results demonstrate the theoretical mechanism for understanding the relationships between the CSFs of sustainable FSMS, the FSMS 4.0 components, and the firm's performance in achieving climate neutrality which provide an additional reference for constructing the conceptual framework of sustainable FSMS 4.0 practices that contribute to achieving the sustainable development goals such as climate neutrality. Moreover, our study also provides theoretical support that sheds light on the important role of advanced IR 4.0 technologies in reducing the carbon footprints of food production and enabling CSR that wields positive social and environmental impacts on society.

5.2 Managerial implications

The globalisation of food supply chains exacerbates the challenges in anticipating, identifying, and responding to climate change risks. Hence, food production firms should be aware of the increasing need to adopt sustainable FSMS for greater preparedness in achieving climate neutrality. Our findings suggest that food production firms should adopt IR 4.0 technologies which aid in the formulation of effective food safety management strategies to solve food safety hazards and contribute to achieving climate neutrality. Besides, our results indicate that top management support, human resource management, infrastructure, and integration appear as the CSFs that play important roles in implementing high food safety and quality standards and cultivating the organisational capabilities and responsibilities to initiate green operational practices in food production for achieving climate neutrality. Hence, the food production firms should devote more endeavours to human resources management, initiating the integration of multiple stakeholders, and gaining top management support to encourage a strong commitment to align their FSMS for achieving climate neutrality, where the IR 4.0 technologies can serve as a pivotal instrument that facilitates the farm-to-fork food safety information sharing via the infrastructure developed for the sustainable FSMS. Nevertheless, there could be pushback and resistance when the transformations in FSMS are required rapidly during the transition process toward climate neutrality. Therefore, it is integral for food production firms to establish collaborative relationships with sustainable business value-aligned multiple stakeholders in food safety management to sustain climate neutrality efforts.

Our study also provides policy implications to policymakers. Our results suggest that policymakers should devise and promote the national strategies and incentives that foster the development of a symbiotic relationship between the CSR of achieving climate neutrality and the business performance of food production firms. For instance, incentive schemes should be given to encourage food production firms to deploy IR 4.0 technologies in managing their FSMS and increase the transparency, traceability, and integrity of food safety management. Specifically, the food production SMEs that lack professional workers and suffer from inadequate infrastructure for food safety management should be given more policy incentives, such as financing incentives for green technology innovation, to promote the adoption of IR 4.0 for sustainable FSMS in the food supply chain.

5.3 Limitations and future research

Despite its contributions, this study has its limitations. As the economies of China and Vietnam are currently in the developmental stage, the empirical findings of this research should be confined to the context of developing economies and it may not be generalisable to developed economies because of disparities in institutional and social contexts. Nevertheless, there is much potential for future studies to utilise the CSFs theory complemented with the components of FSMS 4.0 to address complex decarbonisation problems. Besides, future studies may recruit more respondents across a wider range of sectors in one country or more countries to widen the breadth of this study. For example, various data can be collected from multiple stakeholders in the food supply chain to understand how the role of the identified CSFs influences the firm's commitment to achieving carbon neutrality. Furthermore, more components in the IR 4.0 technologies, such as the technology and diffusion of renewable energy, can be included in future studies to address the research questions.

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Appendix

Table A1. Exploratory factor analysis (EFA) and confirmatory factor analysis (CFA) of the questionnaire survey

Observed items	Exploratory factor analysis (EFA) Factor loadings	Item-total correlations	Confirmatory factor analysis (CFA) Standardised regression weights	Standard errors	R^2
PART 1: To what extent do you think these factors are important to your food safety management system within the organisation? On a scale of 1 (poor), 2 (fair), 3 (average), 4 (good) and 5 (excellent), please rate the condition of the following within your food safety management activities					
	Top management support: E = 2.804; AVE = 70.093; CA = 0.857		Top management support: AVE = 60.7%, CR = 0.859		
Managers commitments	0.881	0.768	0.863	0.044	0.746
Food safety policy	0.872	0.751	0.849	0.052	0.721
Responsibilities and authorities	0.818	0.675	0.726	0.048	0.527
Food safety culture	0.773	0.616	0.659	0.059	0.434
	Human resources management: E = 2.760; AVE = 69.004; CA = 0.850		Human resources management: AVE = 58.9%, CR = 0.851		
Employees' knowledge and skills	0.853	0.723	0.81	0.058	0.656
Awareness of the personnel	0.838	0.699	0.789	0.062	0.622
Training programs for employee	0.782	0.624	0.682	0.063	0.466
Employees' involvement	0.847	0.713	0.782	0.058	0.612
	Infrastructure: E = 2.205; AVE = 73.512; CA = 0.818		Infrastructure: AVE = 60.3%, CR = 0.820		
Qualified facilities and equipment	0.862	0.682	0.788	0.028	0.634
Financial condition	0.846	0.655	0.746	0.046	0.584
Technological condition	0.864	0.685	0.795	0.031	0.645
	External assistance: E = 2.571; AVE = 51.425; CA = 0.756		External assistance: AVE = 65.2%, CR = 0.789		
Support from financial institutions	0.659	0.467	Eliminated		
Supports from business associations	0.819	0.649	0.798	0.042	0.637
Supports from stakeholders in supply chains	0.829	0.663	0.817	0.04	0.668
Support from the government and authorities	0.67	0.468	Eliminated		
Support from non-governmental organisations	0.574	0.39	Eliminated		
	Integration: E = 2.375; AVE = 59.377; CA = 0.770		Integration: AVE = 50.3%, CR = 0.801		
Information exchange	0.765	0.562	0.65	0.041	0.438
Emerging problems	0.832	0.654	0.697	0.04	0.639
Planning and goal-setting activities	0.724	0.518	0.799	0.048	0.356
Continuous improvement programs	0.758	0.554	0.682	0.046	0.423

(continued)

Table A1.

Observed items	Exploratory factor analysis (EFA) Factor loadings	Item-total correlations	Confirmatory factor analysis (CFA) Standardised regression weights	Standard errors	R^2
PART 1: To what extent do you think these factors are important to your food safety management system within the organisation? On a scale of 1 (poor), 2 (fair), 3 (average), 4 (good) and 5 (excellent), please rate the condition of the following within your food safety management activities					
	Food safety administration: E = 2.737; AVE = 68.423; CA = 0.843		Food safety administration: AVE = 58.2%, CR = 0.847		
Food safety audits and inspections	0.818	0.666	0.744	0.055	0.553
Regulatory sanctions	0.844	0.703	0.786	0.046	0.618
Regulatory stimulus	0.866	0.739	0.832	0.036	0.692
Regulatory information and education	0.779	0.615	0.682	0.057	0.466
PART 2: Food safety management system 4.0 activities On a scale of 1 (poor), 2 (fair), 3 (average), 4 (good) and 5 (excellent), please rate the condition of the following within your food safety management system 4.0 activities					
	Ecosystem: E = 5.201; AVE = 65.009; CA = 0.923		Ecosystem: AVE = 60%, CR = 0.901		
Building and infrastructure construction and planning	0.753	0.678	0.707	0.042	0.499
Building design and layout	0.828	0.765	0.788	0.04	0.621
The provision of air, water, energy and other utilities	0.771	0.698	0.727	0.046	0.528
Waste and sewage disposal among other auxiliary services	0.779	0.708	0.742	0.043	0.551
Properness of equipment	0.828	0.768	0.803	0.039	0.646
Material procurement administration	0.837	0.777	0.818	0.041	0.67
Strategies for limiting the spread of diseases	0.828	0.768	0.808	0.044	0.654
Systematic cleaning and disinfection	0.821	0.759	0.798	0.045	0.637
	Quality Standards: E = 5.033; AVE = 71.897; CA = 0.935		Quality Standards: AVE = 67.3%, CR = 0.935		
Hazards identified at each step	0.869	0.815	0.85	0.032	0.722
The points of which control are taken by a quality standard team	0.858	0.801	0.834	0.036	0.695
The scale of effectiveness in determining quality standard critical limits	0.823	0.758	0.787	0.045	0.619
Monitoring procedures and systems at quality standards	0.861	0.804	0.838	0.035	0.702
Installed corrective actions at quality standards	0.833	0.77	0.803	0.043	0.644
Validation procedures	0.84	0.778	0.809	0.039	0.654

(continued)

Table A1.

PART 2: Food safety management system 4.0 activities
On a scale of 1 (poor), 2 (fair), 3 (average), 4 (good) and 5 (excellent), please rate the condition of the following within your food safety management system 4.0 activities

The provision of efficient records and paperwork	0.85	0.791	0.819	0.037	0.67
	Robustness: E = 7.422; AVE = 67.476; CA = 0.952		Robustness: AVE = 64.3%, CR = 0.952		
Traceability system	0.85	0.813	0.836	0.034	0.699
Corrective actions	0.83	0.79	0.809	0.036	0.654
Techniques for safely processing potentially harmful products	0.742	0.691	0.707	0.045	0.499
Control measurements	0.856	0.82	0.842	0.035	0.708
The ability to provide sufficient evidence	0.852	0.814	0.84	0.032	0.706
Internal audits	0.817	0.775	0.793	0.038	0.629
All required records and documents are properly controlled	0.832	0.792	0.816	0.032	0.665
Internal communication	0.775	0.728	0.745	0.044	0.555
External communication	0.797	0.751	0.773	0.037	0.597
Enhancing and constantly upgrading the food safety management system	0.848	0.81	0.834	0.035	0.696
Activeness in pursuing accreditation or registration	0.831	0.79	0.813	0.034	0.661

PART 3: Climate neutrality
On a scale of 1 (poor), 2 (fair), 3 (average), 4 (good) and 5 (excellent), please rate the followings that reflect your recent company's climate neutrality

	Climate neutrality: E = 4.344; AVE = 72.392; CA = 0.923		Climate neutrality: AVE = 67%, CR = 0.924		
Reduction of methane emissions	0.85	0.778	0.826	0.034	0.681
Reduction of nitrous oxide emissions	0.886	0.826	0.868	0.029	0.753
Reduction of carbon emissions	0.829	0.751	0.784	0.038	0.614
Reduction of using natural resources	0.832	0.756	0.793	0.037	0.629
Increase of using renewable energy in the distribution	0.877	0.815	0.849	0.04	0.722
Effectiveness in waste disposal, packaging and recycling	0.829	0.753	0.787	0.046	0.619

Note(s): E = Eigenvalues, AVE = average variance extracted, CA=Cronbach's Alpha, CR=composite reliability
Source(s): Authors' own work

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