UNIVERSITY OF TECHNOLOGY SYDNEY

ANALYSING SUPPLY CHAIN SUSTAINABILITY CHALLENGES IN THE AUSTRALIAN FOOD PROCESSING SECTOR DUE TO THE COVID-19 OUTBREAK

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the degree of

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Certificate of Original Authorship

I, *Ananna Paul,* declare that this thesis is submitted in fulfilment of the requirements for the award of Master of Engineering (Research), in the School of Professional Practice and Leadership at the University of Technology Sydney.

This thesis is wholly my own work unless otherwise referenced or acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

This document has not been submitted for qualifications at any other academic institution.

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Dedication

To my family

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Keywords

Australian food processing sector

COVID-19 outbreak

Pandemic

Supply chain management

Sustainability challenges

Best-worst method

Multi-criteria decision-making

Abstract

The recent coronavirus disease pandemic, known as the COVID-19 outbreak, has significantly impacted most businesses and their supply chains. Due to the negative impacts of the pandemic, businesses have faced numerous challenges, including sustainability challenges that are critical for any supply chain. Several studies have discussed the impacts of the COVID-19 pandemic on supply chains in the literature; however, there is a significant research gap in analysing supply chain sustainability challenges amid the COVID-19 outbreak. As such, this study aims to contribute to the literature by developing a systematic approach to identifying and analysing pandemic-related supply chain sustainability challenges in the context of the Australian food processing sector. Accordingly, the objectives of this study are to identify supply chain sustainability challenges due to the impacts of the COVID-19 outbreak for the Australian food processing sector, and analyse and prioritise them using a quantitative method.

To achieve these objectives, the study develops a mixed-method approach consisting of both qualitative and quantitative techniques. The qualitative techniques include an online survey to identify, finalise and contextualise the list of sustainability challenges. In this phase, a questionnaire survey is conducted among 10 experts from the Australian food processing sector. The generated data is further analysed using a quantitative technique, namely the best-worst method (BWM), to determine the challenges' priority rankings. Data for the BWM analysis is collected from 12 experts from the Australian food processing sector. Finally, a sensitivity analysis is conducted to judge the robustness of the proposed approach.

From the questionnaire survey, 22 sustainability challenges are finalised and organised into four categories: economic, environmental, social and ethical, and operational challenges. The quantitative results reveal that economic and social and ethical challenges dominate the Australian food processing sector amid the COVID-19 outbreak. The findings also reveal that the top five sustainability challenges faced by the Australian food processing sector due to the pandemic are increased food processing cost, lack of transparency and traceability, increase in the price of raw materials, lack of capital and physical resources and spread of fake information.

This study's findings help decision-makers, practitioners and policymakers in the Australian food processing sector by providing a holistic list of supply chain sustainability challenges due to the impacts of the COVID-19 outbreak. This helps them develop the policies, guidelines and strategies to overcome the most impactful sustainability challenges in the Australian food processing sector to ensure sustainable recovery from the effects of the pandemic.

List of Publications

1. Paul, A., Shukla, N., Paul, S. K., & Trianni, A. (2021). Sustainable supply chain management and multi-criteria decision-making methods: A systematic review. *Sustainability*, *13*(13), 7104. https://doi.org/10.3390/su13137104 (SJR rank: Q1, Impact factor: 3.251)
2. Paul, A., Shukla, N., & Trianni, A. (2022). Modelling supply chain sustainability challenges in food processing sector amid COVID-19 outbreak. *Socio-Economic Planning Sciences*. Under review. (SJR rank: Q1; impact factor: 4.923)

Note: This thesis includes the content from the above papers.

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Chapter 1 : Introduction

The recent coronavirus disease, known as COVID-19, originated in Wuhan, China, in December 2019 and spread quickly to most countries worldwide. The World Health Organisation (WHO) declared the COVID-19 outbreak a pandemic on 11 March 2020 (WHO, 2020) because it is highly infectious and can quickly spread to the human population. As of 4 July 2021, COVID-19 had infected more than 184 million people and caused more than 3.9 million deaths globally (Worldometers, 2021).

The COVID-19 outbreak significantly impacted health, economy, social life and supply chain activities. The disruptions in supply chains were severe due to interruptions in transportation, production facilities, supply and demand. The supply chain network became imbalanced. The demand for some necessary items increased, including dried foods, toilet papers, sanitiser and face masks (Paul & Chowdhury, 2021), while the demand for other items, such as apparel, cars and electronics, reduced. During the COVID-19 outbreak, the food processing industry was one of the most affected sectors, with an increased demand for certain food products, such as dried and canned food, due to panic buying (Singhal & Barlass, 2020).

Conversely, exports of other food products, like seafood, decreased due to border closure. In addition, some domestic producers faced a demand decline due to the closure of food services, cafes and restaurants (KPMG, 2020). The food processing sector also faced a shortage of labour, longer supply and delivery lead times, stockout of dried food items, increased market complexity, and increased biosecurity regulations (KPMG, 2020). Hence, a research study to explore and analyse challenges in the Australian food processing sector due to the impacts of the COVID-19 outbreak is crucial.

Broadly, most Australian industries were significantly impacted by the pandemic. By mid-March 2020, it was reported that the COVID-19 outbreak had affected more than 60% of Australian businesses, and among them, the manufacturing sectors were hit hard (RetailWorld, 2020). The food processing sector is one of the biggest manufacturing sectors in Australia and one of the fastest-growing. The demand for food products increased by 2.4% per annum on average from 1988-89 to 2016-17 (Hogan, 2019). According to the report published by the Australian Food and Grocery Council, the food industry in Australia has a turnover of $131.3 billion and more than 324,000 direct employments (AFGC, 2018). Due to the economic importance of the food industry and the devastating impacts of the COVID-19 outbreak, this study takes the Australian food industry as the context of the research to analyse its supply chain sustainability challenges.

Due to the large-scale disruptions of the COVID-19 outbreak, the sustainability practices (economic, environmental and social practices) in the supply chain were significantly affected. Moreover, organisations face numerous challenges in their operations, finances and supply chains (Ivanov, 2020a), with many struggling to survive economically. Environmental and social sustainability practices are also significantly affected as organisations are trying to survive the financial shock (Sharma et al., 2020). Thus, it is essential to investigate the different sustainability challenges brought about by the COVID-19 outbreak. However, a limited number of studies in the extant literature examine sustainability challenges in the supply chain due to a large-scale and global pandemic like the COVID-19 outbreak. Specifically, it is noteworthy to analyse sustainability challenges in the Australian food processing sector due to its growth and economic and social importance. This study addresses these gaps by identifying and analysing supply chain sustainability challenges in the Australian food processing sector due to the impacts of the COVID-19 outbreak. Australia is a vast country with long distances between inhabited regions. The effects of the pandemic on Australian supply chains were severe due to border closures and restricted interstate travel. All of these factors make the supply chain of the Australian food processing sector an innovative case for this thesis.

This study has two phases. In the first phase, a list of sustainability challenges is finalised through an online questionnaire survey of participants from the Australian food processing sector. In the second phase, the final list of sustainability challenges is analysed using a quantitative method. As several challenges are involved in the analysis, a multi-criteria decision-making (MCDM) method is applied to analyse the sustainability challenges. MCDM methods can handle multiple criteria to determine the priority ranking by ascertaining the weights of multiple challenges (Chowdhury & Paul, 2020). The current literature contains several review articles on MCDM methods applied in different dimensions of green supply chains (e.g., see Banasik et al., 2018; Govindan, Rajendran, et al., 2015), which confirm the applicability of MCDM methods in supply chain disciplines.

There are few studies on sustainability challenges in the literature that examine the impacts of large supply chain disruptions. This study contributes to the literature by developing the following research questions (RQs) to fill this research gap:

RQ1: *What are the sustainability challenges faced by the supply chain due to the impacts of the COVID-19 outbreak?*

RQ2: *What are the priority rankings of sustainability challenges?*

This thesis considers the following research objectives to answer these research questions:

i. Identify supply chain sustainability challenges (such as economic, environmental, social and ethical, and operational challenges) in the context of the Australian food processing sector due to the impacts of the COVID-19 outbreak.
ii. Analyse sustainability challenges and prioritise the identified sustainability challenges using the best-worst method (BWM).
iii. Provide implications for the practice.

The structure of this thesis is presented in Figure 1.1. Chapter 1 provided the introduction and background to the study. An in-depth literature review is presented in Chapter 2, and the research methodology in Chapter 3. The results are discussed in Chapter 4, the managerial and theoretical implications are explained in Chapter 5, and conclusions in Chapter 6.

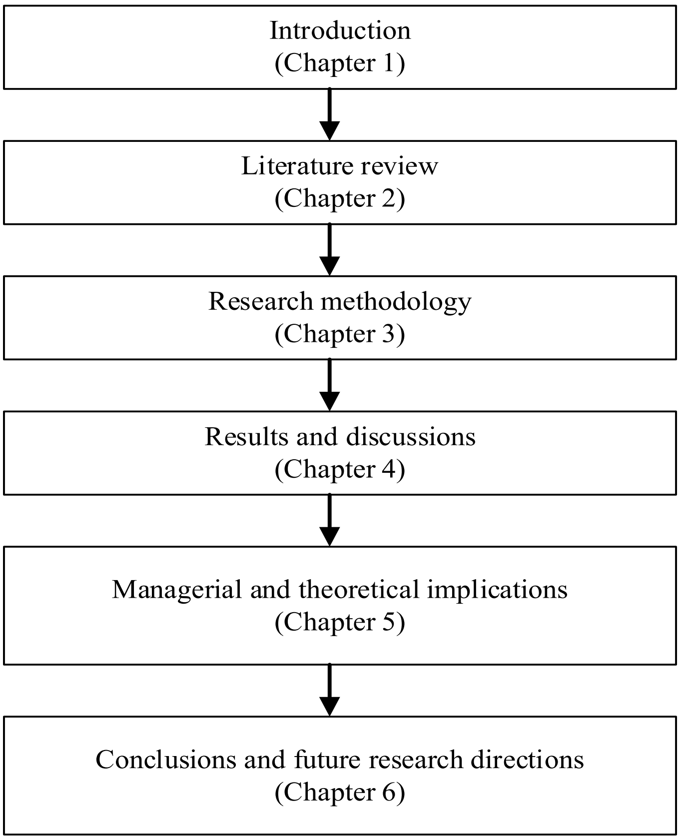

Figure 1.1: Organisation of the thesis

Chapter 2 : Literature Review

This thesis has two dimensions: (i) application of MCDM methods for analysing sustainability challenges and (ii) consideration of the impacts of the COVID-19 outbreak while analysing sustainability challenges. To identify the research gaps and contributions of the study, this chapter presents an in-depth literature review on studies that apply MCDM methods in sustainable supply chain management (SSCM) and supply chain management studies in the context of the COVID-19 outbreak.

In this chapter, the names of the methods and their abbreviated terms are used as follows:

i. decision-making trial and evaluation laboratory (DEMATEL) and fuzzy/grey DEMATEL
ii. analytical hierarchy process (AHP) and fuzzy AHP
iii. the technique for order of preference by similarity to ideal solution (TOPSIS) and fuzzy TOPSIS
iv. best-worst method (BWM)
v. VIseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR) and fuzzy VIKOR
vi. rough set
vii. ELimination Et Choix Traduisant la REalité (ELECTRE) and fuzzy ELECTRE
viii. analytical network process (ANP)
ix. rough strength-relation analysis method (RSRAM)
x. rough simple additive weighting (RSAW)
xi. interpretive structural modelling (ISM)
xii. preference ranking organisation method for enriched evaluation (PROMETHEE)
xiii. TOmada de Decisao Interativa Multicriterio (TODIM)
xiv. Cross-impact matrix multiplication applied to classification (MICMAC)

2.1 Literature review on MCDM methods applied in SSCM

MCDM methods are smart tools to deal with numerous criteria in decision-making. These methods have been widely applied in SSCM because of their computational capabilities. This thesis conducts a systematic literature review on MCDM methods applied in different areas of SSCM. Published journal articles from the literature search are selected and analysed.

Individual and integrated MCDM methods applied in SSCM are reviewed and summarised; contributions, methodological focuses and findings of the reviewed articles are also discussed.

2.1.1 Sustainable supply chain

In this competitive era, every business is part of a supply chain that involves efficient and effective movement of products or services from suppliers to customers via manufacturers, distributors and retailers. A typical supply chain involves multiple businesses, resources, people, technologies and information for buying, manufacturing, distributing, storing and selling products. Several activities within a supply chain present direct social, environmental and economic impacts (Mota et al., 2015), referred to as the triple bottom line (TBL) in sustainable supply chain literature. Social impact includes modern slavery, gender discrimination, unfair wages and child labour (Giannakis & Papadopoulos, 2016; Munny et al., 2019; Stevenson & Cole, 2018). Environmental impact includes the emission of carbon dioxide, polluting water and the environment, and global warming (de Vries & Ferrarini, 2017; Green et al., 2012). Economic impact includes the return on investment, impact on profit and productivity (Mota et al., 2015). Every supply chain is now taking steps to ensure sustainability, considering their significant impact on society, the environment and the economy.

SSCM integrates the supply chain's economic, social and environmental goals to improve long-term performance, evaluating and monitoring business performance against economic, social and environmental dimensions (Mota et al., 2015). Any good social and environmental performance with economic performance ensures better sustainability; however, ensuring all three performances creates the best sustainable supply chain (Carter & Easton, 2011). Some recent studies have considered the TBL aspect of supply chain sustainability (Bai et al., 2019; Padhi et al., 2018; Shou et al., 2019).

Examples of social sustainability include ensuring fair policies, ethical practices, equal opportunities and diversity (Bai et al., 2019; Cole & Aitken, 2019; Mani & Gunasekaran, 2018). Several papers have focused on different social sustainability dimensions in supply chains, such as wages, child labour, equal opportunities, discrimination, ethics, corruption, health-safety, diversity, equity, human rights, labour practice, training and slavery (Mani et al., 2016, 2018a, 2018b; Mani & Gunasekaran, 2018; Rosanna Cole & Aitken, 2019). A summary of social sustainability in SSCM literature is presented in Table 2.1. Empirical research, together with the application of different MCDM methods, is widely used to identify and analyse the social dimension of SSCM. It is evident from the contributions presented in Table

2.1 that most of the research studies analysing social sustainability focus on barriers, enablers and criteria in service and manufacturing supply chains.

When a supply chain is environmentally sustainable, it is known as a green supply chain (Govindan et al., 2015). Examples of environmentally sustainable supply chains include waste treatment, recycling, environmental education and training, green purchasing, green manufacturing and green design (dos Santos et al., 2019; Kazancoglu et al., 2018a). Recent studies in this area widely applied MCDM methods. As Table 2.2 shows, most of the research studies examined focus on evaluating or analysing factors, indicators, criteria, practices, performances and suppliers in green supply chains. Different characteristics of green supply chains—such as recycling, remanufacturing, greenhouse gas emissions, waste management, environmental education and training, green design, green/cleaner production, green purchasing, green logistics/distribution, and energy consumption—are considered (dos Santos et al., 2019; Govindan, et al., 2015; Islam et al., 2018; Kazancoglu et al., 2018a, 2018b; Pourjavad & Shahin, 2018; Rostamzadeh et al., 2015; Wu & Chang, 2015). The different environmental sustainability characteristics and their source studies are presented in Table 2.2.

Table 2:1: Different characteristics of social sustainability studied under SSCM literature

Reference	Characteristic name													Contribution	Methodology
	Wages	Child labour	Equal opportunity	Discrimination	Ethics	Corruption	Health-safety	Diversity	Equity	Human right	Labour practice	Training	Slavery		
(Mani et al., 2015)	√	√	√	√			√	√	√	√	√	√		Analysing relationships between enablers to the social sustainability	ISM-MICMAC
(Mani et al., 2016)	√	√	√	√	√		√	√	√	√	√	√		Identification and analysis of different dimensions of social sustainability in supply chains in India	Semi-structured interview
(Ahmadi et al., 2017)							√			√	√	√		Investigating social sustainability criteria	BWM
(Hussain et al., 2018)			√		√		√		√			√		Identifying motivators, barriers, and enablers of social sustainability	Empirical study
(Mani & Gunasekaran, 2018)	√	√					√	√	√	√	√			Analysing forces for adopting social sustainability in emerging Indian and Portuguese economies	Empirical study
(Stevenson & Cole, 2018)	√	√				√				√	√		√	Analysing modern slavery in supply chains perspective of the United Kingdom from the clothing and textile sector	Secondary data analysis
(Venkatesh Mani et al., 2018b)	√	√	√	√	√		√			√	√	√	√	Developing a taxonomy of supply chain social sustainability practices	Empirical study
(Bai et al., 2019)							√			√	√	√		Selecting supplier bases socially sustainable criteria	Grey BWM – grey TODIM
(Mani et al., 2018a)	√	√		√	√	√	√	√	√	√		√	√	Investigating integrated aspects of social sustainability	Empirical study
(Munny et al., 2019)	√	√		√		√	√					√		Analysing enablers in social sustainability in footwear supply chains	BWM
(Rosanna Cole & Aitken, 2019)	√	√	√		√	√	√			√		√	√	Addressing social sustainability in supplier selection processes	Exploratory case study
(Khosravi & Izbirak, 2019)					√		√		√	√		√		Analysing dimensions of social sustainability in healthcare supply chains	Stochastic exponential distribution model

Table 2:2: Different characteristics of environmental sustainability studied under SSCM literature

Reference	Characteristic name												Contribution	Methodology
	Recycling	Remanufacturing	Circular Economy	Greenhouse Gas Emission	Waste treatment/ management	Use of natural resources	Environmental education and training	Green design	Green/ cleaner production	Green purchasing	Green logistics/ distribution	Energy consumption		
(Wu & Chang, 2015)	√			√			√	√		√			Identifying critical dimensions and factors in green supply chains	DEMATEL and cast study
(Rostamzadeh et al., 2015)	√	√		√	√			√	√	√	√		Evaluating indicators in green supply chains	Fuzzy VIKOR
(Govindan et al., 2015)	√			√	√	√		√	√	√		√	Evaluating suppliers in green supply chain	Literature Review
(Islam et al., 2018)	√	√		√	√			√		√		√	Analysing critical green supply chain practices	FIPA approach
(Kazancoglu et al., 2018b)	√			√	√	√	√	√	√	√	√	√	Analysing criteria for green supply chains	Fuzzy DEMATEL
(Kazancoglu et al., 2018a)	√		√	√	√			√	√	√	√	√	Developing an assessment framework for green supply chain management	Conceptual study
(Pourjavad & Shahin, 2018)			√					√	√	√			Evaluating performance of green supply chain management	Fuzzy inference system
(dos Santos et al., 2019)	√	√		√	√		√	√		√	√	√	Evaluating green suppliers	TOPSIS

Examples of economic sustainability include reducing cost, delivery reliability and quality (Govindan et al., 2013). In the last few years, a good number of studies have been conducted on different dimensions of SSCM, including several papers that review:

- green supply chain management (Fahimnia et al., 2015; Maditati et al., 2018; Tseng et al., 2019)
- different theories in sustainable supply chains (Saenz et al., 2015)
- the evolution of and future challenges in sustainable supply chain management (Ansari & Kant, 2017; Carter & Easton, 2011; Ghadimi et al., 2019; Rajeev et al., 2017)
- trends and future directions in social aspects of sustainable supply chains (Bubicz et al., 2019)
- SSCM in the global supply chain context (Koberg & Longoni, 2019)
- drivers in SSCM (Saeed & Kersten, 2019)
- MCDM methods applied in corporate sustainability (Chowdhury & Paul, 2020).

To become more sustainable, supply chains should implement sustainable practices with a specific impact on various TBL areas; however, decision-makers need to consider multiple criteria to evaluate suppliers, practices, success factors, drivers and challenges in SSCM. This is why MCDM methods have been widely applied in SSCM for decision-making based on multiple criteria.

The Scopus database was used to collect the relevant articles with the following phrases in the article title, abstract and keywords: "sustainable supply chain" and "multi-criteria decision making" or "multi-criteria decision analysis" or "MCDM". The preliminary search of the literature revealed that most of the studies in the SSCM modelling area had been published after 2010. Therefore, this thesis has reviewed the literature on MCDM methods applied in SSCM since 2010. After the preliminary search in Scopus, the search database was refined using the following criteria:

- document type: article
- source type: journals
- language: English.

Other databases, such as the Web of Science and Google Scholar, enhanced the search. The inclusion criteria were articles focused on any dimension of supply chain sustainability, and the search phrases appeared in the body text. The exclusion criterion was one or more keywords presented in the text or reference list without discussing supply chain sustainability using

MCDM methods. The following sub-sections review the applications of both individual and integrated MCDM methods in detail.

2.1.2 Applications of individual MCDM methods

From the literature search, many articles applied individual MCDM methods in SSCM, which are presented as follows.

DEMATEL and fuzzy/grey DEMATEL

Several studies identified and analysed success factors for sustainability initiatives using grey DEMATEL (Luthra et al., 2018a), sustainable food supply chain management using DEMATEL (Sharma et al., 2018), green supply chain practices using fuzzy DEMATEL (Wu et al., 2015), SSCM for Industry 4.0 using DEMATEL (Bhagawati et al., 2019) and implementing green supply chain management using DEMATEL (Gandhi et al., 2015). Several studies analysed and evaluated barriers or challenges to sustainable development using DEMATEL (Gardas et al., 2018), remanufacturing using grey DEMATEL (Bhatia & Srivastava, 2018) and green supply chain using DEMATEL (Kaur et al., 2018). A few studies also analysed drivers for sustainable consumption and production adoption by applying grey DEMATEL (Mangla et al., 2017) and drivers to ICT for sustainability initiatives in supply chains using fuzzy DEMATEL (Luthra et al., 2018b). Other applications include analysing criteria and alternatives in sustainable supply chains using grey DEMATEL (Su et al., 2016), evaluating influential indicators for adopting sustainable supply chains using DEMATEL (Li & Mathiyazhagan, 2016), analysing causal relationships between practices and performance in green supply chains using fuzzy DEMATEL (Govindan, Khodaverdi, et al., 2015), assessing performance in green supply chains considering economic, logistics, operational, organizational and marketing aspects using fuzzy DEMATEL (Kazancoglu et al., 2018b), and selection of suppliers based on multiple criteria using fuzzy DEMATEL (Lin et al., 2018).

AHP and fuzzy AHP

Certain studies applied AHP to evaluate barriers to adopting sustainable consumption and production initiatives (Luthra et al., 2015), analyse criteria for improving effectiveness in green supply chain management implementation (Shen et al., 2015), analyse challenges for Industry 4.0 initiatives towards SSCM (Luthra & Mangla, 2018), evaluate pressures to implement GSCM (Mathiyazhagan et al., 2015), evaluate manufacturing practices for sustainability (S. Gupta et al., 2015) and analyse drivers for sustainable manufacturing processes (Shankar et al., 2016). The remaining studies applied fuzzy AHP to identify and analyse risks in green supply chains (Mangla et al., 2015a), analyse success factors for sustainable food supply chain management (Sharma, Yadav, et al., 2018), evaluate indicators of SSCM (Kumar & Garg, 2017), assess the supply chain performance based on sustainability criteria (Mejías et al., 2019) and evaluate European countries for renewable energy sectors (Mastrocinque et al., 2020).

TOPSIS and fuzzy TOPSIS

In SSCM, TOPSIS and fuzzy TOPSIS are widely applied to evaluate and select suppliers in sustainable and green supply chains based on multiple criteria. These criteria include applications of TOPSIS in selecting sustainable suppliers (Bai & Sarkis, 2018; Li et al., 2019), and applications of fuzzy TOPSIS in evaluating green supplier performance (Rouyendegh et al., 2020; Shen et al., 2013), evaluating sustainable and green suppliers (dos Santos et al., 2019; Memari et al., 2019; Rashidi & Cullinane, 2019), and assessing areas for improvement in implementing green supply chain initiatives (Wang & Chan, 2013).

BWM

In the literature, several articles applied BWM in SSCM. These include an assessment of sustainability in green supply chains in an emerging economy (Suhi et al., 2019), assessment of social sustainability in supply chains (Ahmadi et al., 2017), evaluation of external forces for sustainable supply chains in the context of the oil and gas industries (Wan Ahmad et al., 2017), analysis of enablers for social sustainability in an emerging economy (Munny et al., 2019), evaluation and prioritisation of criteria for sustainable innovation (Kusi-Sarpong et al., 2019), analysis of product-package alternatives in food supply chains (Rezaei et al., 2019), ranking sustainable suppliers (Ghoushchi et al., 2019) and analysing barriers for sustainable supply chain innovation (Gupta et al., 2020).

VIKOR and fuzzy VIKOR

Several articles applied VIKOR or fuzzy VIKOR in SSCM. These articles include evaluating green supply chain management practices using fuzzy VIKOR (Rostamzadeh et al., 2015), selecting development programs for green suppliers using fuzzy VIKOR theory (Awasthi & Kannan, 2016), evaluating green environmental factors in reverse logistics using fuzzy VIKOR (Vahabzadeh et al., 2015a, 2015b), and assessing green supply chain initiatives using a probabilistic linguistic VIKOR method (Zhang & Xing, 2017).

Rough set

The rough set method has been applied in SSCM to select suppliers with sustainability (Bai & Sarkis, 2010); analyse relationships between organisational attributes, supplier development programs and performance in green supply chains (Bai & Sarkis, 2010); evaluate a selection, performance measurement and program development tool in green supply chains (Bai et al., 2010); and measure SSCM performances (Bai & Sarkis, 2012).

ELECTRE and fuzzy ELECTRE

ELECTRE and fuzzy ELECTRE have been applied in SSCM to classify suppliers in the manufacturing industry using the ELETCRE TRI-nC method (Costa et al., 2018) and evaluate supplier performance in green supply chains using the fuzzy ELECTRE method (Kumar et al., 2017).

ANP

A few articles applied the ANP method in SSCM. The applications include selecting suppliers for managing sustainability (Lin et al., 2015) and integrating the TBL aspect (Faisal et al., 2017).

RSRAM, RSAW, ISM and PROMETHEE

Researchers applied the RSTAM to analyse risk factors in SSCM (Song et al., 2017), the RSAW for sustainable supplier selection (Stević et al., 2019), the ISM to rank barriers in SSCM (Raut et al., 2019), and the PROMETHEE to analyse alternatives of biomass (Pehlken et al., 2020).

Summary of applications of individual methods

Researchers applied DEMATEL and fuzzy/Grey DEMATEL, AHP and BWM primarily for analysing success factors, barriers and challenges, drivers and enablers for different aspects of SSCM. Success factors are the important factors decision-makers should consider to ensure success in different dimensions of SSCM. Barriers and challenges are the causes that prevent the success of any dimension of SSCM. Drivers and enablers are the aspects that drive sustainable performance within any dimension of supply chain sustainability. The different MCDM methods applied to analyse and prioritise success factors, barriers and challenges, and drivers and enablers in SSCM are summarised in Tables 2.3, 2.4 and 2.5, respectively.

Table 2:3: Application of MCDM methods to analyse success factors

Analysed success factors in SSCM	References	Method
Green design, recovering and recycling, green purchasing, environmental performance, supplier collaboration, regulation	(Wu et al., 2015)	Fuzzy DEMATEL
Government regulations and standards, top management commitment, environmental certifications, adoption of new technology and processes, reverse logistics, training of suppliers and employees	(Gandhi et al., 2015)	DEMATEL
Technology development and process innovation, training, reverse logistics and waste minimization, ecological considerations in organizations' policies and missions, green design and purchasing, societal considerations, ethical and safe practices, community welfare and development	(Luthra et al., 2018a)	Grey DEMATEL
Climatic change, implementing green practice, governance and cooperation, technological innovation, government regulation	(Sharma, Mangla et al., 2018)	DEMATEL
Proper use of irrigation, demographic and environmental conditions, risk analysis, government policies, food packaging	(Sharma, Yadav et al. 2018)	Fuzzy AHP
Logistics integration, social development, environmental development	(Bhagawati et al., 2019)	DEMATEL

Table 2:4: Applications of MCDM methods to analyse barriers and challenges

Analysed barriers and challenges in SSCM	References	Method
Lack of support from management, lack of innovative methods, lack of technology developments, communication gap, lack of rewards and encouragement programs, lack of governmental regulations, lack of promotion of ethical and safe practices, reluctance of consumers towards sustainable development practices, lack of promotion of sustainable products, lack of knowledge among stakeholders.	(Luthra et al., 2016)	AHP
Lack of environmental regulation, lack of potential liability, high cost of disposal of hazardous materials, poor environmental performance, lack of information, lack of governmental support, high cost for renewable energy, lack of new technology, insufficient societal pressure, poor legislation, lack of adoption of green practices, health and safety issues, employment stability, less profit in remanufacturing, lack of adequate training, lack of management support.	(Kaur et al., 2017).	DEMATEL

Lack of sufficient governmental policies, poor infrastructure, low level of integration, skill shortage, poor quality of raw materials	(Gardas, Raut & Narkhede, 2018)	DEMATEL
Lack of channels to collect used products, imperfect legal system, consumption attitude, customer willingness to return the products, uncertainty in demand of remanufactured product, uncertainty in quality, quantity and timing of returned products.	(Bhatia & Srivastava, 2018)	Grey DEMATEL
Low understanding of industry 4.0 implications, poor research & development of industry 4.0 adoption, legal issues, low management support and dedication, lack of global standards and data-sharing protocols, security issues, lack of governmental support and policies, and financial constraints.	(Luthra & Mangla, 2018)	AHP
Technological, regulatory, social, cultural, organizational, market, and networking barriers.	(Gupta et al., 2020)	BWM

Researchers applied TOPSIS, fuzzy TOPSIS, VIKOR, rough set, and ANP to analyse and evaluate suppliers and practices in sustainable or green supply chains based on sustainable criteria. These studies are summarised in Table 2.6.

Table 2:5: Applications of MCDM methods for analysing drivers and enablers

Analysed drivers and enablers in SSCM	References	Method	Industry context
Commitment to continual improvement and pollution prevention, commitment to comply with legislation, framework for setting and reviewing environmental goals, legal and other requirements, environmental objectives and targets, environmental education and training, green teamwork, best practices, identification of culture, monitoring culture change, quantity of waste released at each stage, and communication between top management and employees.	(Shen, Muduli & Barve 2015)	AHP	Mining industries
Market capabilities, compliance with regulations, green purchasing, green innovation, environmental conservation, education and training, and employee welfare.	(Shankar, Kumar & Kannan 2016)	AHP	Tire manufacturing sector
Sustainable product cost reduction, financial availability for innovation, enhanced sustainability value to customers, investment in R&D for sustainable products, designing sustainable products, green logistics capabilities development, green manufacturing, environment management commitment, conducting regular environmental audits, enhancing the social image of the organization, corporate social responsibility initiatives, cultural, social values and norms, occupational health, safety and rights of the employees.	(Kusi-Sarpong, Gupta & Sarkis 2019)	BWM	Multiple manufacturing sectors
Top management role and support, government support systems and subsidies, information systems network design, socio-environmental impacts of the products, culture related factors, approach to ICT to adopt sustainability, understanding of the nature of sustainability, security and support services, and human expertise.	(Luthra et al. 2018b)	Fuzzy DEMATEL	Information and communication sector
Waste management, reuse and recycling, renewable energy usage, resource utilization, land, air and water pollution, government regulations, and use of hazardous materials.	(Suhi et al. 2019)	BWM	Multiple industry sectors
Wages and benefits, customer requirements, workplace health and safety practices, food, housing, and sanitation, child labour or forced labour, the commitment of top management, education and training of employees, non-discrimination, anti-corruption, and working hours.	(Munny et al. 2019)	BWM	Footwear industry

Table 2:6: Summary of applications in analysing and evaluating suppliers and practices

Sustainable criteria considered	Application area	Method	References
Cost, quality, time, flexibility, innovation, culture, technology, relationships, pollution control and prevention, resource consumption, health and safety, employment practices, local community influence	Supplier selection in sustainable supply chain	Rough Set	(Bai & Sarkis 2010b)
Green design, green purchasing, green production, green warehousing, green transportation, green recycling	Green practice evaluation	Fuzzy VIKOR	(Rostamzadeh et al. 2015)
Cost, resource usage, energy usage, water consumption, emission and waste generation, green manufacturing, product design, transportation, warehouse and procurement, reverse logistics	Evaluation of green supplier development program	VIKOR	(Awasthi & Kannan 2016)
Quality, price, on-time delivery, lead time, flexibility, community initiatives, ethical behaviour, health and safety, diversity, waste reduction, recycling, reverse logistics	Supplier selection in sustainable supply chain	ANP	(Faisal, Al-Esmael & Sharif 2017)
Pollution controls, pollution prevention, environmental management system, resource consumption, employment practices, health and safety, local communities influence, stakeholders influence, cost, quality, innovation	Supplier selection in sustainable supply chain	TOPSIS	(Bai & Sarkis 2018)
Cost reduction activities, products' quality improvement, an increase in supply flexibility, green design of products, green purchasing, green production, internal management support for green development, green logistics, provision for health and safety, protection of employee's rights, human rights, fair-trading and against corruption	Supplier selection in sustainable supply chain	TOPSIS	(Li, Fang & Song 2019)
Quality of products, service performance, cost, environmental efficiency, green image, pollution reduction, green competencies, health and safety, employment practices	Supplier selection in sustainable supply chain	Fuzzy TOPSIS	(Memari et al. 2019)
Cost, financial capability, flexibility, innovation, service capability, environmental management system, green image, greenhouse gas emission, reuse/recycling, pollution control, energy and resource consumption, economic welfare & growth, social responsibility, job safety and labour health, the interest and rights of employees, job opportunities	Supplier selection in sustainable supply chain	Fuzzy TOPSIS	(Rashidi & Cullinane 2019)

2.1.3 Applications of integrated MCDM methods

A reasonable number of articles applied integrated MCDM methods in SSCM. AHP or fuzzy AHP were most widely integrated with other methods such as DEMATEL, ELECTRE, ISM, TOPSIS, VIKOR, and SOWIA, followed by TOPSIS or fuzzy TOPSIS with FPP, rough set, CRITIC and VIKOR. Researchers have made a significant methodological contribution by applying more integrated MCDM methods in recent years; these studies are summarised in this section.

AHP and fuzzy AHP are mostly integrated with TOPSIS, fuzzy TOPSIS, VIKOR and fuzzy VIKOR. AHP-TOPSIS is widely applied in selecting sustainable or green suppliers, evaluating third-party logistics (3PL) service providers, and prioritising solutions and responses in different aspects of SSCM (Azimifard et al., 2018; Freeman & Chen, 2015; Mangla et al., 2015b; Mohammed et al., 2019; Singh et al., 2018; Sirisawat & Kiatcharoenpol, 2018). AHP-VIKOR (with their fuzziness) integrated method was mostly applied for selecting sustainable suppliers and management practices in green supply chain management (Awasthi et al., 2018; Luthra et al., 2017; Sari, 2017). Other integrations of AHP or fuzzy AHP with DEMATEL or fuzzy DEMATEL, ELECTRE or fuzzy ELECTRE, ISM, and SOWIA were applied in analysing success factors (Gandhi et al., 2016), barriers (Uddin et al., 2019), enablers (Kumar & Rahman, 2017) and strategy decisions (Sreekumar & Rajmohan, 2019) in green or SSCM.

ANP is mostly integrated with quality function deployment (QFD) to analyse supplier selection and environmental sustainability and design sustainable supply chains (Lam, 2015; Lam & Dai, 2015; Lam & Lai, 2015; Tavana et al., 2017). Other integrations of ANP with VIKOR (Liu et al., 2018) and grey rational analysis (GRA) (Hashemi et al., 2015) were applied in green/sustainable supplier evaluation.

BWM or fuzzy BWM is mostly integrated with VIKOR or fuzzy VIKOR for evaluating transportation service providers and outsourcing partners based on sustainable criteria (Garg & Sharma, 2020; Paul et al., 2020). Other applications of integrated BWM or fuzzy BWM include evaluating dimensions of human resources in green supply chains using BWM-DEMATEL (Kumar et al., 2019), selecting sustainable suppliers in manufacturing supply chains by integrating BWM and an alternative queuing method (AQM) (Liu et al., 2019), and selecting sustainable suppliers using integrated BWM and combined compromise solution (Jain et al., 2020).

TOPSIS or fuzzy TOPSIS is mainly integrated with VIKOR or fuzzy VIKOR, fuzzy preference programming (FPP), rough set and criteria importance through intercriteria correlation (CRITIC). TOPSIS-VIKOR (and their fuzziness) integrated methods (Bai & Sarkis, 2019; Ploskas & Papathanasiou, 2019) were applied to select third-party reverse logistics service providers and classify rural areas based on social sustainability criteria. TOPSIS-VIKOR-GRA (integrating three methods) was applied in analysing locations for remanufacturing plants based on multiple criteria (Bhatia et al., 2019). Other applications of integrated TOPSIS or fuzzy TOPSIS include evaluating supply chain practices by integrating TOPSIS and rough set (Kusi-Sarpong et al., 2015), analysing risk factors in SSCM using TOPSIS-CRITIC (Rostamzadeh et al., 2018), and selecting sustainable suppliers using TOPSIS-FPP (Fallahpour et al., 2017)

Other integrated methods, such as ELECTRE with VIKOR, were applied in environmental performance evaluation (Chithambaranathan et al., 2015), DEMATEL with MABAC was applied in sustainable freight transport systems (Yazdani, Pamucar, et al., 2020), RSAW with MABAC applied in sustainable supplier selection (Matić et al., 2019), factor relationship (FARE) with MABAC for selecting 3PL providers (Roy et al., 2020), step-wise weight assessment ratio analysis (SWARA) and fuzzy complex proportional assessment of alternatives (COPRAS) were used for analysing risks and solutions in sustainable manufacturing supply chains (Ansari et al., 2020). Finally, fuzzy entropy and fuzzy multi-attribute utility were applied for sustainable performance measures in the supply chain (Erol et al., 2011).

In summary, most of the integrated MCDM methods in SSCM were used for evaluating or analysing suppliers, service providers, barriers, enablers and success factors, and evaluating performance. A summary of different integrated MCDM methods applied in SSCM is presented in Table 2.7.

Table 2:7: Summary of integrated MCDM methods applied in SSCM

Method name	Integrated with														References	Area of application
	DEMATEL/ Fuzzy/Grey DEMATEL	ELECTRE/ Fuzzy ELECTRE	ISM	TOPSIS/ Fuzzy TOPSIS	VIKOR / Fuzzy VIKOR	SOWIA	GRA	QFD	Rough set	CRITIC	FPP	MABAAC	AQM	TODIM		
AHP/ Fuzzy AHP	√														(Gandhi et al., 2016)	Evaluating success factors of green supply chain
		√													(Uddin et al., 2019)	Analysing barriers to green supply chain management
			√												(Kumar & Rahman, 2017)	Analysing enablers in SSCM
				√											(Azimifard et al., 2018; Freeman & Chen, 2015; Mangla et al., 2015; Mohammed et al., 2019; Muhammad et al., 2020; R. K. Sharma et al., 2020; Singh et al., 2018; Sirisawat & Kiatcharoenpol, 2018)	Selecting sustainable/green suppliers, prioritising solutions for reverse logistics, prioritising the responses to manage risks, Third-party logistics (3PL) selection
					√										(Awasthi et al., 2018; Luthra et al., 2017; Sari, 2017)	Evaluating green supply chain management practices, sustainable supplier selection
				√		√									(Sreekumar & Rajmohan, 2019)	Analysing supply chain strategy decisions
ANP/ Fuzzy ANP							√								(Hashemi et al., 2015)	Green supplier selection
								√							(Lam, 2015; Lam & Dai, 2015; Lam & Lai, 2015; Tavana et al., 2017)	Analysing environmental sustainability, designing a sustainable maritime supply chain, global logistics service provider, sustainable supplier selection
					√										(Liu et al., 2018)	Sustainable supplier evaluation
	√				√										(Phochanikorn & Tan, 2019)	Sustainable supplier selection
	√		√												(Chauhan et al., 2020)	Investigating agri-produce sustainable supply chains
	√			√											(Tirkolaee et al., 2020)	Sustainable supplier selection

BWM/ Fuzzy BWM	√														(Kumar et al., 2019; Yazdani, Torkayesh, et al., 2020)	Evaluating human resource dimensions of green supply chain
					√										(Garg & Sharma, 2020; A. Paul et al., 2020)	Evaluating sustainable transportation service providers, Sustainable outsourcing partner selection
													√		(Liu et al., 2019)	Sustainable supplier selection in watch manufacturing
					√									√	(Abdel-Basset et al., 2020)	Evaluating measurement for sustainable supply chain finance
TOPSIS / Fuzzy TOPSIS					√										(Bai & Sarkis, 2019; Ploskas & Papathanasiou, 2019; Rajesh, 2020)	Third-party reverse logistics provider selection, classification of rural areas based on social sustainability indicators
					√		√								(Bhatia et al., 2019)	Location for remanufacturing plant
									√						(Kusi-Sarpong et al., 2015)	Green supply chain practices evaluation
										√					(Abdel-Basset & Mohamed, 2020; Rostamzadeh et al., 2018)	Evaluation of sustainable supply chain risk management
											√				(Fallahpour et al., 2017)	Sustainable supplier selection
							√								(Chen, 2019)	Sustainable supplier selection for building materials
ELECTRE					√										(Chithambaranathan et al., 2015)	Supply chain environmental performance evaluation
DEMATEL												√			(Yazdani, Pamucar, et al., 2020)	Sustainable freight transport system evaluation

2.2 Supply chain management studies in the context of the COVID-19 outbreak

A recently published systematic literature review on COVID-19 related supply chain studies discussed the impacts of COVID-19, resiliency, sustainability and the importance of implementing technologies during the COVID-19 outbreak (Chowdhury et al., 2021). This section discusses a brief literature review on COVID-19 outbreak-related studies in supply chains and sustainability areas to streamline this review.

2.2.1 Studies on COVID-19 outbreak in supply chains

There are several COVID-19 outbreak-related studies published in the literature in the supply chain area. Most of them discuss the impacts of the COVID-19 outbreak on the supply chains of different industry sectors (Chowdhury, Paul et al., 2021). For example, the COVID-19 outbreak impacted the supply chains of many industry sectors, including food supply chains (Abhishek et al., 2020; Cappelli & Cini, 2020; Deaton & Deaton, 2020; Reardon et al., 2020; Richards & Rickard, 2020; Rizou et al., 2020; Siche, 2020), healthcare supply chains (Armani et al., 2020; Govindan et al., 2020; Iyengar et al., 2020; Kumar et al., 2020; Leite et al., 2020; Mehrotra et al., 2020; Shokrani et al., 2020; Yu et al., 2020), apparel supply chains (Majumdar et al., 2020), retail (Yuen et al., 2020), the airline industry (Amankwah-Amoah, 2020) and other manufacturing sectors (Guan et al., 2020; Paul & Chowdhury, 2020).

Researchers also discussed several impacts of COVID-19 on supply chains, such as the breakdown of transportation and supply chain networks (Ivanov & Dolgui, 2020, 2021; Shokrani et al., 2020), supply failures and delays (Baveja et al., 2020; V. Gupta et al., 2021; Iyengar et al., 2020; Lozano-Diez et al., 2020; Remko, 2020), reduction in manufacturing capacities (Leite et al., 2020), adverse economic impacts (Hakovirta & Denuwara, 2020), and rise of health and safety issues (Rizou et al., 2020; Trautrims et al., 2020).

The contributions, findings, methodology and context of different COVID-19 related studies in supply chains are summarised in Table 2.8.

Table 2:8: Different COVID-19 outbreak related studies in supply chains

Reference	Contributions and Findings	Area of supply chain	Methodology Used	Context
(Deaton & Deaton, 2020)	The authors analysed the effect of COVID-19 on the food security of the Canadian food supply chain. They identified several impacts, including food shortages and price increases, limited international exchange, and a lack of farm's financial stability.	Entire supply chain	Researcher's perspective	Food supply chain of Canada
(Cappelli & Cini, 2020)	The authors investigated if there is a relevance of short food supply chains. They concluded that a short supply chain and local production could help the food supply chain.	Entire supply chain	Researcher's perspective	Food supply chain
(Abhishek et al., 2020)	The authors investigated the mitigation strategies for the disruptions from the COVID-19 outbreak. They found that the movement of necessary goods and labour safety is important to mitigate the impacts.	Entire supply chain	Commentary	The food supply chain of India
(Reardon et al., 2020)	The authors analysed how the COVID-19 outbreak will impact the food supply chain. They found that the entire food supply chain will be affected significantly, including upstream and downstream supply farms.	Entire supply chain	Researcher's perspective	The food supply chain of India
(Richards & Rickard, 2020)	The authors analysed the impacts of COVID-19 on the fruits and vegetable supply chain. They found both short-term and long-term impacts on fruits and vegetable markets, including demand loss, the closer of distribution, and a price increase.	Entire supply chain	Secondary data analysis	Food supply chain of Canada
(Siche, 2020)	The authors analysed the impact of the COVID-19 outbreak on the agriculture sector. They found that there will be significant global impacts on the agricultural supply chain, including difficulties in the accessibility of food, issues with food security, price volatility, issues with food safety, and broken supply chains	Entire supply chain	Secondary data analysis	Food supply chain
(Rizou et al., 2020)	The authors summarised the possible transmission ways of COVID-19 through the food supply chain, surfaces, and the environment. They found that more safety measures are needed when the supply chain is long as more people are involved in the supply chain process.	Entire supply chain	Review	Food supply chain
(Armani et al., 2020)	The authors provided solutions for medical equipment needed during the COVID-19 outbreak and recommended that 'low-tech' solutions have a real impact.	Entire supply chain	Researcher's perspective	Healthcare supply chain
(Govindan et al., 2020)	The authors developed a decision support system for demand management during COVID-19 in the healthcare supply chain.	Demand	Fuzzy inference system	Healthcare supply chain

(Iyengar et al., 2020)	The authors assessed the role of innovative technologies in recovering the production and supply chain of the ventilators.	Production and distribution	Review	Healthcare supply chain
(Mehrotra et al., 2020)	The authors analysed the allocation, reallocation of ventilators and estimation of shortfall during the COVID-19 outbreak and observed that there would be a shortfall in the production of ventilators.	Entire supply chain	Stochastic optimisation	Healthcare supply chain
(Ivanov, 2020a)	The author predicted the impacts of the COVID-19 outbreak on the global supply chain and reported several impacts, including ripple effect, supply chain disruption, disturbances in supply, logistics infrastructure and demand, long-term disruption existence, economic impact, supply chain performance,	Entire supply chain	Simulation modelling	Global supply chain
(Ivanov, 2020b)	The author theorised the viable supply chain in the light of the COVID-19 outbreak and reported that there would be long-term impacts and disruptions in supply chain.	Entire supply chain	Simulation modelling	General context
(Ivanov & Dolgui, 2020)	The authors introduced a concept of integrity of the intertwined supply network and viability to improve resiliency in the wake of the COVID-19 outbreak. They reported that there are ripple effects and supply chain collapse due to the impacts of the COVID-19 outbreak.	Entire supply chain	Dynamic game-theoretic modelling	General context
(Yu et al., 2020)	The authors reported that the quick ramp-up of COVID-19 drugs could help mitigate the demand surge.	Production and demand	Researcher's perspective	Pharmaceutical supply chain
(Sarkis et al., 2020)	The authors provided directions of research for moving towards sustainable supply and demand in the post-COVID-19 era	Entire supply chain	Researcher's perspective	General context
(Jabbour et al., 2020)	The authors addressed the prioritisation and focus of supply chain managers to deal with the impacts of the COVID-19 outbreak. They highlighted that building smarter and more resilient supply chains and an increase of a sustainable consumption perspective can be useful to manage the impacts.	Entire supply chain	Researcher's perspective	General context
(Queiroz et al., 2020)	The authors presented a systematic analysis of the impacts of epidemic outbreaks on supply chains guided by a structured literature review	Entire supply chain	Review	General context
(Paul & Chowdhury, 2020)	The authors investigated strategies to manage the disruptions due to the COVID-19 outbreak in toilet paper manufacturing.	Production	Analytical model	Toilet paper manufactur-ing supply chain
(Choi, 2020)	The author explored how logistics and technologies together can transform the "static service operations" to become the "bring-service-near-your-home" mobile service operations and reported that "bring-service-near-your-home" can be an effective strategy.	Entire supply chain	Analytical model	Supply chains of Hong Kong
(Trautrims et al., 2020)	The authors analysed the implications of the COVID-19 outbreak on modern slavery risks in supply chain and reported that there could be	Entire supply chain	Discussion	General context

	a rise in worker vulnerability and modern slavery risks			
(Majumdar et al., 2020)	The authors investigated the reasons behind the lack of social sustainability in the clothing supply chain operating in South Asian countries and suggested ways to address them. They reported that sharing risk, prohibiting unauthorised subcontracting, and encouraging NGO participation can effectively deal with the impacts.	Sourcing and production	Case study	Apparel supply chain in south Asian countries
(Amankwah-Amoah, 2020)	The authors examined the new contemporary challenges of adopting and implementing the environmental sustainability policies	Entire supply chain	Researcher's perspective	Global airline industry
(Paul & Chowdhury, 2021)	The authors developed a production model to recover from the impacts of COVID-19 for a high-demand item. They found that recovery strategies can play a big role.	Production system	Mathematical model and optimisation	General context
(Paul, Chowdhury, Moktadir, et al., 2021)	The authors identified and analysed a list of supply chain recovery challenges in the ready-made garment industry.	Entire supply chain	Delphi and grey DEMATEL	Ready-made garment industry
(Rahman et al., 2021)	The authors analysed the impacts of the COVID-19 outbreak and developed a recovery planning model using a simulation approach.	Entire supply chain	Agent-based modelling and simulation	PPE manufactur-ing supply chain

2.2.2 COVID-19 outbreak and sustainability

Several COVID-19 related studies considered supply chain sustainability as the main focus. A recently published article reported the impacts of the COVID-19 outbreak on the decarbonisation of agroecosystems. The authors found that the emission of carbon dioxide has been reduced in the agri-food sectors in European countries (Adelodun et al., 2021). Orji and Ojadi (2021) investigated the criteria for sustainable supplier selection during the COVID-19 outbreak in the Nigerian manufacturing sector and found the pandemic significantly changed the criteria for selecting sustainable suppliers. Petrudi et al. (2021) evaluated suppliers based on social sustainability innovation criteria in a similar dimension. They found that criteria related to health and safety, remote working and localisation were essential during the COVID-19 outbreak. Majumdar et al. (2021) analysed and prioritised the mitigation strategies to improve environmental performance in the clothing supply chain and found that agility, green sourcing and practice, and trust and coordination were essential during the pandemic. Moreover, Karmaker et al. (2021) explored the enablers and drivers of a sustainable supply chain to mitigate the impacts of the COVID-19 outbreak and found that an established health protocol and automation in supply chain operations were important for improving supply chain sustainability performance.

Recently, Babbitt et al. (2021) investigated the impacts of human behaviours on food shortage and food waste during the COVID-19 outbreak and discussed the implications for food supply chain sustainability. Derqui et al. (2021) measured community pharmacies' engagement in sustainability practices during the pandemic and found that green procurement practices should be enhanced to improve sustainability practices. Sarkis (2021) discussed the TBL dimensions of sustainability and identified research questions focusing on economic, social and environmental sustainability amid the COVID-19 outbreak. Dubey et al. (2021) explored the drivers of sustainable global supply chains for frugal innovation. They found that government support, leadership and emerging technologies could help deal with the humanitarian crisis of the COVID-19 outbreak. Pereira et al. (2020) analysed the impacts of the pandemic on sustainability learning and found that social sustainability was the main focus of suppliers during the COVID-19 outbreak.

Chatterjee and Chaudhuri (2021) analysed the impacts of several strategies on supply chain sustainability performance and found that the organisation's capabilities, leadership and contingency plan positively impacted sustainability performance during the COVID-19 outbreak. Cole and Shirgholami (2021) investigated the trend of modern slavery in the post-pandemic era and found that modern slavery risk could increase, and government should explore the governance gaps to fill them. Some other studies on different dimensions of sustainable supply chain and the COVID-19 outbreak are also available in the literature (Cariappa et al., 2021; Rowan & Laffey, 2020; Tareq et al., 2021; Yu & Khan, 2021)

2.3 Research gaps

Although researchers mostly discussed the economic and operational impacts and challenges on different industry sectors, a number of studies only mentioned some challenges in their studies in the context of the COVID-19 outbreak. Some examples of the reported sustainability challenges in the literature due to the effects of the pandemic are a lack of cash flow in the market (Hakovirta & Denuwara, 2020), an increase in the price of raw materials (Deaton & Deaton, 2020; Farias & Araújo, 2020), lack of green manufacturing practices (Hosseini, 2020), negative environmental impacts of continuous cleaning and disinfecting activities (Lenzen et al., 2020), increase in waste (Dente & Hashimoto, 2020; Trautrims et al., 2020), increase rate of unemployment (Hakovirta & Denuwara, 2020; ILO, 2020), violation in code of conduct in ethical practices (Majumdar et al., 2020), rise in modern slavery (Trautrims et al., 2020), and reduction in production capacity and longer supply lead-time (Leite et al., 2020; Paul & Chowdhury, 2020).

In summary, while the academic literature identified a few supply chain sustainability challenges due to the impacts of the COVID-19 outbreak in different industry and country contexts, most studies were based on researchers' perspectives and opinions. As a result, there is a significant gap in the research comprehensively analysing sustainability challenges in a particular context using a systematic research methodology. To address this research gap, the current study takes the first step to thoroughly identify, analyse and prioritise COVID-19 outbreak-related supply chain sustainability challenges in the Australian food processing sector by applying a systematic research methodology that integrates both qualitative and quantitative methods.

The next chapter discusses the research methodology.

Chapter 3 : Research Methodology

This research integrates a qualitative online survey and a quantitative method to identify and analyse the challenges to achieving the objectives. The research methodology is presented in Figure 3.1.

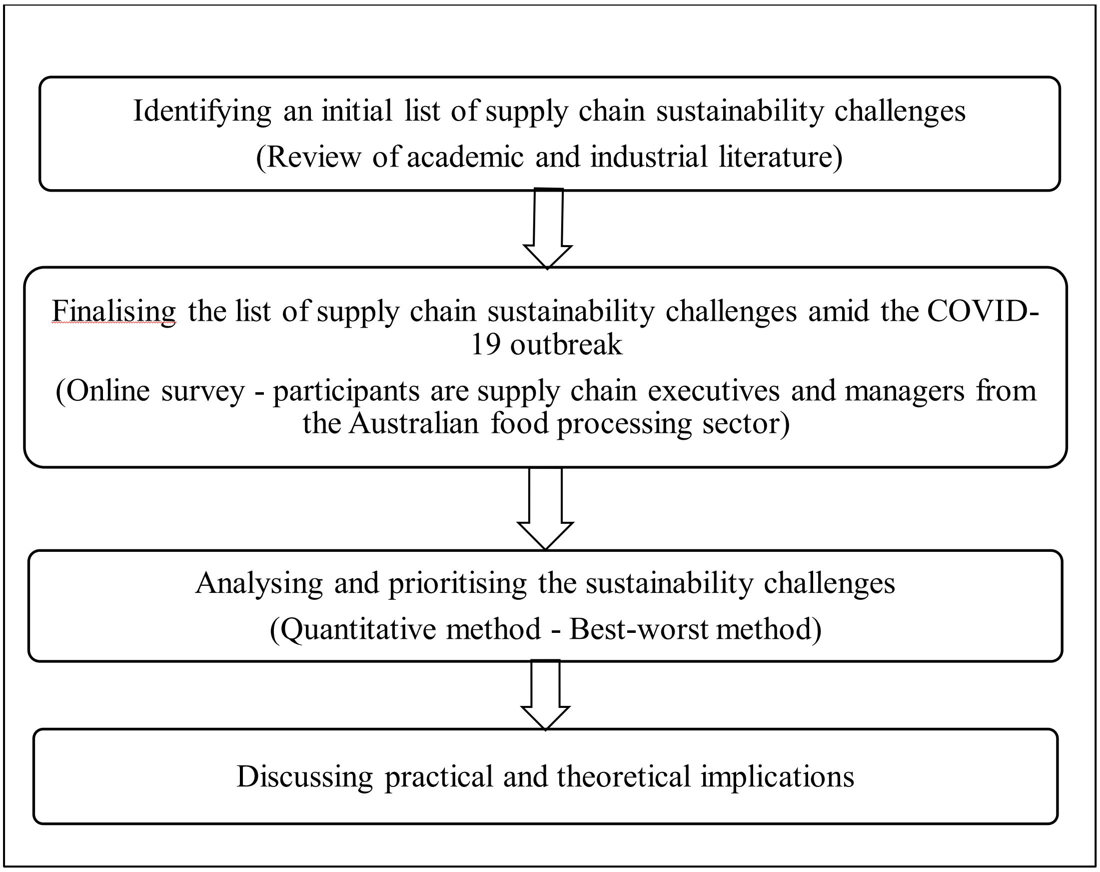

Figure 3.1: Research methodology for analysing sustainability challenges

3.1 Identifying the initial list of sustainability challenges

The initial list of sustainability challenges was determined through a review of academic literature and industry literature such as news and magazine articles. The Scopus and Google Scholar databases were used to search academic articles, and the Google search engine was used to find industry articles from reputed newspapers and professional magazines. Keywords such as "COVID-19", "coronavirus", "supply chain" and "sustainability challenges" were used to search the articles. Several opinions and short articles related to the COVID-19 outbreak and sustainability were published in the academic literature. In addition, there were a good number of industry articles related to sustainability and the COVID-19 outbreak. Both academic and industry articles were reviewed to prepare an initial list of sustainability challenges due to the impacts of the COVID-19 outbreak.

3.2 Finalising the list of sustainability challenges

The initial list was prepared through a review of academic and industry articles; however, this list should be contextualised for the specific context of the study. In this regard, an expert survey was conducted to finalise the list of sustainability challenges for the food supply chain in Australia. The survey participants were supply chain executives and managers working in the food processing sector in Australia.

3.3 Analysing and prioritising the sustainability challenges

The final list, determined through the online survey, was used to further analyse and prioritise the sustainability challenges. The BWM was employed to analyse and prioritise the challenges due to the following advantages:

- easy data collection as this method does not require a pairwise comparison; data can be collected using a linguistic 1–9 scale
- can determine optimal weight
- data-efficient method; the results are reliable and consistent (Rezaei, 2015).

The steps of the BWM are as follows (Rezaei, 2015).

Step 1: Determine the *best* and *worst* sustainability challenges.

The best sustainability challenge is the most critical one, and the worst sustainability challenge is the least critical one. In this step, experts mention the best and worst challenges without any comparison.

Step 2: Determine the preference of the *best* sustainability challenge over the other sustainability challenges

In this step, experts compare the best sustainability challenge over the other challenges using a linguistic scale, as shown in Table 3.1. The comparison vector can be formatted as follows:

$$A_B = (a_{B1}, a_{B2}, ..., a_{Bn})$$

Where a_{Bj} represents the preference of the best sustainability challenge over the sustainability challenge j. Hence, $a_{BB} = 1$.

Table 3:1: Linguistic scale of the BWM

Linguistic scale	Meaning
1	Equal preference
2	Equal to moderate preference
3	Moderate preference
4	Moderate to strong preference
5	Strong preference
6	Strong to very strong preference
7	Very strong preference
8	Very strong to extreme preference
9	Extreme preference

Examples:

When determining the preference of the *best* sustainability challenge over the other sustainability challenges, linguistic 3 represents moderately less preference. Similarly, linguistic 9 represents extremely less preference. The other scales should be interpreted similarly.

When determining the preferences of all other sustainability challenges over the *worst* sustainability challenge, linguistic 3 represents moderately more preference. Similarly, linguistic 9 represents extremely more preference. The other scales should be interpreted similarly.

***Step 3**: Determine the preferences of all the other sustainability challenges over the* *worst* sustainability challenge.

In this step, again, experts compare the other sustainability challenges to the worst sustainability challenge using the same linguistic scale as shown in Table 3.1. The formulated comparison vector can be formatted as follows.

$$A_W = (a_{1W}, a_{2W}, \ldots, a_{nW})$$

Where a_{jW} indicates the preference of the j challenge over the worst challenge and $a_{WW} = 1$.

***Step 4**: Finding the optimal weights of* challenges $(w_1^*, w_2^*, \ldots, w_n^*)$

To acquire the optimal weights of sustainability challenges ($w_1^*, w_2^*, \ldots, w_n^*$), the maximum absolute differences for all j challenges can be minimised among the set of $\{|w_B - a_{Bj}w_j|, |w_j - a_{jW}w_W|\}$, and the problem can be formulated as follows.

$$\min \max_j \{|w_B - a_{Bj}w_j|, |w_j - a_{jW}w_W|\}$$

Subject to,

$$\sum_j w_j = 1, \qquad \text{(model 1)}$$

$w_j \geq 0$, for all j

The non-linear model (1) can be transferred to a linear model and is given below.

$$\min \xi^L,$$

Subject to,

$|w_B - a_{Bj}w_j| \leq \xi^L$, for all j,

$|w_j - a_{jW}w_W| \leq \xi^L$, for all j, (model 2)

$\sum_j w_j = 1$,

$w_j \geq 0$, for all j

The optimal weights of sustainability challenges ($w_1^*, w_2^*, \ldots, w_n^*$) and ξ^L can be established by solving the linear programming (LP) problem shown in model (2). The Excel Solver can be used to solve the model (2). After solving the model, the arithmetic average of the calculated weights for all experts is used to determine the optimal weight of each sustainability challenge (Moktadir et al., 2021; Paul et al., 2021c). In BWM, all experts are equally important; hence, the arithmetic average is commonly used to aggregate the weight.

3.4 Discussing practical and theoretical implications

In this stage, the results are discussed, and the practical and theoretical implications of the results are provided. This discussion helps food processing sector practitioners prepare and formulate strategies to deal with the COVID-19 related supply chain sustainability challenges.

3.5 Justification of methodology

The justification of the methodology is as follows:

- Some articles in academic and industry literature discussed different challenges due to the impacts of COVID-19. The review of these articles helped determine the initial list of sustainability challenges.
- It is not possible to determine the full list of sustainability challenges in the context of the study by reviewing the academic and industry literature. An online survey by Australian food processing sector practitioners helps to include and exclude the challenges for this specific context.
- After conducting the online survey, the final list of sustainability challenges was prepared. A quantitative tool was required to analyse and prioritise those challenges, so the BWM was applied.
- Finally, the discussion on results and practical implications can help practitioners from the food processing sectors formulate strategies to deal with the supply chain sustainability challenges due to the impacts of the COVID-19 outbreak.

The next chapter provides the results and discussions.

Chapter 4 : Results and Discussions

This chapter discusses the results for identifying and finalising the list of supply chain sustainability challenges and analysing those challenges using the BWM. It also discusses the sensitivity analysis to prove the robustness of the findings. In this thesis, data were collected during August – November 2021.

4.1 Finalising the list of sustainability challenges

A number of articles on the COVID-19 outbreak in supply chain management were discussed in Chapter 2. The supply chain sustainability literature examined job loss and issues in health and safety (Hakovirta & Denuwara, 2020), social, economic and health inequality (Ibn-Mohammed et al., 2021), modern slavery risk (Trautrims et al., 2020), damage in code of conduct (Majumdar et al., 2020), lack of green practices (Hosseini, 2020), increase in food waste and resource uses (Dente & Hashimoto, 2020), increase in plastic and food waste (Sharma et al., 2020) and the challenge in maintaining environmental sustainability practices (Amankwah-Amoah, 2020). The list of sustainability challenges is scattered in the literature on the COVID-19 outbreak in SSCM. A few studies thoroughly identified and analysed supply chain sustainability challenges using a systematic methodological approach in the food processing sector. Subsequently, an initial list of sustainability challenges and their sources were collected through academic and industrial literature reviews, as presented in Table 4.1

To finalise and contextualise the list of sustainability challenges, information was collected from 10 Australian food processing industry experts through an online questionnaire survey (see Appendix A). The online survey questionnaire was sent to 36 experts from the Australian food processing sector who have more than four years of work experience. Among them, 10 experts responded and completed the survey, similar to those used in existing studies to collect data (Paul et al., 2021b; Kumar et al., 2021; Dwivedi & Paul, 2022). The experts' profiles are presented in Table 4.2.

The surveyed experts indicated that several sustainability challenges from the initial list were not valid for the Australian food processing industry and suggested a number of additional sustainability challenges that should be considered. The results of consolidating the expert opinions on sustainability challenges due to the impact of the COVID-19 pandemic are shown in Table 4.3: the challenges removed from the list are highlighted in yellow and those added are highlighted in green. The finalised list of sustainability challenges and their notations are presented in Table 4.4, which are considered for BWM analysis to determine their priorities.

Table 4:1: Initial list of sustainability challenges

Category	Name of the challenge	Sources
Economic challenges	Lack of capital and physical resources	(Dente & Hashimoto, 2020)
	Lack of cash flow in the market	(Hakovirta & Denuwara, 2020)
	Increase in price of raw materials	(Deaton & Deaton, 2020; Farias & Araújo, 2020)
Environmental challenges	Difficulty in implementing environmental sustainability policies	(Amankwah-Amoah, 2020)
	Lack of green manufacturing practices	(Hosseini, 2020)
	Negative environmental impacts of continuous cleaning and disinfecting activities	(Lenzen et al., 2020)
	Increase in waste	(Dente & Hashimoto, 2020; Trautrims et al., 2020)
Social and ethical challenges	Loss of jobs/ Increase rate of unemployment	(Hakovirta & Denuwara, 2020; ILO, 2020)
	Violation in code of conduct in ethical practices	(Majumdar et al., 2020)
	Rise in modern slavery	(Trautrims et al., 2020)
	Lack of health and safety equipment	(EDIE, 2020; Hakovirta & Denuwara, 2020)
	Lack of collaborations	(Remko, 2020)
Operational challenges	Lack of skilled workforce	(KPMG, 2020; Kumar et al., 2020; Trautrims et al., 2020)
	Fluctuating market demand	(Abhishek et al., 2020; Chiaramonti & Maniatis, 2020; Majumdar et al., 2020)
	Shortage of supply/raw material	(Baveja et al., 2020; Ivanov & Das, 2020; Paul & Chowdhury, 2021; Paul & Chowdhury, 2020)
	Breakdown of the transportation network	(Chiaramonti & Maniatis, 2020; Deaton & Deaton, 2020; Gray, 2020; Kumar et al., 2020)
	Reduction in production capacity	(Leite et al., 2020; Paul & Chowdhury, 2020)
	Long lasting impacts	(Lenzen et al., 2020)
	Longer supply lead-time	(Ivanov & Das, 2020; KPMG, 2020)

Table 4:2: Experts' profiles for finalising sustainability challenges

Expert no.	Years of experience	Position	Size of organisation (full-time employees)
1	20	Manager	0–19
2	15	Head of logistics	20–199
3	11	Supervisor	20–199
4	22	Regional manager	>200
5	18	Manager	>200
6	4	Owner	0–19
7	18	Manager	20–199
8	10	Relationship Manager	0–19
9	8	Owner	0–19
10	16	Manager	20–199

Table 4:3: List of sustainability challenges obtained from the survey

Category	Name of the challenge	Sources (LR = Literature review)
Economic challenges	Lack of capital and physical resources	LR + Survey
	Lack of cash flow in the market	LR + Survey
	Increase in price of raw materials	LR + Survey
	Increased food processing cost	Survey
Environmental challenges	Difficulty in implementing environmental sustainability policies	Removed
	Lack of green manufacturing practices	LR + Survey
	Negative environmental impacts of continuous cleaning and disinfecting activities	LR + Survey
	Increase in food waste	LR + Survey
Social and ethical challenges	Loss of jobs/ Increase rate of unemployment	Removed
	Violation in code of conduct in ethical practices	Removed
	Rise in modern slavery	LR + Survey
	Lack of health and safety equipment	Removed
	Breakdown of trust in supply chain	Survey
	Lack of transparency and traceability	Survey
	Spread of fake information	Survey
	Lack of collaborations	LR + Survey
	Slow communication	Survey
Operational challenges	Lack of skilled workforce	LR + Survey
	Fluctuating market demand	LR + Survey
	Shortage of supply/raw material	LR + Survey
	Breakdown of the transportation network	LR + Survey
	Reduction in production capacity	LR + Survey
	Long lasting impacts	LR + Survey
	Longer supply lead-time	LR + Survey
	Delay in upgrading supply chain technology	Survey
	Frequent changes in planning	Survey

Table 4:4: Final list of sustainability challenges to be analysed by BWM

Category and notation	Name of the challenge and notation	Sources LR = Literature review
Economic challenges (SC1)	Lack of capital and physical resources (SC11)	LR + Survey
	Lack of cash flow in the market (SC12)	LR + Survey
	Increase in price of raw materials (SC13)	LR + Survey
	Increased food processing cost (SC14)	Survey
Environmental challenges (SC2)	Lack of green manufacturing practices (SC21)	LR + Survey
	Negative environmental impacts of continuous cleaning and disinfecting activities (SC22)	LR + Survey
	Increase in food waste (SC23)	LR + Survey
Social and ethical challenges (SC3)	Rise in modern slavery (SC31)	LR + Survey
	Breakdown of trust in supply chain (SC32)	Survey
	Lack of transparency and traceability (SC33)	Survey
	Spread of fake information (SC34)	Survey
	Lack of collaborations (SC35)	LR + Survey
	Slow communication (SC36)	Survey
Operational challenges (SC4)	Lack of skilled workforce (SC41)	LR + Survey
	Fluctuating market demand (SC42)	LR + Survey
	Shortage of supply/raw material (SC43)	LR + Survey
	Breakdown of the transportation network (SC44)	LR + Survey
	Reduction in production capacity (SC45)	LR + Survey
	Long-lasting impacts (SC46)	LR + Survey
	Longer supply lead-time (SC47)	LR + Survey
	Delay in upgrading supply chain technology (SC48)	Survey
	Frequent changes in planning (SC49)	Survey

4.2 Analysing and prioritising the sustainability challenges

Another questionnaire survey was conducted to analyse the sustainability challenges using BWM (see Appendix B). The questionnaire was sent to 27 experts from the Australian food processing sector who have more than four years of work experience, and 12 experts responded. As with the earlier survey, this number of experts aligns with several comparable studies in the literature (Paul et al., 2020; Moktadir et al., 2021; Dwivedi & Paul, 2022). A Google Form link was distributed to participants from the Australian food processing sector to fulfil the values in a Microsoft Excel file. The profiles of the 12 experts for BWM are presented in Table 4.5.

Table 4:5: Experts' profiles for BWM analysis

Expert	Years of experience	Position	Size of organisation (full-time employees)
E1	14	Regional manager	20–199
E2	11	Operations manager	20–199
E3	8	Logistics specialist	0–19
E4	11	Manager	20–199
E5	5	Supply chain analyst	0–19
E6	7	Inventory analyst	20–199
E7	10	Purchasing manager	0–19
E8	6	Supervisor	20–199
E9	14	Manager	>200
E10	17	Manager	20–199
E11	4	Owner	0–19
E12	8	Purchasing manager	>200

Experts were asked to select the best and worst challenges as per the questionnaire shown in Table B1 in Appendix B. The data for the best and worst challenges are summarised and presented in Table 4.6. For the main categories, it was observed that experts recommended either economic challenges (SC1) or social and ethical challenges (SC3) as the best categories. Conversely, seven experts recommended environmental challenges (SC2), three experts recommended social and ethical challenges (SC3), and two experts recommended operational challenges (SC4) as the worst categories. Similarly, experts recommended their best and worst challenges under those four categories, as detailed in Table 4.6. Notably, most of the experts recommended increased food processing cost (SC14), increase in food waste (SC23), lack of transparency and traceability (SC33), and fluctuating market demand (SC42) as their best challenges. Meanwhile, most experts recommended lack of cash flow in the market (SC12), lack of green manufacturing practices (SC21), rise in modern slavery (SC31), and reduction in production capacity (SC45) as the worst challenges.

Table 4:6: Feedback from experts for BWM

Category	Name of the challenge	Experts mentioned as best challenge	Experts mentioned as worst challenge
Economic challenges (SC1)		E1, E2, E4, E5, E8, E10	
	Lack of capital and physical resources (SC11)	E10	E3, E6, E11
	Lack of cash flow in the market (SC12)	E1	E2, E4, E5, E7, E8, E9, E12
	Increase in price of raw materials (SC13)	E4, E6, E9	E10
	Increased food processing cost (SC14)	E2, E3, E5, E7, E8, E11, E12	E1
Environmental challenges (SC2)			E3, E4, E5, E7, E8, E11, E12
	Lack of green manufacturing practices (SC21)		E1, E3, E4, E5, E6, E8, E9, E10, E12
	Negative environmental impacts of continuous cleaning and disinfecting activities (SC22)	E4, E6, E9	E2, E7, E11,
	Increase in food waste (SC23)	E1, E2, E3, E5,E7,E8,E10,E11,E12	
Social and ethical challenges (SC3)		E3, E6, E7, E9, E11, E12	E1, E2, E10
	Rise in modern slavery (SC31)		E2,E4,E5,E6,E7,E9, E11,E12
	Breakdown of trust in supply chain (SC32)		E10
	Lack of transparency and traceability (SC33)	E1, E3,E4,E5,E6,E7,E8,E9,E10,E12	
	Spread of fake information (SC34)	E2, E11	
	Lack of collaborations (SC35)		E1,E3,E8
	Slow communication (SC36)		
Operational challenges (SC4)			E6, E9
	Lack of skilled workforce (SC41)		
	Fluctuating market demand (SC42)	E3,E4,E7,E8,E10,E12	
	Shortage of supply/raw material (SC43)	E2,E5,E11	
	Breakdown of the transportation network (SC44)		
	Reduction in production capacity (SC45)		E1,E3,E5,E6,E7,E8, E10,E12
	Long lasting impacts (SC46)		
	Longer supply lead-time (SC47)	E1, E6, E9	
	Delay in upgrading supply chain technology (SC48)		E2,E4,E9
	Frequent changes in planning (SC49)		E11

Note: “Best” challenge means most impactful, and “worst” challenge means least impactful

The experts were also asked to make the comparison matrix for *best* challenge preference over the other challenges and for all challenges over the w*orst* challenge using the linguistic 1–9 scale, as per the questionnaire shown in Tables B3 and B4 in Appendix B. These data are summarised into four main categories and challenges under those categories. Table 4.7 presents the data obtained from 12 experts for the best category over the other categories and all other categories over the worst category. Using this comparison data, the weight of each category was computed by solving model 2 as presented in Section 3.3. The computed weights of each category using the BWM are also presented in Table 4.7. It was observed that the economic challenges (SC1) obtained the highest average weight of 0.3743, followed by the social and ethical challenges (SC3), operational challenges (SC4) and environmental challenges (SC2), with average weights of 0.3472, 0.1710 and 0.1075, respectively. These results are consistent with the experts' preferences as most of the experts recommended economic challenges (SC1) and social and ethical challenges (SC3) as their best preferences.

Similarly, the best challenge over the other challenges and all other challenges over the worst challenges were summarised and are presented in Tables 4.8–4.11 for challenges under SC1, SC2, SC3 and SC4, respectively. Next, the weights of challenges were computed by using the BWM. Table 4.8 shows that the increased food processing cost (SC14) obtained the highest average weight of 0.4029, following the increase in the price of raw materials (SC13), lack of capital and physical resources (SC11) and lack of cash flow in the market (SC12), with average weight values of 0.2492, 0.2165 and 0.1314, respectively. These results are consistent with the experts' preferences as most of the experts recommended increased food processing cost (SC14) as their best challenge.

Under the environmental challenges (SC2) category, the increase in food waste (SC23) obtained the highest average weight of 0.5480, as most experts recommended as the best challenges under SC2. The computed weights of challenges under SC2 are presented in Table 4.9. Under the social and ethical challenges (SC3) category, lack of transparency and traceability (SC33) obtained the highest average weight of 0.3431. This is also consistent with the experts' recommendations, as most selected SC33 as their best preference. The computed weights of challenges under SC3 are presented in Table 4.10. Finally, under the operational challenges (SC4) category, fluctuating market demand (SC42) obtained the highest average weight of 0.2474. This result is consistent with the experts' recommendation, as most selected SC42 as their best preference under SC4. The computed weights of challenges under SC4 are presented in Table 4.11.

Table 4:7: Computed weights for the categories of sustainability challenges

Expert		SC1	SC2	SC3	SC4
E1	Best (SC1)	1	3	7	4
	Worst (SC3)	7	4	1	3
	Weights	0.5614	0.2105	0.0702	0.1579
E2	Best (SC1)	1	4	7	3
	Worst (SC3)	7	3	1	4
	Weights	0.5614	0.1579	0.0702	0.2105
E3	Best (SC3)	4	7	1	3
	Worst (SC2)	3	1	7	4
	Weights	0.1579	0.0702	0.5614	0.2105
E4	Best (SC1)	1	8	5	3
	Worst (SC2)	8	1	3	5
	Weights	0.5817	0.0619	0.1337	0.2228
E5	Best (SC1)	1	6	3	4
	Worst (SC2)	6	1	6	2
	Weights	0.5350	0.0637	0.2293	0.1720
E6	Best (SC3)	3	4	1	7
	Worst (SC4)	4	3	7	1
	Weights	0.2105	0.1579	0.5614	0.0702
E7	Best (SC3)	5	7	1	4
	Worst (SC2)	4	1	7	5
	Weights	0.1485	0.0655	0.6004	0.1856
E8	Best (SC1)	1	6	5	4
	Worst (SC2)	7	1	6	5
	Weights	0.5815	0.0617	0.1586	0.1982
E9	Best (SC3)	3	4	1	7
	Worst (SC4)	4	3	7	1
	Weights	0.2105	0.1579	0.5614	0.0702
E10	Best (SC1)	1	5	7	4
	Worst (SC3)	7	6	1	5
	Weights	0.5914	0.1561	0.0575	0.1951
E11	Best (SC3)	3	7	1	4
	Worst (SC2)	4	1	7	5
	Weights	0.2252	0.0596	0.5464	0.1689
E12	Best (SC3)	6	7	1	4
	Worst (SC2)	4	1	7	5
	Weights	0.1269	0.0672	0.6157	0.1903
Average weight (k*=0.1173)		0.3743	0.1075	0.3472	0.1710
Rank		1	4	2	3

Table 4:8: Computed weights for the sustainability challenges under the economic challenges category

Expert		SC11	SC12	SC13	SC14
E1	Best (SC12)	3	1	4	7
	Worst (SC14)	5	7	3	1
	Weights	0.2186	0.5531	0.1640	0.0643
E2	Best (SC14)	2	7	4	1
	Worst (SC12)	6	1	4	7
	Weights	0.2941	0.0588	0.1471	0.5000
E3	Best (SC14)	7	5	4	1
	Worst (SC11)	1	6	3	7
	Weights	0.0575	0.1561	0.1951	0.5914
E4	Best (SC13)	5	9	1	3
	Worst (SC12)	3	1	9	5
	Weights	0.1319	0.0579	0.5903	0.2199
E5	Best (SC14)	2	9	3	1
	Worst (SC12)	7	1	6	9
	Weights	0.2825	0.0448	0.1883	0.4843
E6	Best (SC13)	7	4	1	2
	Worst (SC11)	1	2	7	4
	Weights	0.0721	0.1351	0.5225	0.2703
E7	Best (SC14)	4	7	5	1
	Worst (SC12)	5	1	4	7
	Weights	0.1856	0.0655	0.1485	0.6004
E8	Best (SC14)	3	9	5	1
	Worst (SC12)	7	1	5	9
	Weights	0.2328	0.0506	0.1397	0.5769
E9	Best (SC13)	3	7	1	4
	Worst (SC12)	4	1	7	5
	Weights	0.2252	0.0596	0.5464	0.1689
E10	Best (SC11)	1	5	7	4
	Worst (SC13)	7	4	1	5
	Weights	0.6004	0.1485	0.0655	0.1856
E11	Best (SC14)	7	4	5	1
	Worst (SC11)	1	3	4	7
	Weights	0.0681	0.1825	0.1460	0.6034
E12	Best (SC14)	3	7	5	1
	Worst (SC12)	5	1	4	7
	Weights	0.2294	0.0642	0.1376	0.5688
Average weight (k*=0.1107)		0.2165	0.1314	0.2492	0.4029
Rank		3	4	2	1

Table 4:9: Computed weights for the sustainability challenges under the environmental challenges category

Expert		SC21	SC22	SC23
E1	Best (SC23)	5	2	1
	Worst (SC21)	1	3	5
	Weights	0.1111	0.3056	0.5833
E2	Best (SC23)	5	3	1
	Worst (SC21)	1	2	5
	Weights	0.1250	0.2250	0.6500
E3	Best (SC23)	7	2	1
	Worst (SC21)	1	4	7
	Weights	0.0833	0.3125	0.6042
E4	Best (SC22)	6	1	2
	Worst (SC21)	1	6	4
	Weights	0.0909	0.5909	0.3182
E5	Best (SC23)	6	2	1
	Worst (SC21)	1	4	6
	Weights	0.0909	0.3182	0.5909
E6	Best (SC22)	9	1	2
	Worst (SC21)	1	9	5
	Weights	0.0667	0.6167	0.3167
E7	Best (SC23)	4	6	1
	Worst (SC22)	5	1	6
	Weights	0.2222	0.0833	0.6944
E8	Best (SC23)	7	2	1
	Worst (SC21)	1	4	7
	Weights	0.0833	0.3125	0.6042
E9	Best (SC22)	6	1	3
	Worst (SC21)	1	6	3
	Weights	0.1000	0.6600	0.2400
E10	Best (SC23)	6	2	1
	Worst (SC21)	1	4	6
	Weights	0.0909	0.3182	0.5909
E11	Best (SC23)	4	7	1
	Worst (SC22)	2	1	7
	Weights	0.1833	0.1000	0.7167
E12	Best (SC23)	7	3	1
	Worst (SC21)	1	4	7
	Weights	0.0833	0.2500	0.6667
Average weight (k*=0.0502)		0.1109	0.3411	0.5480
Rank		3	2	1

Table 4:10: Computed weights for the sustainability challenges under the social and ethical challenges category

Expert		SC31	SC32	SC33	SC34	SC35	SC36
E1	Best (SC33)	7	3	1	2	9	1
	Worst (SC35)	3	6	9	5	1	7
	Weights	0.0546	0.1274	0.3262	0.1911	0.0306	0.2701
E2	Best (SC34)	9	3	4	1	7	2
	Worst (SC31)	1	4	2	9	2	7
	Weights	0.0394	0.1512	0.1134	0.4043	0.0648	0.2268
E3	Best (SC33)	7	4	1	2	9	3
	Worst (SC35)	2	7	9	6	1	5
	Weights	0.0685	0.1199	0.3806	0.2398	0.0313	0.1599
E4	Best (SC33)	7	3	1	2	4	6
	Worst (SC31)	1	5	7	6	3	2
	Weights	0.0447	0.1521	0.3848	0.2282	0.1141	0.0761
E5	Best (SC33)	9	3	1	2	4	5
	Worst (SC31)	1	5	9	7	3	2
	Weights	0.0384	0.1474	0.3941	0.2211	0.1105	0.0884
E6	Best (SC33)	9	4	1	3	6	2
	Worst (SC31)	1	5	9	6	2	7
	Weights	0.0361	0.1145	0.3916	0.1526	0.0763	0.2289
E7	Best (SC33)	9	2	1	3	5	6
	Worst (SC31)	1	7	9	5	3	2
	Weights	0.0399	0.2295	0.4092	0.1530	0.0918	0.0765
E8	Best (SC33)	7	2	1	3	9	6
	Worst (SC35)	2	7	9	5	1	4
	Weights	0.0689	0.2411	0.4112	0.1607	0.0378	0.0804
E9	Best (SC33)	7	2	1	3	5	6
	Worst (SC31)	1	7	9	5	3	2
	Weights	0.0447	0.2349	0.3915	0.1566	0.0940	0.0783
E10	Best (SC33)	7	9	1	3	5	6
	Worst (SC32)	2	1	9	5	3	2
	Weights	0.0783	0.0481	0.4902	0.1826	0.1096	0.0913
E11	Best (SC34)	7	3	2	1	5	6
	Worst (SC31)	1	4	6	7	3	2
	Weights	0.0484	0.1533	0.2300	0.3995	0.0920	0.0767
E12	Best (SC33)	7	3	1	2	5	6
	Worst (SC31)	1	4	5	7	3	2
	Weights	0.0556	0.1296	0.1944	0.1944	0.3611	0.0648
Average weight (k*=0.0752)		0.0515	0.1541	0.3431	0.2237	0.1012	0.1265
Rank		6	3	1	2	5	4

Table 4:11: Computed weights for the sustainability challenges under the operational challenges category

Expert		SC41	SC42	SC43	SC44	SC45	SC46	SC47	SC48	SC49
E1	Best (SC47)	5	2	3	6	9	4	1	8	7
	Worst (SC45)	5	8	7	4	1	6	9	2	3
	Weights	0.0766	0.1915	0.1277	0.0638	0.0274	0.0958	0.3146	0.0479	0.0547
E2	Best (SC43)	8	2	1	4	7	5	3	9	6
	Worst (SC48)	2	8	9	6	3	5	7	1	4
	Weights	0.0479	0.1915	0.3146	0.0958	0.0547	0.0766	0.1277	0.0274	0.0638
E3	Best (SC42)	6	1	2	7	9	5	3	8	4
	Worst (SC45)	4	9	8	3	1	5	7	2	6
	Weights	0.0638	0.3146	0.1915	0.0547	0.0274	0.0766	0.1277	0.0479	0.0958
E4	Best (SC42)	3	1	2	8	5	6	4	9	7
	Worst (SC48)	8	9	7	2	5	4	6	1	3
	Weights	0.1290	0.3095	0.1935	0.0484	0.0774	0.0645	0.0967	0.0258	0.0553
E5	Best (SC43)	3	2	1	5	9	4	8	7	6
	Worst (SC45)	8	7	9	5	1	6	3	2	4
	Weights	0.1290	0.1935	0.3095	0.0774	0.0258	0.0967	0.0484	0.0553	0.0645
E6	Best (SC47)	8	2	3	5	9	4	1	7	6
	Worst (SC45)	2	8	7	5	1	6	9	3	4
	Weights	0.0479	0.1915	0.1277	0.0766	0.0274	0.0958	0.3146	0.0547	0.0638
E7	Best (SC42)	8	1	2	4	9	3	5	7	6
	Worst (SC45)	2	9	8	6	1	7	4	3	5
	Weights	0.0480	0.3133	0.1920	0.0960	0.0270	0.1280	0.0768	0.0549	0.0640
E8	Best (SC42)	8	1	2	4	9	3	5	6	7
	Worst (SC45)	3	9	8	6	1	7	5	4	2
	Weights	0.0479	0.3146	0.1915	0.0958	0.0274	0.1277	0.0766	0.0638	0.0547
E9	Best (SC47)	8	2	3	4	7	6	1	9	5
	Worst (SC48)	2	8	7	6	3	4	9	1	5
	Weights	0.0479	0.1915	0.1277	0.0958	0.0547	0.0638	0.3146	0.0274	0.0766
E10	Best (SC42)	8	1	2	4	9	7	6	5	3
	Worst (SC45)	2	9	8	6	1	3	4	5	7
	Weights	0.0479	0.3146	0.1915	0.0958	0.0274	0.0547	0.0638	0.0766	0.1277
E11	Best (SC43)	7	3	1	4	8	6	2	5	9
	Worst (SC49)	3	7	9	6	2	4	8	5	1
	Weights	0.0547	0.1277	0.3146	0.0958	0.0479	0.0638	0.1915	0.0766	0.0274
E12	Best (SC42)	8	1	2	3	9	5	4	7	6
	Worst (SC45)	2	9	8	7	1	5	6	3	4
	Weights	0.0479	0.3146	0.1915	0.1277	0.0274	0.0766	0.0958	0.0547	0.0638
Average weight (k*=0.0701)		0.0657	0.2474	0.2061	0.0853	0.0376	0.0851	0.1541	0.0511	0.0677
Rank		7	1	2	4	9	5	3	8	6

The global weights of the challenges were also determined to obtain the overall priority ranking for all challenges (see Table 4.12). The results show that increased food processing cost (SC14), lack of transparency and traceability (SC33), increase in the price of raw materials (SC13), lack of capital and physical resources (SC11), spread of fake information (SC34), increase in food waste (SC23), breakdown of trust in the supply chain (SC32), lack of cash flow in the market (SC12), slow communication (SC36) and fluctuating market demand (SC42) are the top 10 sustainability challenges due to the impacts of the COVID-19 outbreak. Notably, all four challenges under SC1 were ranked in the top 10, with another four challenges from SC3 and one challenge each from SC2 and SC4. This means the economic challenges were most significant for the Australian food processing industry during the COVID-19 outbreak. Also, ethical and social challenges became dominant during the pandemic.

Table 4:12: Final weights and priority ranking

Category	**Weight**	**Name of the challenge**	**Weight**	**Global Weight**	**Overall rank**
Economic challenges (SC1)	0.3743	Lack of capital and physical resources (SC11)	0.2165	0.0810	4
		Lack of cash flow in the market (SC12)	0.1314	0.0492	8
		Increase in price of raw materials (SC13)	0.2492	0.0933	3
		Increased food processing cost (SC14)	0.4029	0.1508	1
Environmental challenges (SC2)	0.1075	Lack of green manufacturing practices (SC21)	0.1109	0.0119	18
		Negative environmental impacts of continuous cleaning and disinfecting activities (SC22)	0.3411	0.0367	11
		Increase in food waste (SC23)	0.5480	0.0589	6
Social and ethical challenges (SC3)	0.3472	Rise in modern slavery (SC31)	0.0515	0.0179	15
		Breakdown of trust in supply chain (SC32)	0.1541	0.0535	7
		Lack of transparency and traceability (SC33)	0.3431	0.1191	2
		Spread of fake information (SC34)	0.2237	0.0777	5
		Lack of collaborations (SC35)	0.1012	0.0351	13
		Slow communication (SC36)	0.1265	0.0439	9
Operational challenges (SC4)	0.1710	Lack of skilled workforce (SC41)	0.0657	0.0112	20
		Fluctuating market demand (SC42)	0.2474	0.0423	10
		Shortage of supply/raw material (SC43)	0.2061	0.0352	12
		Breakdown of the transportation network (SC44)	0.0853	0.0146	16
		Reduction in production capacity (SC45)	0.0376	0.0064	22
		Long lasting impacts (SC46)	0.0851	0.0145	17
		Longer supply lead-time (SC47)	0.1541	0.0263	14
		Delay in upgrading supply chain technology (SC48)	0.0511	0.0087	21
		Frequent changes in planning (SC49)	0.0677	0.0116	19

4.3 Sensitivity analysis

In this section, a sensitivity analysis is conducted to check the robustness of the proposed approach. In this paper, the value of the highest-ranked category (economic challenges) is changed from 0.1 to 0.9 (Moktadir et al., 2021; Paul et al., 2021a) to check the changes in weights of all categories and sustainability challenges. Table 4.13 shows the changes in weights of four categories (SC1, SC2, SC3 and SC4). It was observed that the SC3 obtains the highest weight when SC1 has values until 0.3. After then, SC1 obtains the highest weight. This variation is normal as most experts rated SC1 and SC3 as the most preferred (best) categories.

Table 4:13: Changes in weight of the categories for the sensitivity analysis

Selected Challenges		**Values of preference weights for listed challenges**								
	Normal (0.3743)	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
SC1	0.3743	0.1000	0.2000	0.3000	0.4000	0.5000	0.6000	0.7000	0.8000	0.9000
SC2	0.1075	0.1546	0.1374	0.1203	0.1031	0.0859	0.0687	0.0515	0.0344	0.0172
SC3	0.3472	0.4994	0.4439	0.3884	0.3329	0.2774	0.2219	0.1665	0.1110	0.0555
SC4	0.1710	0.2460	0.2187	0.1913	0.1640	0.1367	0.1093	0.0820	0.0547	0.0273
Total	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

Similarly, the changes in weights of all sustainability challenges were evaluated with the change of values of SC1 from 0.1 to 0.9. These changes in weights are presented in Table 4.14. It was observed that the lack of transparency and traceability (SC33) obtains the highest weight when SC1 has values until 0.3. After then, increased food processing cost (SC14) obtains the highest weight. This variation is expected as most of the experts rated SC14 and SC33 as the most preferred (best) sustainability challenges. These variations in weights of sustainability challenges are graphically presented in Figure 4.1. The changes in the ranking of sustainability challenges are presented numerically in Table 4.15.

Table 4:14: Changes in weights of the sustainability challenges

Selected Challenges		Weights								
		Values of preference weights for listed challenges								
	Normal (0.3743)	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
SC11	0.0810	0.0217	0.0433	0.0650	0.0866	0.1083	0.1299	0.1516	0.1732	0.1949
SC12	0.0492	0.0131	0.0263	0.0394	0.0526	0.0657	0.0788	0.0920	0.1051	0.1183
SC13	0.0933	0.0249	0.0498	0.0748	0.0997	0.1246	0.1495	0.1745	0.1994	0.2243
SC14	0.1508	0.0403	0.0806	0.1209	0.1611	0.2014	0.2417	0.2820	0.3223	0.3626
SC21	0.0119	0.0172	0.0152	0.0133	0.0114	0.0095	0.0076	0.0057	0.0038	0.0019
SC22	0.0367	0.0527	0.0469	0.0410	0.0352	0.0293	0.0234	0.0176	0.0117	0.0059
SC23	0.0589	0.0847	0.0753	0.0659	0.0565	0.0471	0.0377	0.0282	0.0188	0.0094
SC31	0.0179	0.0257	0.0228	0.0200	0.0171	0.0143	0.0114	0.0086	0.0057	0.0029
SC32	0.0535	0.0769	0.0684	0.0598	0.0513	0.0427	0.0342	0.0256	0.0171	0.0085
SC33	0.1191	0.1713	0.1523	0.1333	0.1142	0.0952	0.0762	0.0571	0.0381	0.0190
SC34	0.0777	0.1117	0.0993	0.0869	0.0745	0.0621	0.0496	0.0372	0.0248	0.0124
SC35	0.0351	0.0505	0.0449	0.0393	0.0337	0.0281	0.0225	0.0168	0.0112	0.0056
SC36	0.0439	0.0632	0.0562	0.0491	0.0421	0.0351	0.0281	0.0211	0.0140	0.0070
SC41	0.0112	0.0162	0.0144	0.0126	0.0108	0.0090	0.0072	0.0054	0.0036	0.0018
SC42	0.0423	0.0609	0.0541	0.0473	0.0406	0.0338	0.0270	0.0203	0.0135	0.0068
SC43	0.0352	0.0507	0.0451	0.0394	0.0338	0.0282	0.0225	0.0169	0.0113	0.0056
SC44	0.0146	0.0210	0.0186	0.0163	0.0140	0.0117	0.0093	0.0070	0.0047	0.0023
SC45	0.0064	0.0093	0.0082	0.0072	0.0062	0.0051	0.0041	0.0031	0.0021	0.0010
SC46	0.0145	0.0209	0.0186	0.0163	0.0139	0.0116	0.0093	0.0070	0.0046	0.0023
SC47	0.0263	0.0379	0.0337	0.0295	0.0253	0.0211	0.0168	0.0126	0.0084	0.0042
SC48	0.0087	0.0126	0.0112	0.0098	0.0084	0.0070	0.0056	0.0042	0.0028	0.0014
SC49	0.0116	0.0166	0.0148	0.0129	0.0111	0.0092	0.0074	0.0055	0.0037	0.0018
Total	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

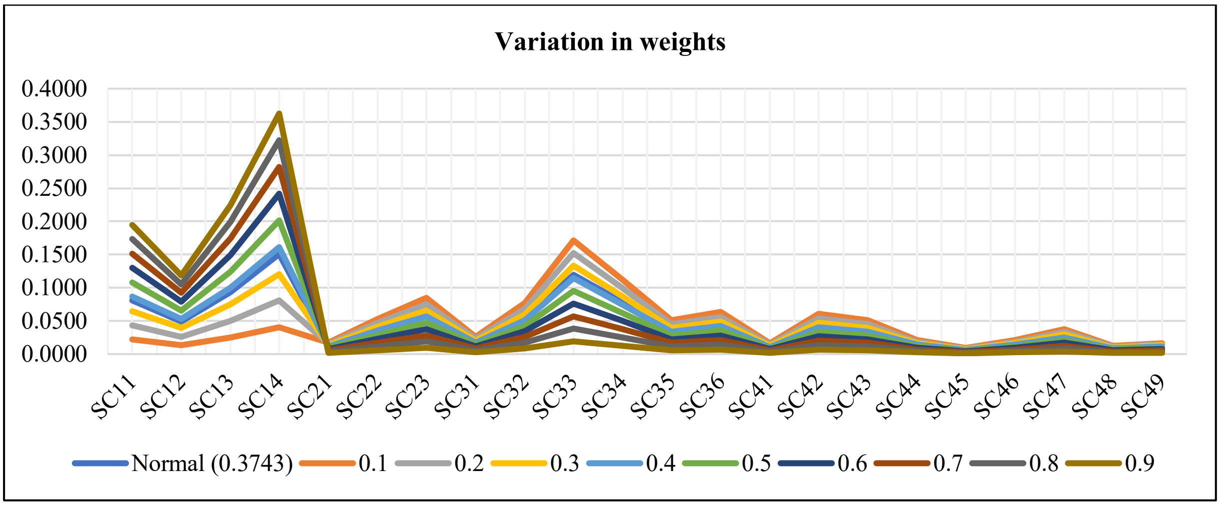

Figure 4.1: Variation in weights of challenges while changing category SC1 weights

Table 4:15: Changes in ranking of the sustainability challenges

Selected Challenges		Ranking								
		Values of ranking for listed challenges								
	Normal (0.3743)	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
SC11	4	14	12	6	4	3	3	3	3	3
SC12	8	20	14	12	7	5	4	4	4	4
SC13	3	13	8	4	3	2	2	2	2	2
SC14	1	10	3	2	1	1	1	1	1	1
SC21	18	17	18	18	18	18	18	18	18	18
SC22	11	7	9	10	11	11	11	11	11	11
SC23	6	3	4	5	6	7	7	7	7	7
SC31	15	12	15	15	15	15	15	15	15	15
SC32	7	4	5	7	8	8	8	8	8	8
SC33	2	1	1	1	2	4	5	5	5	5
SC34	5	2	2	3	5	6	6	6	6	6
SC35	13	9	11	13	13	13	13	13	13	13
SC36	9	5	6	8	9	9	9	9	9	9
SC41	20	19	20	20	20	20	20	20	20	20
SC42	10	6	7	9	10	10	10	10	10	10
SC43	12	8	10	11	12	12	12	12	12	12
SC44	16	15	16	16	16	16	16	16	16	16
SC45	22	22	22	22	22	22	22	22	22	22
SC46	17	16	17	17	17	17	17	17	17	17
SC47	14	11	13	14	14	14	14	14	14	14
SC48	21	21	21	21	21	21	21	21	21	21
SC49	19	18	19	19	19	19	19	19	19	19

4.4 Discussion of findings

From the final list of sustainability challenges (see Tables 4.3 and 4.4), it was observed that difficulty in implementing environmental sustainability policies, loss of jobs/increased rate of unemployment, violation in code of conduct in ethical practices, and lack of health and safety equipment were removed from the final list as they are not valid in the context of the Australian food processing sector. There have been job losses in many countries due to the impacts of COVID-19; however, during the recovery from the impact of COVID-19 in Australia, the unemployment rate has decreased to the pre-COVID level (Marsh, 2021). Hence, it can be said that COVID-19 disruption has not impacted local jobs in Australia. Other challenges—such as difficulty in implementing environmental sustainability policies, violation of code of conduct in ethical practices, and lack of health and safety equipment—are not valid in the Australian manufacturing business context, as the government provided significant crisis support to businesses (Treasury, 2021). Conversely, seven new COVID-19 outbreak-related sustainability challenges were added to the final list, including increased food processing cost, breakdown of trust in the supply chain, lack of transparency and traceability, the spread of fake information, slow communication, delay in upgrading supply chain technology, and frequent changes in planning. The experts suggested that those challenges were elevated due to impacts of COVID-19 in the Australian food processing industry.

The analysis of prioritising the sustainability challenges revealed that the category of economic challenges obtained the highest weight among the four different categories (see Table 4.7). This is because the COVID-19 outbreak impacted most businesses financially; specifically, the Australian food processing sector has also been going through an unprecedented financial crisis due to the pandemic (KPMG, 2020). Moreover, the social and ethical challenges were also seen as necessary for the Australian food processing sector, as this category of challenges obtained the second-highest weight. It was observed that social and ethical concerns had increased significantly in many businesses during the COVID-19 outbreak (Pournader & Wohlgezogen, 2021). The operational and environmental challenges categories were the following two important categories. Operational challenges seem more common in businesses during the COVID-19 outbreak (Paul et al., 2021c). Specifically, the Australian food processing sector faced many operational challenges, such as fluctuating market demand and supply/raw material shortages. The COVID-19 outbreak also brought many environmental challenges (Rizou et al., 2020). The environmental challenges faced by the Australian food processing sector include increased food waste and negative environmental impacts of continuous cleaning and disinfecting activities.

In the final global priority ranking of sustainability challenges shown in Table 4.12, it was observed that the economic challenge of increased food processing costs was ranked first. The COVID-19 outbreaks disrupted the global supply chain network, resulting in a shortage of raw materials and skilled labour. Also, to control the outbreak, the government imposed lockdown and social distancing rules, which ultimately led to uncertainties in food processing and contributed to increasing its processing cost. The second-ranked challenge, lack of transparency and traceability, belongs to social and ethical challenges. The COVID-19 outbreak is responsible for the lack of food transparency and traceability. During the pandemic, transparency and traceability became increasingly important to enhance the sustainability of the food processing sectors (Fedunik-Hofman, 2021). An increase in the price of raw materials and lack of capital and physical resources, both from the category of economic challenges, obtained the third and fourth positions in the priority ranking. This is because the economic challenges are most dominant in the Australian food processing sector due to the impacts of the COVID-19 outbreak (KPMG, 2020). Under the category of social and ethical challenges, the spread of fake information has become one of the most critical challenges and obtained the fifth position in the priority ranking. This is because there has been a spread of fake information on social media about COVID-19 (Nyilasy, 2020), which ultimately negatively impacted the food processing sector.

It was observed that the top five sustainability challenges came from two categories, namely economic and social and ethical challenges. This is consistent with the expert feedback as most of the experts prioritised either economic challenges or social and ethical challenges due to the impacts of the COVID-19 outbreak. The analysis found that the increase in food waste, breakdown of trust in the supply chain, lack of cash flow in the market, slow communication and fluctuating market demand have become dominant and placed in the top 10 sustainability challenges for the Australian food processing sector.

The next chapter discusses the managerial and theoretical implications of the study.

Chapter 5 : Managerial and Theoretical Implications

This chapter discusses managerial and theoretical implications based on the study's findings.

5.1 Managerial implications

The effects of the COVID-19 outbreak have impacted most businesses. The food processing sector is no exception, as it has faced numerous COVID-19 related challenges. Supply chains of the Australian food processing sector consist of both local and international partners and markets. As a global pandemic, COVID-19 has impacted the Australian food processing sector locally and internationally (KPMG, 2020). Hence, this study considered a real-life problem to identify and analyse sustainability challenges the Australian food processing sector faced amid the COVID-19 outbreak. The findings of this study are important for both practitioners and policymakers. There are four key managerial implications, which are detailed below.

i. The study's findings provide Australian food processing practitioners with a holistic view of all possible sustainability challenges amid the COVID-19 outbreak. This study found 22 different sustainability challenges raised by the impacts of the COVID-19 outbreak. Among them, nine challenges are operational as COVID-19 has significantly affected operational activities within supply chains. Decision-makers should focus on developing resilience strategies to overcome operational challenges; for example, strategies for preparedness, response and recovery can help mitigate the impacts of COVID-19 on supply chain operations. Ultimately, this helps overcome the economic challenges in the long term. In addition, this study identified six different ethical and social challenges related to the pandemic, including the lack of transparency and traceability and the spread of fake information as the most common during the COVID-19 outbreak. It is important that decision-makers develop appreciative corporate social strategies to overcome these challenges. Decision-makers can use the final list of sustainability challenges to associate and compare with lists from their organisations to identify and address any sustainability challenges they overlooked.

ii. This study applied the quantitative method BWM to analyse and prioritise the sustainability challenges. Industry practitioners can use the same tool to analyse their challenges. Also, the final priority ranking helps practitioners understand which sustainability challenges on which to focus. Australian food processing practitioners should initially concentrate on overcoming the most significant challenges, such as increased food processing cost (ranked first) and lack of transparency and traceability (ranked second). This study found that economic challenges are more significant. To overcome these, decision-makers should think about developing resilience in their supply chains. For example, the challenge of increased food processing costs can be mitigated by collaborating with multiple suppliers from different regions of the world and using advanced technologies in manufacturing processes. Also, strategies for mitigating operational, social and ethical challenges help mitigate economic challenges.

iii. Policymakers can consider the findings of this study to formulate overcoming strategies. Developing risk management plans and appropriate proactive and reactive strategies related to supply chain resilience would help mitigate the challenges. The organisation should also focus on developing strategies for environmental sustainability for its long-term strategic plan. For example, policymakers can consider the top five or 10 sustainability challenges to develop overcoming strategies as a first step and then consider other challenges gradually. This reduces the pressure of using resources.

iv. This study's findings can also be applied in the context of other supply chain disruptions. For example, food processing costs and raw material prices can be increased due to a regional disruption such as the Ukraine war (Shalal & Lawder, 2022). Shortage of supply/raw material, breakdown of the transportation network, reduction in production capacity, lack of collaborations, and longer supply lead-time are common challenges raised by supply chain disruptions (Moktadir et el., 2021).

5.2 Theoretical implications

Analysing supply chain sustainability challenges due to the impacts of the COVID-19 outbreak is a significant and practical research problem. COVID-19 has brought numerous challenges to businesses and their supply chains. Among them, sustainability challenges are one of the most critical areas for research. The theoretical implications of this study are as follows.

i. The main contribution of this study is to explore a significant new research problem on supply chain sustainability challenges due to the impacts of the COVID-19 outbreak. There was a significant research gap in the literature on quantitative analysis of COVID-19 outbreak-related sustainability challenges in supply chain disciplines. This study fulfils this research gap.

ii. This study considers the supply chain of the Australian food processing sector as the context of the study, which had little focus in the literature for analysing the impacts of the pandemic.

iii. This study develops a mixed-method approach to identify and analyse COVID-19 outbreak-related supply chain sustainability challenges. The mixed-method includes both qualitative and quantitative approaches, making the analysis and findings more comprehensive.

The next chapter discusses the conclusions and limitations of the study and future research directions.

Chapter 6 : Conclusions and Future Research Directions

This chapter provides concluding remarks and discusses the study's limitations and future research directions.

6.1 Concluding remarks

The main objectives of this thesis were to identify and analyse supply chain sustainability challenges in the context of the Australian food processing sector amid the COVID-19 outbreak. A mixed-method approach consisting of an online survey and the BWM was applied to achieve the objectives. The online survey was applied to finalise the list of sustainability challenges in the specific context; the BWM was used to analyse the sustainability challenges to determine their priority ranking. Moreover, a sensitivity analysis was conducted to check the robustness of the proposed approach.

From the literature review and online survey, 22 sustainability challenges were finalised under four categories (economic, environmental, social and ethical, and operational challenges). The finalised list was then used to collect data for the BWM analysis from 12 supply chain experts from the Australian food processing sector. The quantitative analysis revealed that the COVID-19 outbreak significantly impacted the supply chain of the Australian food processing sector economically. Social and ethical challenges were also ranked highly. In summary, the top 10 sustainability challenges for the Australian food processing sector are increased food processing cost, lack of transparency and traceability, increase in price of raw materials, lack of capital and physical resources, spread of fake information, increase in food waste, breakdown of trust in supply chain, lack of cash flow in the market, slow communication, and fluctuating market demand (see Table 4.12).

6.2 Limitations and future research directions

This thesis contributes significantly to the food processing sector in the context of the COVID-19 outbreak by analysing sustainability challenges. However, this study also has some limitations. First, the study considered only the Australian food processing sector as its context and identified and analysed sustainability challenges due to the impacts of the COVID-19 outbreak. Second, strategies to overcome sustainability challenges were not in the scope of the study; and third, interrelationships among the sustainability challenges were not analysed.

The abovementioned limitations can be overcome by conducting further research in this area. Future research could extend this study with a more in-depth analysis in the context of different branches of food processing sectors, such as processed, fresh and frozen food sectors. Moreover, this study can be extended in the context of supply chains of developing and emerging economies to compare and generalise the findings. Further, supply chain sustainability challenges could influence each other. The relationships among supply chain sustainability challenges and impacts on sustainability performance can be investigated in the future using some other techniques such as DEMATEL and structural equation modelling. In addition, longitudinal studies can be conducted to explore how companies and supply chains "re-emerged" from the COVID-19 outbreak in terms of sustainability challenges. A comparative study on supply chain sustainability challenges across different geographical contexts could also be valuable. Finally, the strategies to overcome supply chain sustainability challenges can be further investigated to offer solutions and policymaking guidelines.

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Appendices

Appendix A: Questionnaire for the online survey

Part A: Identifying supply chain sustainability challenges due to the COVID-19 outbreak

Q1. Does your firm face the following supply chain sustainability challenges due to the COVID-19 outbreak? In the response column, write 'Yes or Y' if your firm face the challenge and 'No or N' if your firm does not face the challenge.

No.	Name of the challenge	Response
1	Lack of capital and physical resources	
2	Lack of cash flow in the market	
3	Increase in price of raw materials	
4	Difficulty in implementing environmental sustainability policies	
5	Lack of green manufacturing practices	
6	Negative environmental impacts of continuous cleaning and disinfecting activities	
7	Increase in waste	
8	Loss of jobs/ Increase rate of unemployment	
9	Violation in code of conduct in ethical practices	
10	Rise in modern slavery	
11	Lack of health and safety equipment	
12	Lack of skilled workforce	
13	Fluctuating market demand	
14	Shortage of supply	
15	Breakdown of the transportation network	
16	Reduction in production capacity	
17	Long lasting impacts	
18	Longer supply lead-time	
19	Lack of collaborations	

Q2. What are the other supply chain sustainability challenges, if any, your firm faces due to the COVID-19 outbreak? Please list them in the below box:

Part B: Demographic Questions:

Q3: Please specify the firm size (approximate number of employees such as 0-19, 20-199, or 200 and more):

Q4. Please specify your position in the firm (such as officer, manager, and so on):

Q5: Please specify your number of years of experience (such as 1, 2, …., 20, so on):

Appendix B: Questionnaire for the analysis using the Best-Worst Method

Part A: Collecting data for supply chain sustainability challenges for the best-worst method

Q1: Please mark the best and worst sustainability challenges by putting 'X' in the corresponding column. An example is shown in Table B1.

Table B1: Determination of best and worst sustainability challenges

Name of the challenge	Best challenge (most impactful)	Worst challenge (least impactful)
SC1		
SC2		
SC3	X	
SC4		
SC5		X
.		
.		
.		
SCn		

Table B2: Linguistic scale for the best-worst method

Linguistic scale	Meaning
1	Equal preference
2	Equal to moderate preference
3	Moderate preference
4	Moderate to strong preference
5	Strong preference
6	Strong to very strong preference
7	Very strong preference
8	Very strong to extreme preference
9	Extreme preference

Examples:

When determining the preference of the *best* sustainability challenge over the other sustainability challenges, linguistic 3 represents moderately less preference. Similarly, linguistic 9 represents extremely less preference. The other scales should be interpreted similarly.

When determining the preferences of all other sustainability challenges over the *worst* sustainability challenge, linguistic 3 represents moderately more preference. Similarly, linguistic 9 represents extremely more preference. The other scales should be interpreted similarly.

Q2: Please make the comparison matrix in Table A3 for *Best* sustainability challenge preference over the other sustainability challenges using the linguistic 1-9 scale provided in Table B2. An example is shown in Table B3.

Table B3: *Best* sustainability challenge preference over the other sustainability challenges

Expert	Best to Others	SC1	SC2	SC3	SC4	.	.	.	.	SCn
E1	SC3	5	3	1	9	.	.	.	.	7
E2										
E3										
.										
.										

Q3: Please make the comparison matrix in Table B4 for all challenges over the *Worst* challenge using the linguistic 1-9 scale provided in Table B2. An example is shown in Table B4.

Table B4: Preference of all sustainability challenges over the *worst* sustainability challenge

	Others to the worst challenge				
	Expert				
	E1	E2	E3	.	.
Name of the challenge	SC5				
SC1	3				
SC2	5				
SC3	2				
SC4	8				
SC5	1				
.	.				
.	.				
.	.				
SCn	5				

Part B: Demographic Questions:

Q4: Please specify the firm size (approximate number of employees such as 0-19, 20-199, or 200 and more):

Q5. Please specify your position in the firm (such as officer, manager, and so on):

Q6: Please specify your number of years of experience (such as 1, 2, ….20, so on):