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ORIGINAL RESEARCH

Industry readiness measurement for circular supply chain implementation: an Irish dairy industry perspective

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Abstract

The implementation of a circular supply chain (CSC) has potential to help the Irish dairy industry mitigate their negative environmental impacts. However, the industry does not have a clear understanding on their level of readiness to implement CSC in factors that ensure success. While there have been few studies that have identified barriers and critical success factors of CSC implementation, limited attention has been given to developing a comprehensive framework capable of measuring an industry's readiness for CSC implementation, especially in the dairy industry. This study provides novelty in the development and application of a novel hybrid approach based on best–worst method and fuzzy inference system (BWM–FIS) to evaluate readiness for CSC implementation in the Irish dairy industry. By identifying a comprehensive set of readiness measures and sub-measures and integrating them into the assessment framework, we provide a valuable tool for industry stakeholders to gauge their readiness level and make informed decisions regarding CSC implementation. The applicability of the proposed approach is then demonstrated with an empirical study of the Irish dairy industry. The data was collected from 34 supply chain and senior professionals from all 13 main processing and manufacturing companies in the Irish dairy industry. The empirical results for the Irish dairy industry suggests it has a moderate level of readiness on the CSC readiness scale. This indicates that dairy manufacturers in Ireland are not yet in an ideal state of readiness for CSC implementation.

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Abbreviations

CSC	Circular supply chain
BWM	Best–worst method
FIS	Fuzzy inference system
GHG	Greenhouse gas
CLSC	Closed-loop supply chain
CSF	Critical success factor
CE	Circular economy
MCDM	Multi-criteria decision-making
CSCM	Circular supply chain management
AHP	Analytical hierarchy process
MF	Membership function
NGO	Non-governmental organisation
SC	Supply chain
B2B	Business to business
CO2	Carbon dioxide
EU	European Union
USA	United States of America
ANP	Analytic network process
VIKOR	Viekriterijumsko kompromisno rangiranje
DEMATEL	Decision-making trial and evaluation laboratory
RL	Reverse logistics
MATLAB	Matrix laboratory software
DM	Decision-maker
B2O	Best-to-others
O2W	Others-to-worst

List of symbols

C_i	ith category, $i = 1,2,\ldots$, m
W_i	Importance weight of the ith criterion
A_i	Membership function score related to the ith criterion.
W_{ij}	Weight of the jth sub-measure and the ith category
a_{Bj}	Preference of the best criterion/category over jth criterion/category
a_{jW}	Preference of jth criterion/category criterion over the worst
W^*_{avg}	Average weight of a criterion
ξ^*	Consistency of the comparisons, values close to zero show a high level of consistency

1 Introduction

The dairy industry is a key component of the economy on the island of Ireland and provides much-needed employment spread across many rural areas. According to Bordbia (2021) there are 13 main dairy processors in the Republic of Ireland, and over €4 billion worth of dairy products, ingredients and other nutritional products, are exported annually to over 155 markets worldwide (IBEC, 2020). However, despite the opportunities for economic growth of the dairy industry, their supply chain is responsible for a significant amount of greenhouse gas (GHG) emissions and other wastes, such as packaging and production residuals, which are having a negative environmental impact (Thoma et al., 2013; Zucali et al., 2020). The dairy industry supply chain consists of five main stages, inputs—production—primary & secondary processing—marketing & distribution—& retail, which all contribute to the final supply of dairy products to the consumer (Heery et al., 2016; Hennessy & Donnellan, 2018). At each of these stages and particularly during the production process, several by-products such as whey, clots, cheese pieces, and packaging are often treated as wastes (Kazancoglu et al., 2021; Szmelter, 2016). Dairy industry wastes can also be attributed to other factors including excess buying, inadequate labelling and storage instructions, poor storage facilities and transportation, production errors, trial runs, packaging defects, and wrong weights and sizes (Ali et al., 2021; Szmelter, 2016). In a circular supply chain (CSC) these wastes have the potential to be used as raw materials for several secondary products such as animal foods, food supplements, and whey beverages rather than being disposed of (Ada et al., 2021; Kazancoglu et al., 2021). In a closed loop supply chain (CLSC) the materials and energy are conserved and reused within the industry in which they are produced (Guide and Van Wassenhove 2009), whereas in a CSC the by-products and other materials that are recovered can be utilised outside of the industry from which they originate (Koh et al., 2017; Batista et al., 2018). A CSC could help to mitigate these waste issues, along with other benefits such as improved availability of resources, improved end-of-life strategies, enhanced value propositions, reduced waste generation, improved sustainability, and enhanced social benefits (Koh et al., 2017; Lahane et al., 2020).

For this reason, CSC is more suited for the dairy industry as 'wastes' and by-products have the potential to be used in a multitude of different industries such as sports nutrition, infant formula, alcoholic beverages and bio-packaging (Hennessy et al., 2017; Kazancoglu et al., 2021). However, despite all the potential benefits of a CSC, several studies have observed that there are situations in which organisations or entire industries may not be successful in their implementation efforts (Ada et al., 2021; Kayikci et al., 2022; Kazancoglu et al., 2020; Lahane & Kant, 2021; Ozkan-Ozen et al., 2020). This largely depends on the extent to which the industry has implemented the necessary prerequisites, often referred to as critical success factors (CSFs), to become ready for the successful implementation of CSC (Pacchini et al., 2019). Therefore, there is a need for Irish dairy organisations to measure their readiness for implementation of CSC against a comprehensive list of readiness measures and sub-measures.

The recent literature in the CSC domain indicates that while there have been a few studies on identifying CSFs, barriers, and risks to successful CSC implementation (Ada et al., 2021; Govindan & Hasanagic, 2018; Kayikci et al., 2022; Kazancoglu et al., 2020; Lahane & Kant, 2021; Ozkan-Ozen et al., 2020), there is a lack of studies which have focused on developing an industry readiness measurement for implementing CSC. The primary contribution of this study therefore lies in the development and application of a novel approach to assess the readiness for CSC implementation in the Irish dairy industry. Our research addresses a significant gap in the existing literature, as there is limited attention given to developing a comprehensive framework capable of measuring an industry's readiness for CSC implementation, particularly in the context of the dairy industry.

The overall aim of this study is to develop a comprehensive framework for measuring the readiness of the Irish dairy industry for CSC implementation. Having conducted a review of the literature and consulted with professionals from the Irish dairy industry, the following research objectives were established:

Objective 1: To identify and extract the relevant measures and sub-measures for measuring the readiness of the Irish dairy industry to implement a CSC.
Objective 2: To weight these measures and sub-measures using a multi-criteria decision-making method known as best-worst method (BWM).
Objective 3: To develop and construct a fuzzy inference system (FIS) capable of performing the industry readiness measurement.
Objective 4: To measure and score the Irish dairy industry's readiness to implement a CSC using the novel FIS.

To address these objectives, we identified a list of readiness measures and sub-measures, derived from an extensive review of the literature, and validated them using the Delphi method. Building upon these readiness measures, we applied a unique combination of the BWM and FIS to evaluate the Irish dairy industry's readiness for CSC implementation. This integrated approach allowed us to assign weights to the input variables and capture the complexities and uncertainties inherent in readiness assessment.

This study provides novelty in the in the development and application of a novel hybrid approach based on best–worst method and fuzzy inference system (BWM–FIS) to evaluate readiness for CSC implementation in the Irish dairy industry. By identifying a comprehensive set of readiness measures and sub-measures and integrating them into the assessment framework, we provide a valuable tool for industry stakeholders to gauge their readiness level and make informed decisions regarding CSC implementation. The applicability of the proposed approach is then demonstrated with an empirical study of the Irish dairy industry using an integrated approach of the BWM–FIS.

The remainder of this paper is structured as follows: Sect. 2, presents a review of the relevant literature and provides a comprehensive list of readiness measures and sub-measures. In Sect. 3 the methodology and the steps involved in the research process are outlined along with the empirical protocol. Section 4 presents the findings and results from the research process. Then, Sect. 5 discusses the managerial and policy implications of these results. Finally, in Sect. 6 a conclusion to the study is presented along with directions for future research.

2 Literature review

2.1 Circular economy and sustainable business management

The concept of sustainability has become of great importance for management in all organisations as they are in a particularly unique position to have an impact on the implementation of sustainable practices (Carter & Rogers, 2008). This has been reflected in the literature with increased attention from academics on the paradigm of sustainability with the topic witnessing an exponential growth in papers being published (Panigrahi et al., 2019). This growth in attention to sustainability has not been exclusive to academia as organisations have also begun to realise the potential improvements that can be made in terms of financial performance through significant investment in social and environmental aspects of their business and subsequent model (Pagell & Shevchenko, 2014). In addition, governments and policymakers worldwide, including the EU, have actively promoted initiatives which attempt to decarbonise the economy and create climate-change resistant growth (Isik et al., 2023). One such example, which is closely aligned with this study includes the efforts towards responsible research innovation. Responsible research innovation underscores the need for research and innovation to be driven by societal needs, ethical considerations, and sustainability imperatives which in turn encourages the implementation of sustainable solutions, such as CSC (Isik et al., 2023).

There are three pillars of sustainability identified by the World Summit of United Nations in 2005 which are economic, social and environmental. All three pillars must be deployed and engaged with for sustainability to be present. Rajeev et al. (2017) supports this by stating that consumption and production practices along with the management of natural resources and poverty elimination make up the three pillars of sustainability (economic, social & environmental) which directly translate to the triple bottom line. In terms of business development, sustainability is closely related to the concept of creating shared value under a circular economy (CE) by developing policies and practices that increase an organisations competitiveness while improving the economic and social conditions of the communities in which it operates (De et al., 2020). The Ellen MacArthur Foundation defined the CE as "Looking beyond the current 'take, make and dispose' extractive industrial model, the CE is restorative and regenerative by design. Relying on system-wide innovation, it aims to redefine products and services to design waste out, while minimising negative impacts" (MacArthur, 2013).

Although classic economic theory such as that of Rostow (1959) conveys that production and consumption patterns which are disproportionate are desirable because they create wealth through increased economic activity, it is now accepted that economic and production systems must no longer be separated from the environment if sustainability is to be obtained. At an industrial level practitioners view the CE as a mechanism to create regenerative industrial transformations in order to achieve sustainable production and consumption, in turn the idea is this transformation will result in a positive impact on the environment as well as contributing to the overall economic growth of both organisations and the world economy (MacArthur, 2013). The EU have also promoted the concept by investing €650 million into their transition package towards a CE (Millar et al., 2019).

Much of the existing work on the CE has been carried out on the practical and technical levels of the physical flows of materials and energy in production and consumption systems (Korhonen et al., 2018). Merli et al. (2018) found that CE studies follow three main lines of action: changing the social and economic dynamics at a macro level, supporting firms to implement circular processes at a micro level to spread new production and consumption designs and thirdly, discussing the industrial symbiosis that exists at a meso level. Practitioners in business have orientated the CE approach to emphasise product, component and material conservation through reuse, remanufacture, refurbishment etc. alongside the development of sustainable energy such as wind, biomass, wave and solar to create value in the chain using a cradle-to-cradle approach (Korhonen et al., 2018).

The CE is still an emerging subject and although the potential of improved circularity in terms of resources contributing to sustainable development has been widely accepted, the relations between the concepts of sustainability and the CE in terms of the TBL are underexplored in the literature (Millar et al., 2019; Velenturf et al., 2019). Without further research Millar et al. (2019) suggests that the CE as it is currently understood could continue to cause environmental degradation just at a slower pace than the linear economic model, maintaining a reliance on the extraction of raw materials for economic growth & development and not improving social equity. The adoption of the CE is expected to fundamentally transform industrial and economic activities away from a reliance on non-renewable materials and energy to a more sustainable production and consumption paradigm (Mishra et al., 2023). Korhonen et al. (2018) acknowledges this transformation will be holistic in nature as all supply chains in the industrial system are set to be impacted at different levels.

2.2 Circular supply chain

Batista et al. (2018, p. 446) defined CSC as, "*harmonised forward and reverse supply chains through the incorporation of value creation aspects from products, by-products, and useful waste flows through prolonged life cycle that improves the three dimensions of organisational sustainability*". The global and competitive nature of today's business environment has led to organisations wanting their operations and supply chain to become more sustainable in terms of the economic, environmental and social bottom lines (Knight et al., 2022). Adopting circular business practices as an organisation not only offers competitive advantages (Abdul-Rashid et al., 2017), in many jurisdictions, it has become a requirement under legislation in order to remain operational (Levering & Vos, 2019). This has put increased pressure on organisations to implement CE initiatives into their supply chain network (Batista et al., 2018; Koh et al., 2017). Govindan and Hasanagic (2018) claim that the integration of the CE has become one of the most vital strategies for supply chain innovation. However, the comprehensive review studies of both Lahane et al. (2020) and Govindan and Hasanagic (2018) indicate that the literature in the domain of CSC is in the infancy stage.

It is important to distinguish the difference between "readiness" and "maturity" as these terms are often used interchangeably in the literature but do not occupy the same definition. Pacchini et al. (2019) defined readiness as the state in which an organisation/industry is ready to accomplish a task, whereas maturity is the level of evolution that an organisation/industry has accomplished concerning a given task or project. The development of a readiness measurement framework capable of producing a readiness index as an output will provide a significant contribution to the CSC literature in addition to the practical applications for the dairy industry. Most of the studies in the literature just identified the barriers or CSFs to the implementation of CSC. These studies tend to use MCDM methods or descriptive analytics to identify and rank these CSFs. In addition, there is a scarcity of studies which have utilised a structured technique such as FIS that can provide a readiness index while addressing the inherent vagueness of expert judgements when conducting such research to analyse the data collected appropriately (Azadnia et al., 2022). The majority of CSC implementation papers that mention barriers are focused on the manufacturing industry (Govindan & Hasanagic, 2018; Levering & Vos, 2019; Mangla et al., 2018a; Tura et al., 2019; Vermunt et al., 2019), with the food industry (Farooque et al., 2019) and the dairy industry (Kazancoglu et al., 2021) receiving much less attention. Table 1 presents an overview of the relevant recent literature in the CSC domain.

Kazancoglu et al. (2021) identified and extracted the barriers to implementing circularity in dairy supply chains from four articles specific to the dairy industry. They then used a fuzzy hybrid decision framework to rank the barriers and sub-barriers with the help of both fuzzy ANP and fuzzy VIKOR. Their results indicated the economic group of barriers was of the highest importance followed by, 'technological', 'environmental', 'strategic', 'supply chain management' and finally the 'social and legal' group. Agyemang et al. (2019) adopts an

Table 1 An overview of the methods, industry, and region of studies in recent CSC literature and the relative position of this study

Author	Method	Context	Country	Industry/Sector
Mangla et al. (2018a)	Fuzzy-DEMATEL	Barrier analysis	India	Manufacturing
Masi et al. (2018)	Exploratory—Descriptive Statistics	Barrier analysis	England	Manufacturing
Moktadir et al. (2018)	Graph Theory & Matrix Approach	Critical success factor analysis	Bangladesh	Leather industry
Agyemang et al. (2019)	Descriptive Statistics/Interviews	Barrier & enabler analysis	China	Automobile
Farooque et al. (2019)	Fuzzy-DEMATEL	Barrier analysis	China	Food
Levering and Vos (2019)	Theoretical Sampling	Barrier analysis	Netherlands	Manufacturing
Tura et al. (2019)	Descriptive Statistics/Interviews	Barrier & enabler analysis	Finland	Manufacturing
Vermunt et al. (2019)	Descriptive Statistics/Interviews	Barrier analysis	Netherlands	Manufacturing
Kazancoglu et al. (2020)	Descriptive Statistics/Focus Group	Barrier analysis	Turkey	Textile
Ozkan-Ozen et al. (2020)	Fuzzy ANP	Barrier analysis	Turkey	Multiple
Ada et al. (2021)	Descriptive Statistics	Barrier analysis	-	-
Lahane and Kant (2021)	Pythagorean Fuzzy-AHP/DEMATEL	Risk analysis	India	Automotive
Kazancoglu et al. (2021)	Fuzzy ANP & Fuzzy VIKOR	Barrier analysis	Turkey	Dairy
Kayikci et al. (2022)	DEMATEL-Likert Scale	Maturity analysis	Turkey	Textile
This study	Best–Worst Method & Fuzzy Inference System (BWM–FIS)	Industry readiness measurement	Ireland	Dairy

explorative approach to identify drivers and barriers of CSCM implementation. Internal barriers identified included: ‘lack of expertise’, ‘lack of awareness’, ‘top management resistance to change’, ‘cost and financial constraints’, ‘lack of technological and technical capabilities’ and ‘profit and market demand level’. External barriers included: ‘government policy’, ‘lack of industrial support’ and ‘lack of supply chain integration or complexity’. Levering and Vos (2019) used a case study approach along with theoretical sampling to derive barriers of CSCM. Their analysis of multiple industries found similar barriers to previous studies such as ‘costs’, ‘specification’ and ‘differing stakeholder interests’ among others.

Tura et al. (2019) combined insights from their analysis of previous CSCM literature with results from an empirical case study which they then used to develop an integrative framework of drivers and barriers for circular business activity. Vermunt et al. (2019) also classified the barriers to CSCM as either internal relating to the organisation itself or external relating to the organisation's environment before listing them under six categories. 'Financial', 'Organisational' and 'Knowledge & technology' were identified as internal barrier categories while 'Supply Chain', 'Market', and 'Institutional'.

Govindan and Hasanagic (2018) provides one of the most comprehensive studies on barriers by conducting a systematic review on drivers, barriers and practices for CE implementation from a supply chain perspective. Again, as in previous studies, they clustered these factors into eight categories; 'Governmental', 'Economic', 'Technological', 'Knowledge & Skill', 'Management', 'CE Framework', 'Cultural & Social' and 'Market' respectively. An alternative categorisation of barrier to CSCM implementation is found in Mangla et al. (2018a) who classified 16 drivers into one of four groups; 'Autonomous', 'Dependent', 'Linkage', and 'Drivers'. The authors identified these 16 drivers to CSCM in the context of the manufacturing industry in the developing nation of India. Farooque et al. (2019) developed a theoretical framework of barriers to implementing CSCM using multiple organisational theories. The applicability of the framework is then demonstrated in a quantitative study of barriers to CSCM in the food industry in China using a fuzzy DEMATEL technique. The most prominent barriers to CSCM implementation found in this study are 'Weak environmental regulations/enforcement', 'Lack of market pressure' and 'Lack of collaboration between supply chain actors'.

2.3 Circular supply chain readiness

To assess the Irish Dairy Industry's readiness to implement a CSC it was first necessary to create a pool of measurements that can be used. In the proposed study, the relevant literature was searched for enablers, critical success factors and barriers to CSC implementation. To do this, the keywords relating to the study were identified to enable the construction of search strings for entry into various relevant databases. Details of these are shown in Table 2. The search results were then imported and filed to enable the removal of duplicates and to act as a tracker. After a literature review, many sub-measures that could be used to perform an industry readiness measurement were identified. The most relevant sub-measures were extracted and are listed in Table 3 under seven categories. An explanation of each criterion and the associated sub-measures is provided in Sects. 2.3.1–2.3.7.

2.3.1 Financial and economic aspects

Implementing the CE at a supply chain level requires new infrastructure and process improvements, all of which are supported through financial capital (Govindan & Bouzon, 2018;

Table 2 Keywords, and inclusion/exclusion criteria used for literature search

Keywords	Circul* OR circular econ* OR CE OR CSC OR Circul* suppl* chain
AND	Readi* OR ready or matur* OR barrier* OR challenge* OR inhibit* OR enable* OR critical success factor OR CSF OR driver* OR assess* OR framework OR tool*
Language	Limit to "English"
Year	Last 5 Years
Document type	Journal article OR conference paper
Database	Scopus OR ProQuest (ABI Inform) OR Emerald OR Google Scholar

Table 3 The pool of readiness measures and sub-measures extracted from literature

Measure	Sub-measure	Source
Technology & Infrastructure	Products that are designed for reuse, recycling & remanufacturing	Masi et al. (2018), Farooque et al. (2019), Vermunt et al. (2019), Ozkan-Ozen et al. (2020), Kayikci et al. (2022)
	Information Technology that supports a Circular Supply Chain e.g., Information sharing technology, tracking technology & labelling standards	Mangla et al. (2018b), Agyemang et al. (2019), Farooque et al. (2019), Tura et al. (2019), Ozkan-Ozen et al. (2020), Kazancoglu et al. (2021), Kayikci et al. (2022)
	Infrastructure for product recovery activities such as collection, sorting and disassembly centres	Agyemang et al. (2019), Vermunt et al. (2019), Kazancoglu et al. (2020), Ada et al. (2021), Kayikci et al. (2022)
	Accessible location of facilities for recovery and waste management activities (collection, recycling)	Vermunt et al. (2019), Kazancoglu et al. (2020), Ada et al. (2021), Lahane and Kant (2021), Kayikci et al. (2022)
Environmental	Use of clean process technology	Masi et al. (2018), Lahane et al. (2020), Ozkan-Ozen et al. (2020)
	Use of environmentally friendly materials (Initial procurement)	Ozkan-Ozen et al. (2020), Kayikci et al. (2022)
	Use of Environmental impact measurement system (Metrics)	Masi et al. (2018), Tura et al. (2019), Kazancoglu et al. (2021)
	Adherence to Environmental standards set for the industry	Mangla et al. (2018a), Ada et al. (2021)
	Environmental awareness among supply chain partners	Ozkan-Ozen et al. (2020), Kayikci et al. (2022)
Market & Social	Customer commitment to return used products	Tura et al. (2019)
	Existing market for recovered products	Mangla et al. (2018a), Vermunt et al. (2019)
	Pressure to adopt sustainable practices such as circular supply chain from NGO's (non-governmental organisations), the media and society	Farooque et al. (2019), Vermunt et al. (2019), Kazancoglu et al. (2021)

Table 3 (continued)

Measure	Sub-measure	Source
	Consumer awareness on environmental and sustainability issues	Moktadir et al. (2018), Tura et al. (2019), Kazancoglu et al. (2020), Ada et al. (2021)
Supply Chain & Operations	Integration of manufacturing, remanufacturing, and recycling activities	Agyemang et al. (2019), Vermunt et al. (2019), Lahane et al. (2020)
	Quantity and Quality of recovered products/materials available	Masi et al. (2018), Kazancoglu et al. (2020)
	Use of forecasting and planning for supply & demand	Levering and Vos (2019), Lahane and Kant (2021), Kayikci et al. (2022)
	Availability and use of third-party reverse logistics providers	Kazancoglu et al. (2020), Kayikci et al. (2022)
	Inventory management system in place	Kazancoglu et al. (2020), Lahane and Kant (2021)
	Communication and collaboration between supply chain members (Transparency)	Mangla et al. (2018a), Masi et al. (2018), Farooque et al. (2019), Tura et al. (2019), Lahane et al. (2020)
Management, Organisation & Human Capital	Commitment of leadership to bring organisational change	Moktadir et al. (2018), Kazancoglu et al. (2020), Ozkan-Ozen et al. (2020), Kazancoglu et al. (2021), Kayikci et al. (2022)
	Managerial support for the implementation of circular supply chain (Sustainable practices)	Farooque et al. (2019), Tura et al. (2019), Ada et al. (2021), Kazancoglu et al. (2021)
	Employee commitment to sustainable practices	Farooque et al. (2019), Tura et al. (2019), Lahane and Kant (2021), Kayikci et al. (2022)
	Management level of training in environmental and sustainable business activity	Agyemang et al. (2019), Tura et al. (2019), Kazancoglu et al. (2020)
	Management awareness and consciousness of natural resource limitations	Masi et al. (2018), Moktadir et al. (2018), Agyemang et al. (2019), Kazancoglu et al. (2020)

Table 3 (continued)

Measure	Sub-measure	Source
Government & Policy	Support of government legislation to adopt sustainable business practices	Moktadir et al. (2018), Tura et al. (2019), Vermunt et al. (2019), Lahane and Kant (2021), Kayikci et al. (2022)
	Enforcement of legislation on the industry; e.g., licence to operate	Mangla et al. (2018a), Farooque et al. (2019), Kazancoglu et al. (2020), Ada et al. (2021)
	Non-legislative Government driven incentives for adopting sustainable business practices; e.g., tax breaks/grants/infrastructure assistance	Agyemang et al. (2019), Vermunt et al. (2019), Ada et al. (2021), Lahane and Kant (2021)
Financial & Economic	Clear Economic benefits & Financial feasibility of implementing Circular supply chain	Mangla et al. (2018a), Agyemang et al. (2019), Farooque et al. (2019), Tura et al. (2019), Vermunt et al. (2019), Kazancoglu et al. (2021), Kayikci et al. (2022)
	Access to funding and support from financial institutions specifically for investment in sustainable business practices	Agyemang et al. (2019), Farooque et al. (2019), Levering and Vos (2019)
	Raw material price inflation (increase)	Masi et al. (2018), Kazancoglu et al. (2020), Kayikci et al. (2022)

Kazancoglu et al., 2021). Therefore, access to funding and the level of support financial institutions are offering for investment in circular economy practices is an indicator of successful implementation. The increasing price of raw materials has a positive impact on the adoption of circular practices and the use of sustainable materials in the supply chain as they contribute to procurement cost savings (Govindan & Hasanagic, 2018). On the other hand, if raw material prices were low, some incentive for CSC implementation has been taken away. Finally, the perceived economic value placed on used products within the industry can also be used as a readiness indicator (Kayikci et al., 2022).

2.3.2 Technology and infrastructure

The successful implementation of a CSC relies heavily on the adoption of the right technology and the establishment of proper infrastructure (Govindan & Bouzon, 2018; Govindan & Hasanagic, 2018). Specifically, CSC requires infrastructure for product recovery activities such as collection, sorting, and disassembly centres which need to be established at accessible locations for both industry and society (Farooque et al., 2019; Frei et al., 2020). The products that exist in a CSC should be designed for reuse, recycling and remanufacturing as the more consideration that is given to these aspects at the design stage the easier it will be when it comes to utilising the recovered products (Govindan & Bouzon, 2018; Murali et al., 2019). Many researchers agree with Govindan and Bouzon (2018) that information technology which supports a CSC is important for successful implementation. This includes information sharing technology, tracking technology, and labelling standards across the SC (Murali et al., 2019).

2.3.3 Environmental aspects

The environmental category contains measures that relate to environmental protection, sustainability and sustainable development within the industry (Waqas et al., 2018). The environmental impact of CSC activities is something that must be measured if implementation is to be successful (Münch et al., 2022). Environmental impact can include GHG emission, water pollution and ineffective solid waste management. The use of environmentally friendly materials such as packaging made from recycled material (Gardas et al., 2019) is recognised as an important factor in a CSC, this coupled with the use of clean technology (Bhatia & Kumar Srivastava, 2019) is a stepping stone to a more circular economy. Waqas et al. (2018) highlights the importance of having specific measurements and metrics for the environmental impact of CSC implementation as conserving the environment and reducing the impact of the SC is the main reason for implementation in the first place. Sangwan (2017) furthers this importance of environmental measurement stating there must be a presence of environmental standards for the industry and a heightened environmental awareness among SC partners.

2.3.4 Market and social aspects

This category includes measures which can help understand market competition in the industry, meanwhile the social aspect of this section taps into the motivations of consumers and their psychology for creating greater awareness of CSC activities and impact (Waqas et al., 2018). The need to have an existing market for recovered products (Govindan & Bouzon, 2018; Lapko et al., 2018; Prajapati et al., 2019; Sangwan, 2017) alongside the need to have proper sales channels for remanufactured products (Bhatia & Kumar Srivastava, 2019) has been mentioned in previous studies. When both are present there is a much greater chance of success for the CSC. It is important to measure the level of consumer awareness on environmental protection and the CE which can be heightened through campaigns and advertising (Li et al., 2021). Additionally, pressure from NGOs and society are effective mechanisms for increasing customer interest in circular practices and the associated products (Rainville, 2021) along with customer commitment to returning their used products (Zhang & Zhang, 2018).

2.3.5 Supply chain and operations

The supply chain and operations category contains measures that assess SC-related issues such as inventory management and supply/demand forecasts along with operational issues such as quality, quantity and logistics providers (Waqas et al., 2018). A common prerequisite for CSC implementation success is the integration of manufacturing, remanufacturing and recycling activities (Zhang & Zhang, 2018). Other measures of readiness in this category include the quantity and quality of recovered products (Frei et al., 2020), accurate forecasting of supply and demand (Govindan & Hasanagic, 2018), availability of third-party reverse logistics providers (Govindan & Bouzon, 2018), and existing inventory management systems (Gaur & Mani, 2018). Finally, the level of effective communication and collaboration between CSC members is important as it will enhance co-ordination and the efficiency of the activities in operation (Kausar et al., 2017; Lapko et al., 2018; Mangla et al., 2018b; Shekarian, 2020).

2.3.6 Management, organisation and human capital

When implementing a CSC the commitment of leadership in each organisation belonging to the supply chain (Schulze & Bals, 2020) and the level of managerial support for the implementation of CSC (Govindan & Bouzon, 2018) can often be the deciding factors between success and failure. If management is not unanimously in support of CSC activities, this will filter down through the SC and will harm the commitment of employees to circular practices (Roy et al., 2020). There must also be adequate availability of skilled labour especially in operations (Farooque et al., 2019) and in the absence or lack of this skill, there must be training for CSC and environmental activities for employees (Prakash & Barua, 2016; Waqas et al., 2018). Münch et al. (2022) states that the level of management awareness and consciousness of natural resource limitations should also be used as an indicator of CSC readiness.

2.3.7 Government and policy

The government and policy category measures the action that governments are taking towards a circular economy and the responsibility the government have when it comes to CSC implementation (Waqas et al., 2018). The impact and level of government support, incentive schemes and motivation for CSC members is an often cited success factor (Gaur & Mani, 2018; Kausar et al., 2017). There must be supportive environmental legislation/regulations to adopt circular practices and these must also be enforced by the government (Rainville, 2021). This enforcement can increase the effectiveness of already existing set recycling policies to obtain high-quality materials (Vermunt et al., 2019) which feeds back into the CSC. Both Govindan and Bouzon (2018) & Shekarian (2020) found that a licence to operate can increase the buy in from CSC members and the push towards a circular economy. Figure 1 shows an illustrative view of the seven categories for measuring CSC implementation readiness.

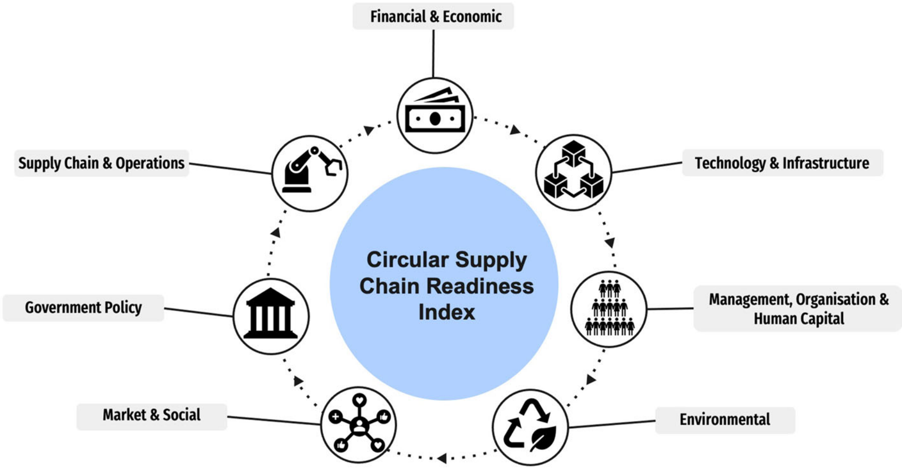

Fig. 1 Circular supply chain readiness index with associated categories

3 Methodology and implementation

There are five systematic steps involved in this study as illustrated in Fig. 2. The first step involved identifying the readiness measures and sub-measures from a review of the relevant literature and experts' opinions. The second step is where these measures and sub-measures were then weighted using the BWM (Rezaei, 2015). In the third step, the novel weighted FIS was developed using MATLAB software. In fourth step, the proposed FIS model is utilised to perform the readiness measurement using inputs from experts in the Irish dairy industry. Finally, the output scores from the FIS were used to create a readiness index which provides an overall score for the industry as well as individual scores in each of the seven areas of readiness (see Table 10).

There are many reasons for the application of our integrated BWM–FIS approach. Firstly, the use of the BWM and FIS in conjunction allows us to address the specific research objective

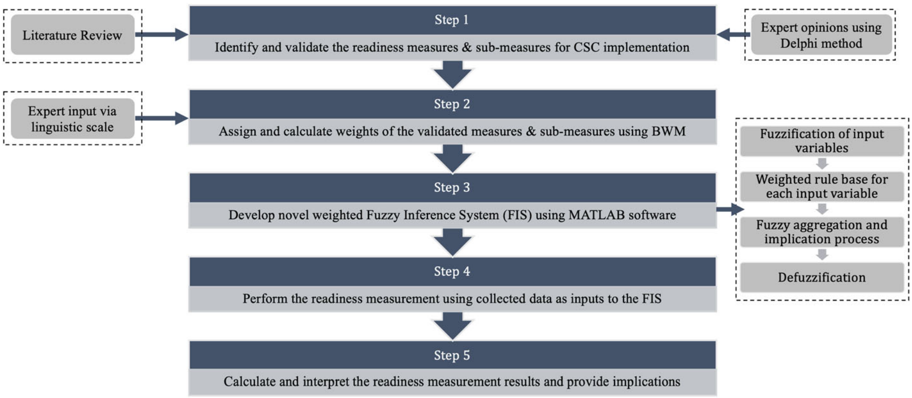

Fig. 2 Research process flowchart with steps and inputs

of developing a comprehensive readiness index for CSC implementation. While MCDM methods are commonly employed in assessing complex problems, they are primarily designed to deal with decision-making scenarios involving alternatives or choices (Lahane & Kant, 2021). In this study, the focus is on evaluating the readiness level rather than comparing alternatives. Therefore, a traditional MCDM method alone would not suffice in capturing the multidimensional nature of readiness assessment.

To address this limitation and ensure a holistic evaluation, we integrated the BWM with the FIS. The BWM enables the identification and ranking of the most critical readiness measures and sub-measures, which are derived from the literature and validated using the Delphi method (Rezaei, 2015). By employing the BWM, we capture the relative importance and significance of each readiness factor, allowing us to construct a weighted readiness index that reflects the priorities and preferences of the industry professionals. Additionally, the FIS component of our methodology leverages the advantages of fuzzy logic, which is particularly suitable for dealing with uncertainties and imprecise data (Mamdani, 1974). The use of FIS has been successfully applied in previous studies within the literature to assess green marketing risks (Azadnia et al., 2021) and measure the performance of business incubation centres (Azadnia et al., 2022) for example. This highlights its effectiveness in capturing complex, vague, and subjective information, which aligns well with the nature of readiness assessment in the context of CSC implementation.

By combining the BWM and FIS, we develop a comprehensive readiness index that accounts for the relative importance of readiness measures and sub-measures while considering the uncertainty and imprecision inherent in such assessments. This integrated approach allows us to overcome the limitations of traditional standalone MCDM methods and provides a robust framework for evaluating readiness. We will now discuss each of the steps involved in the study.

3.1 Step one: Identifying the relevant readiness measures and sub-measures for CSC implementation

This step involved both extracting and validating the readiness measures and sub-measures for CSC implementation. To do this, the relevant literature was reviewed, and the measures were extracted as shown in Table 3. Next, a Delphi method was utilised to perform an adjustment mechanism which involved using a group of experts to reach a consensus through discussion and voting during a series of structured interviews. These experts were selected based on their expertise in SC management, sustainability, and knowledge of the Irish dairy industry (See Table 4 for expert's details).

These experts were provided with a yes/no-based questionnaire as a supplement for the structured interview to validate the measures extracted from the relevant literature. The Delphi panel were provided with the opportunity to give their opinion on the categorisation and wording of the measures, and, in addition, they were asked to provide any measure they felt was relevant but had not been included already based on their expertise. After the first round, the answers were analysed and if 50% or more of the experts voted yes then the measure was accepted, otherwise, it was omitted. It is worth noting at this stage the wording and categorisation of some measures were changed based on the expert's recommendation. For example, the original category name "organisation" was extended to "management, organisation, & human capital". Then for the second round, all remaining measures were sent to the same group of experts for validation. Their answers were again analysed, and the finalised list of readiness measures and sub-measures was agreed and is presented in Fig. 3.

Table 4 Profile of the experts consulted for validation and weighting of the measures

No.	Job title/position	Experience (Years)	Area
1	Senior Manager	15	Industry
2	Full Professor	15	Academic
3	Professor	23	Academic
4	Consultant	8	Consultancy
5	Senior Manager	12	Industry
6	Assistant Professor	10	Academic
7	Senior Lecturer	16	Academic
8	Management Consultant	10	Consultancy
9	Assistant Professor	12	Academic
10	Assistant Professor	9	Academic

3.2 Step two: Weighting the readiness measures and sub-measures using the BWM

The next step in the process was to find the weight for each of the measures in terms of importance. This step is important as not every measure or sub-measure is equal when it comes to measuring readiness. Weighting the measures and sub-measures involves using a MCDM method. Having reviewed the many MCDM methods available to the researcher, it was decided that the BWM would be used to weight the measures and sub-measures due to its many advantages over the traditionally used analytical hierarchy process (AHP) including:

I For the BWM there is only a need for *2n-3* comparisons while AHP requires *n(n-1)/2* where *n* is the number of criteria being compared (Rezaei, 2015).

II The weights that are derived from BWM are highly reliable as it provides more consistent comparisons compared to AHP. For example, while in AHP and most other MCDM methods the consistency ratio is used to check if the comparisons are reliable, in BWM the consistency ratio is used to calculate the level of reliability as it is consistent (Rezaei, 2015).

III When using most other MCDM methods a comparison matrix is used and the decision maker will have to deal with integers and fractional numbers (e.g., 1, 1/9) whereas in BWM only integers are used which makes it much easier to complete (Rezaei, 2015).

While fuzzy logic can be merged with the BWM and Fuzzy-BWM does exist in the literature (Guo & Zhao, 2017), it has been subject to criticism and correction such as errors in the equations and mathematical modelling proposals (Dong et al., 2021). Therefore, to ensure reliability in this study it was decided to use the original linear BWM (Rezaei, 2016) and instead the integration of fuzzy logic in this study would be realised in the development of the FIS.

The BWM requires the decision maker (DM) to complete five steps in order to assign weights to the criteria being considered (Rezaei, 2015). A nominal group of experts were invited to complete these steps and a virtual meeting was conducted to do so. During this meeting the experts were asked to discuss and reach a consensus on the pairwise comparison of the readiness measures and sub-measures. This method allowed for the DM's to share their expert opinions in a group setting and a final pairwise comparison vector was completed. Microsoft Excel was utilised to complete the following steps of the BWM as outlined below:

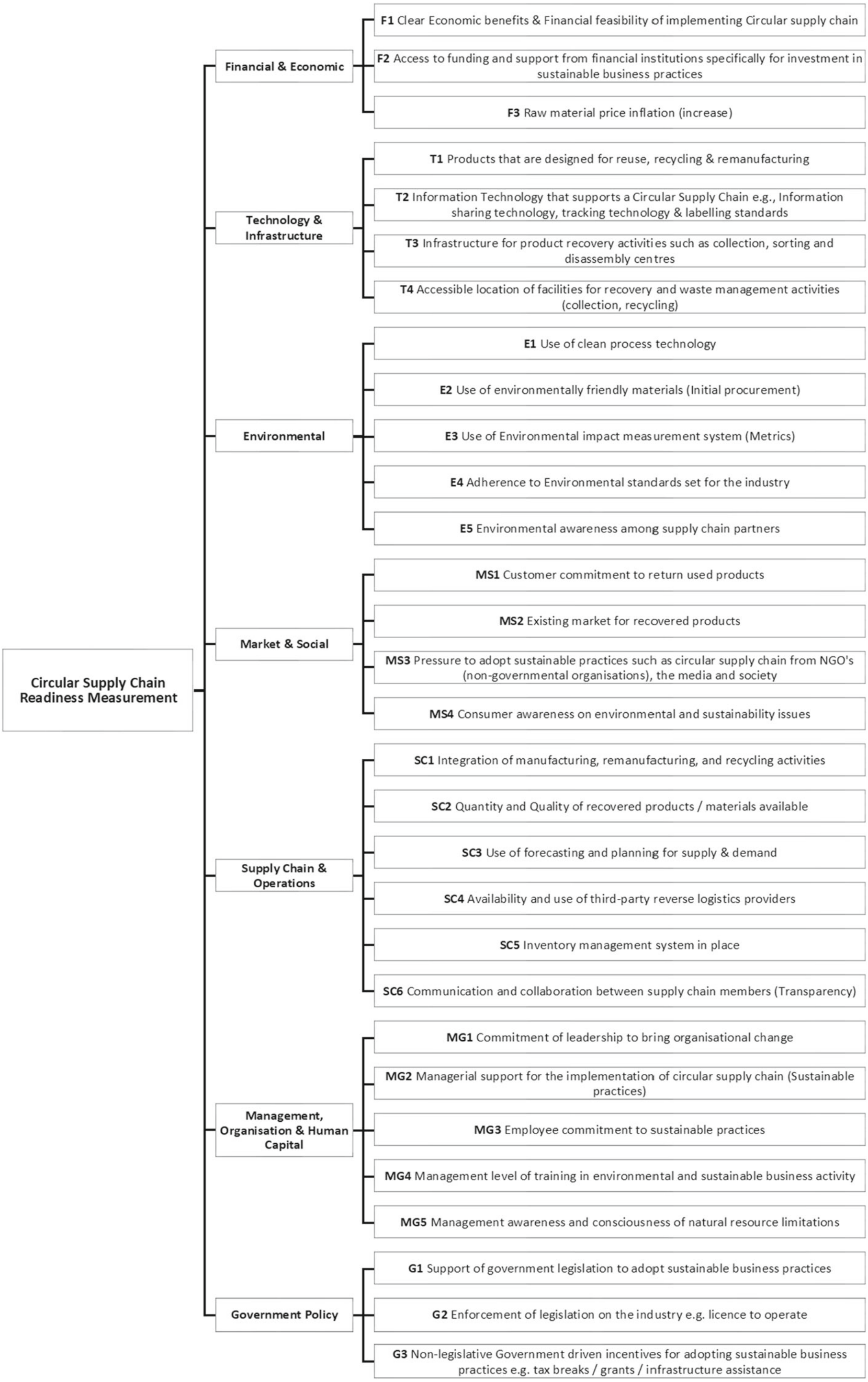

Fig. 3 Circular supply chain readiness measures and sub-measures used for this study

Step 1: Determine a set of decision criteria.
The decision-making criteria defined as $\{C = C_1, C_2, \ldots, C_n\}$ are identified by the decision maker.
Step 2: Determine the best and the worst criteria.
Next the DM is asked to determine the best (most desirable or important) and the worst (least desirable or important) criteria from the set C from step 1. No comparisons between the criteria is made at this stage.
Step 3: Determine the preference of the best criterion over all the other criterion using a number between 1 and 9.
The DM performs a pairwise comparison between the best criterion and all other criteria. The DM states their preference of the best criterion over the others by assigning a number between 1 and 9. With the value 1 meaning the best and other criterion are of equal importance and a value of 9 meaning the best criterion is absolutely more important than the other criterion being considered. This will form the best-to-others (B2O) vector A_B, such that

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

where a_{Bj} represents the preference of the best criterion over the other criterion and $a_{BB} = 1$.
Step 4: Determine the preference of all the other criteria over the worst criteria using a number between 1 and 9 in a similar fashion to step 3. This will form the others-to-worst (O2W) vector

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

where a_{jW} represents the preference of the other criterion over the worst and $a_{WW} = 1$.
Step 5: Find the optimum weights of the criterion $\left(W^* = W_1^*, W_2^*, \ldots, W_n^*\right)$.

There are several different methods that can be used to assign the optimum weights to the criteria. One of which is to linearise the BWM as follows (Rezaei, 2016):

$$\min \max_j \left\{ \left| \frac{W_B}{W_j} - a_{Bj} \right|, \left| \frac{W_j}{W_w} - a_{jW} \right| \right\}$$

such that

$$\sum_j w_j = 1,$$

$$w_j \geq 0 \quad for\ all\ j.$$

The problem can then be programmed linearly and is equivalent to:

$$\min \xi$$

such that

$$\left| \frac{W_B}{W_j} - a_{Bj} \right| \leq \xi \quad \text{for all } j,$$

$$\left| \frac{W_j}{W_w} - a_{jW} \right| \leq \xi \quad \text{for all } j,$$

$$\sum_j w_j = 1,$$

$$w_j \geq 0 \quad \text{for all j.}$$

Table 5 Weights of the categories derived from BWM application

Measure	Weight
Financial & Economic	0.179
Technology & Infrastructure	0.314
Environmental	0.071
Market & Social	0.044
Supply Chain & Operations	0.119
Management, Organisation & HC	0.089
Government & Political	0.179
Total	**1.000**
Consistency ξ^*	**0.044**

By solving the above problem, the optimal weights $\left(w_1^*, w_2^*, \ldots, w_3^*\right)$ and ξ^* can be found. ξ^* can then be used as a direct indicator of the consistency of the comparisons, values close to zero show a high level of consistency. The responses of the experts are amalgamated using the arithmetic mean calculated by $W_{avg}^* = \frac{1}{n}\sum_{j=1}^{n} W_j^*$.

To facilitate the application of the BWM, structured interviews were conducted with experts instead of solely distributing questionnaires. This approach was chosen because experts may encounter difficulties and confusion when answering pairwise comparison questionnaires without guidance (Azadnia et al., 2023). Additionally, supervising the experts during the interview process aimed to ensure better consistency in their responses. To conduct the structured interviews, BWM questionnaires were designed based on the identified readiness measures and sub-measures. Each expert was individually interviewed, and their opinions were sought using the designed questionnaires. The purpose of these interviews was to determine the relevant weights of the readiness measures and sub-measures through the application of BWM. Consequently, the same set of questions was used for conducting pairwise comparisons.

During the interviews, the experts were asked to identify the most important and least important readiness sub-measure within each category based on their opinion. They were also asked to express their preference regarding "the most important sub-measures over all the other sub-measures" and "all the other sub-measures over the least important sub-measure" by selecting a number from 1 to 9 (Rezaei, 2015). To facilitate this process, an Excel file was provided to the experts, allowing them to select the desired number from a drop-down menu while having access to the corresponding meaning of each number. Once the experts completed the pairwise comparisons through the "B2O" and "O2W" vectors, the collected data was analysed. Based on this analysis, numerical weight values were assigned to each risk factor and their respective categories. The calculations required to derive these weights were performed using a BWM Excel spreadsheet template, which aided in the analysis of the interview data. The results of conducting the BWM are presented in Tables 5 and 6, these weights are then integrated into the design of fuzzy rules for the FIS.

Table 6 Weights of the sub-measures derived from BWM application

Category	No	Sub-measure	Local weight
Financial & Economic	1	Clear Economic benefits & Financial feasibility of implementing Circular Supply chain	0.571
	2	Access to funding and support from financial institutions specifically for investment in sustainable business practices	0.286
	3	Raw material price inflation (increase)	0.143
Technology & Infrastructure	1	Products that are designed for reuse, recycling & remanufacturing	0.259
	2	Information Technology that supports a Circular Supply Chain; e.g., Information sharing technology, tracking technology & labelling standards	0.172
	3	Infrastructure for product recovery activities such as collection, sorting and disassembly centres	0.466
	4	Accessible location of facilities for recovery and waste management activities (collection, recycling)	0.103
Environmental	1	Use of clean process technology	0.205
	2	Use of environmentally friendly materials (initial procurement)	0.205
	3	Use of Environmental impact measurement system	0.369
	4	Adherence to Environmental standards set for the industry	0.082
	5	Environmental awareness among supply chain partners	0.137
Market & Social	1	Customer commitment to return used products	0.393
	2	Existing market for recovered products	0.107
	3	Pressure to adopt sustainable practices such as CSC from NGO's, the media and society	0.429
	4	Consumer awareness on environmental and sustainability issues	0.071
Supply Chain & Operations	1	Integration of manufacturing, remanufacturing, and recycling activities	0.333
	2	Quantity and Quality of recovered products/materials available	0.133

Table 6 (continued)

Category	No	Sub-measure	Local weight
	3	Use of forecasting and planning for supply & demand	0.100
	4	Availability and use of third-party reverse logistics providers	0.100
	5	Inventory management system in place	0.067
	6	Communication and collaboration between supply chain members (Transparency)	0.267
Management, Organisation & Human Capital	1	Commitment of leadership to bring organisational change	0.378
	2	Managerial support for the implementation of circular supply chain (Sustainable practices)	0.339
	3	Employee commitment to sustainable practices	0.059
	4	Management level of training in environmental and sustainable business activity	0.139
	5	Management awareness and consciousness of natural resource limitations	0.084
Government Policy	1	Support of government legislation to adopt sustainable business practices	0.428
	2	Enforcement of legislation on the industry e.g. licence to operate	0.143
	3	Non-legislative government-driven incentives for adopting sustainable business practices; e.g., tax breaks, grants, infrastructure assistance	0.429

3.3 Step three: Developing the proposed weighted FIS capable of performing the readiness measurement

In this step, the proposed FIS model is developed with the utilisation of MATLAB software (cf. Figs. 4 and 5). A FIS is a model that uses fuzzy set theory to map inputs to outputs using a series of steps. There are two types of FIS; Mamdani-type and Sugeno-type, with the main difference between the two, is how outputs are determined (Jain & Singh, 2020). The developed FIS model in this study is based on the Mamdani-type (Mamdani, 1974). The proposed FIS will address the previously mentioned inherent vagueness of expert judgements in the assessment stage. The Mamdani FIS is made up of four main stages: fuzzification of the inputs, the weighted rule base, the engine, and finally the defuzzification leading to a "readiness index" in this case (Mamdani, 1974). Each of these stages is now explained in further detail:

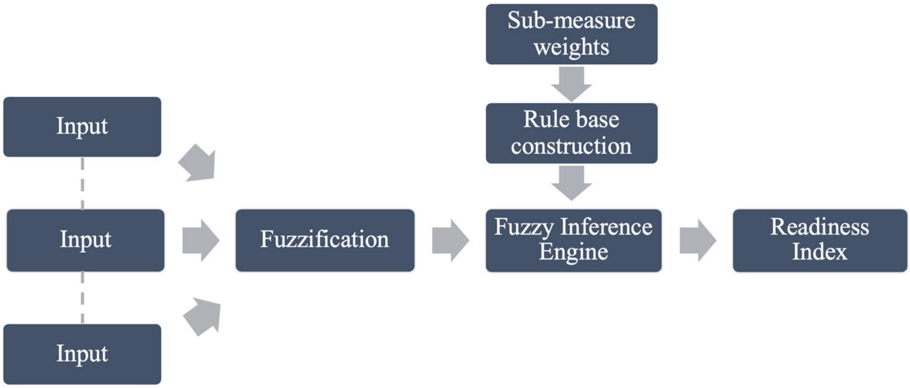

Fig. 4 Outline of the FIS for measuring CSC readiness in this study

3.3.1 Phase 1: Fuzzification

The fuzzy sets of inputs were represented by membership functions (MFs) in order to transfer crisp inputs into fuzzy inputs. Various grades of MF's were assigned to the input data obtained for each measure and sub-measure. Then, a target range was set for the measures using a minimum and maximum possible value. The proposed FIS model utilised three triangular MF variations which mapped the inputs to each sub-measure (Azadnia et al., 2022). The MFs were determined using three target scales labelled low (L), moderate (M), and high (H). In addition, seven output MFs were determined to map the output onto a scale between 0–100 and were labelled as very low (VL), low (L), low-moderate (LM), moderate (M), moderate-high (MH), high (H), and very high (VH) (Azadnia et al., 2021).

3.3.2 Phase 2: Weighted rule base construction

After constructing the MFs for each input variable, a rule base that mediates the internal behaviours of each of these MFs was defined. This rule base consisted of several IF_THEN fuzzy rules. Fuzzy rules are the main part of the FIS model and therefore must be constructed properly. Since the importance of each assessment criterion is different, it is critical that the importance weights from step two are incorporated in the proposed model. However, the traditional FIS is unable to deal with this matter of assigning weights to the rule base (Azadnia et al., 2015; Ghadimi et al., 2012). In a more recent study, Azadnia et al. (2021) proposed a novel heuristic approach to deal with this exact problem in the traditional FIS. The heuristic works on defining the various ranges for constructing fuzzy rules while taking each sub-measures weight into account. Hence, this study adopts this novel heuristic approach to incorporate the importance weights of the measures and sub-measures to form a 'weighted-fuzzy rule base'. The ranges used for constructing the rules are as follows:

$$A) IF \sum_{i=1}^{m} W_i A_i = 1 \; THEN \; readiness \; is \; Very \; Low \; (VL),$$

$$B) IF \; 1 < \sum_{i=1}^{m} W_i A_i \leq 1.33 \; THEN \; readiness \; is \; Low \; (L),$$

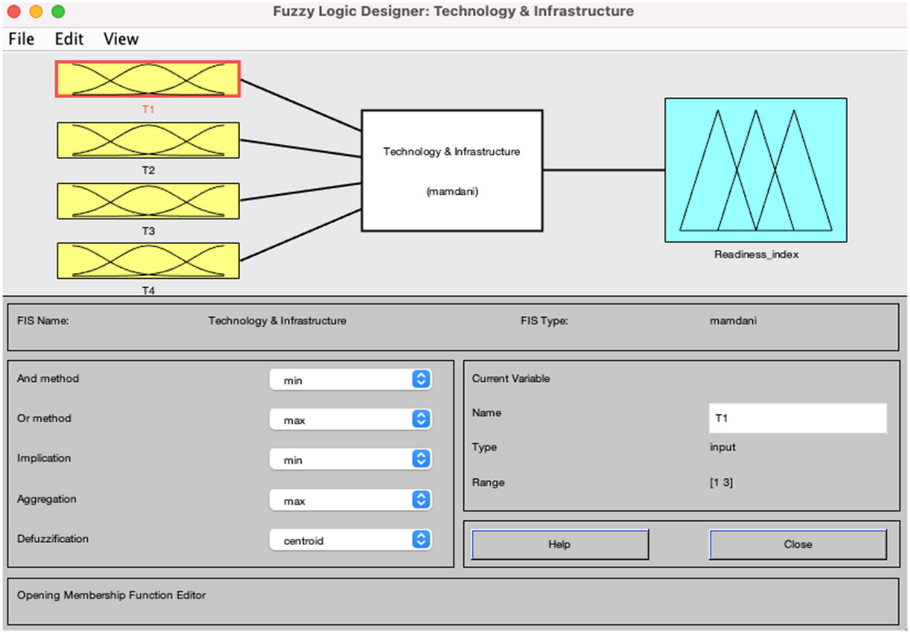

Fig. 5 Constructed inputs and output for the technology & infrastructure category in MATLAB

$$C)\,IF\,1.5 < \sum_{i=1}^{m} W_i A_i \leq 1.66\,THEN\,readiness\,is\,Low - Moderate\,(LM),$$

$$D)\,IF\,1.5 < \sum_{i=1}^{m} W_i A_i \leq 2.33\,THEN\,readiness\,is\,Moderate\,(M),$$

$$E)\,IF\,2 < \sum_{i=1}^{m} W_i A_i \leq 2.66\,THEN\,readiness\,is\,Moderate - High\,(MH),$$

$$F)\,IF\,2.5 < \sum_{i=1}^{m} W_i A_i \leq 2.99\,THEN\,readiness\,is\,High\,(H),$$

$$G)\,IF\,\sum_{i=1}^{m} W_i A_i = 3\,THEN\,readiness\,is\,Very\,High\,(VH),$$

where W_i is the importance weight of the ith criterion and A_i is the MF score related to the ith criterion.

The following equation provides a formula which calculates the number of fuzzy rules that need to be constructed for each sub-measure (Azadnia et al., 2022).

$$R = n^v,$$

where R Number of potential rules for each main category, n : Number of MF types for each sub-category, v : Number of sub-categories (input variables) related to each main category.

For example, the Technology and infrastructure category has 3 MF's and 4 sub-measures. Based on the equation, the technology & infrastructure FIS will have 81 rules. The number of rules for each category were calculated and are shown in Table 7.

Table 7 Number of fuzzy rules required for each category

Measure	Number of Rules
Financial & Economic	27
Technology & Infrastructure	81
Environmental	243
Market & Social	81
Supply Chain & Operations	729
Management, Organisation & HC	243
Government & Political	27
Total	1431

Table 8 Examples of fuzzy rules from the Financial & Economic category

IF (F1 is Low) AND (F2 is Low) AND (F3 is Low), THEN (FE is Very Low)
IF (F1 is Low) AND (F2 is Mod) AND (F3 is Mod), THEN (FE is Low-Moderate)
IF (F1 is Mod) AND (F2 is High) AND (F3 is High), THEN (FE is Moderate-High)
IF (F1 is High) AND (F2 is Mod) AND (F3 is High), THEN (FE is High)
IF (F1 is High) AND (F2 is High) AND (F3 is High), THEN (FE is Very High)

The low, moderate, and high MF scores are 1, 2 and 3 respectively while the six IF statements were used to aggregate the weighted readiness measures and sub-measures which resulted in a THEN statement for each of the considered readiness measurement categories (Azadnia et al., 2021). Examples of the constructed fuzzy rules from the technology & infrastructure FIS are presented in Table 8.

3.3.3 Phase 3: Fuzzy assessment engine

In this phase the implication process output was determined. To do this the typical fuzzy operators known as AND, NOT and OR were used to link the fuzzy rules together which formed a string (Ghadimi et al., 2012). Then a single fuzzy set was derived from the aggregating the outputs together (Azadnia et al., 2022). These outputs were then used in phase 4, defuzzification.

3.3.4 Phase 4: Defuzzification

The defuzzification part of the FIS transformed fuzzy output into a crisp output much like the reverse of the first step seen in fuzzification. Of all the parts of the system, defuzzification is the most complex in terms of computation (Jain & Singh, 2020). According to Jain and Singh (2020) the most popular defuzzification methods include the centre of area, bisector of area, mean of maximum, smallest of maximum, and largest of maximum methods respectively. The defuzzification step for this study used the centre of area method and identified a numerical output value on a 0–100 scale which was the final output of the FIS and represents the readiness score for that category.

3.4 Step four: Performing the readiness measurement using the developed FIS and interpreting the output scores for each category

Finally, in this step, the developed FIS was utilised to perform the industry readiness measurement for CSC implementation. To do this the FIS required data in the form of crisp inputs. The crisp inputs that were entered to the FIS are detailed in Table 10. The corresponding sub-measure number (1–6) of the input is also included and details on each of these sub-measures are illustrated in Table 6. The data for the readiness of the Irish dairy industry in each sub-measure was acquired from experts in the industry through a structured interview format using a purposive sampling method. The structured interview technique was utilised in order to obtain better data accuracy which was based on a predesigned questionnaire. During the meetings the professionals were asked to provide their opinions on the level to which the dairy industry had implemented each of the readiness factors presented in the questionnaire format. A profile of the respondents is illustrated in Table 9. It is worth noting the purposive sampling qualification criteria of at least 5 years' management experience in the Irish dairy industry in the area of SC management, operations, or sustainability. To maintain the anonymity of respondents, details on their company name or location are not included here. Afterwards, in order to achieve a better data accuracy, several meetings were conducted to do structured interviews based on the designed questionnaire (cf. Table 10).

After collecting the necessary data in this format, the developed FIS was utilised to calculate a readiness measurement score for each category using MATLAB software. An example of the readiness measurement calculation for the Technology & Infrastructure category that took place in MATLAB is provided in Fig. 6. Each subsequent category was then calculated in a similar fashion. The calculated readiness scores for each category are shown in Table 11.

However, this readiness score as an output from the FIS also needed to consider the weights of each category in order to provide a final weighted readiness score. To calculate the weighted score, the readiness score obtained from the FIS was multiplied by the corresponding weight of each category. Finally, the sum of these weighted scores for each measure gave a total weighted readiness score for the industry.

4 Results and discussion

An immediate observation of the fuzzy output scores for each category highlights the areas which appear most ready for CSC implementation and the areas which need improvement (Table 11). The management & organisation (68.2), environmental (65.7), and supply chain & operations (60.8) categories respectively obtained the highest scores and can therefore be perceived as the areas in which the industry is most ready in terms of CSC implementation. The market & social (46.4) and government policy measures (44.1) appear to have been given some attention while the technology & infrastructure (33.1) and financial & economic (32.1) categories received the lowest readiness scores of all the areas considered. To further enhance the discussion of our findings, Fig. 7 presents the overall readiness index obtained for the Irish Dairy industry, while Fig. 8 illustrates the CSC implementation readiness scale which ranges from 0–100 and very weak to very strong.

Table 9 Profile of professionals consulted from the Irish dairy industry

No.	Job title/position	Experience in Irish dairy industry (Years)	No	Job title/position	Exp. Years
1	Supply Chain Manager	21	18	Chief Executive Officer	16
2	Procurement & Logistics Director	20	19	Dairy Business Unit Manager	5
3	Operations Manager	25	20	Operations Manager	10
4	Supply Chain & Logistics Manager	20	21	Head of Supply Chain	9
5	Commercial Manager	35	22	Chief Executive Officer	20
6	Head of Dairy production	5	23	Chief Executive Officer	28
7	Supply Chain Manager & Consultant	40	24	Inventory and Procurement Manager	6
8	Chief Executive Officer	10	25	Supply Chain Manager	8
9	Quality Manager	5	26	Supply Chain Manager	6
10	Chief Executive Officer	35	27	Sustainability Manager	5
11	Chief Executive Officer	30	28	Operations Manager	7
12	Procurement Manager	5	29	Logistics & Supply Chain Manager	12
13	Consumer Dairy Sector Manager	5	30	Quality Manager—Dairy	11
14	Supply Chain & Operations Manager	8	31	Supply Chain Manager	19
15	Head of Production	14	32	Head of Dairy Production	8
16	Chief Operating Officer	35	33	Supply & Operations Manager	16
17	Group Sustainability Manager	5	34	Head of Dairy Procurement	9

Utilising both the radar chart in Fig. 7 and the CSC readiness scale in Fig. 8 the areas of readiness can be classified into one of five groups depending on their score namely, very weak readiness (0–19), weak readiness (20–39), moderate readiness (40–59), strong readiness (60–79), and very strong readiness (80–100) respectively. The scores of each category can be placed on the CSC readiness scale as well as the total industry score which will be discussed further on in this section.

Table 10 Inputs for the FIS

Category	Corresponding sub-measure (No.)					
	1	*2*	*3*	*4*	*5*	*6*
Financial & Economic	1.37	1.52	2.74			
Technology & Infrastructure	1.78	1.52	1.52	1.48		
Environmental	2.41	2.3	2.37	2.85	2.56	
Market & Social	1.44	1.56	2.26	2.44		
Supply Chain & Operations	2.19	1.85	2.85	2.07	2.63	2.33
Management, Organisation & HC	2.7	2.41	2.48	2.07	2.56	
Government & Policy	1.85	2.37	1.93			

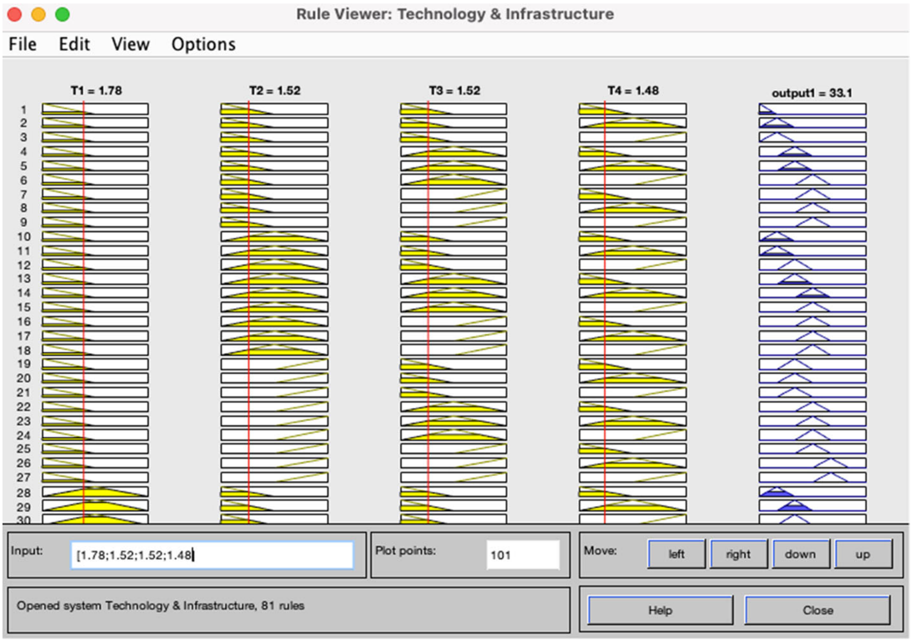

Fig. 6 Calculation of fuzzy output score for technology & infrastructure category in MATLAB

Looking at the radar chart and readiness scale it is observable that no areas are classified as having very strong levels of readiness for CSC implementation which would be the ideal situation and where the dairy industry should aim to be. Placing each category on the readiness scale shows that the areas of management & organisation (68.2), environmental (65.7), and supply chain & operations (60.8) are strong in terms of readiness and will only require small improvements to the already existing work that has been undertaken to prepare for CSC implementation. The market & social (46.4) and government policy measures (44.1) are classified as moderate on the readiness scale which signals that they will require significant improvement to move into strong or very strong levels of readiness. The final two categories

Table 11 Irish dairy industry's readiness measurement scores

Category	Fuzzy output score	Category weight	Weighted overall score
Financial & Economic	32.1	0.179	5.77
Government Policy	44.1	0.179	7.92
Market & Social	46.4	0.045	2.08
Technology & Infrastructure	33.1	0.314	10.41
Environmental	65.7	0.072	4.72
Management & Organisation	68.2	0.089	6.13
Supply Chain & Operations	60.8	0.119	7.28
		Total Industry Score	44.31

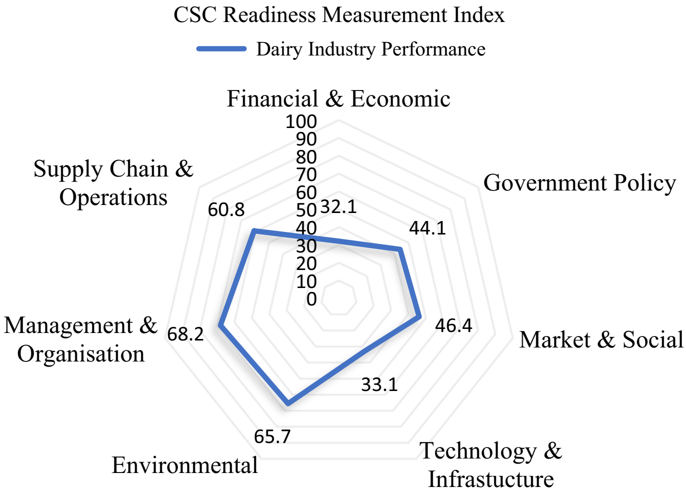

Fig. 7 Radar chart depicting the CSC readiness score for the Irish dairy industry

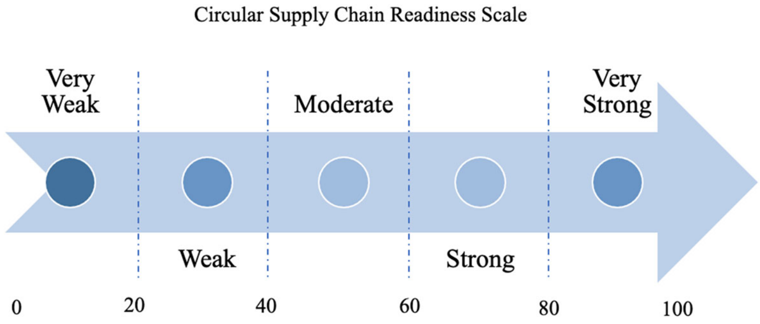

Fig. 8 CSC implementation readiness scale

of technology & infrastructure (33.1) and financial & economic (32.1) measures fall in the weak readiness classification. This means that in terms of improvement the dairy industry should focus their efforts on these two areas of weakness as they could be the deciding factors between success and failure in implementing CSC. It is also worth noting that the technology & infrastructure category ranked the highest when weighting the measures in terms of importance for CSC implementation readiness and therefore it is concerning to observe the most important measure of readiness receiving one of the lowest scores and a weak readiness classification. It is also worth mentioning the financial & economic category was joint 2nd for the weight of importance, thus improving the individual readiness of these two categories could significantly improve the overall industry readiness score for the Irish dairy industry. None of the areas was deemed to have very weak levels of readiness which is positive.

The total industry score shown in Table 11 is derived by calculating the sum product of the score for each category and the corresponding weight of each category. The total industry readiness score for the Irish dairy industry was found to be 44.31. To enhance the context of what this score means for the industry it can also be mapped onto the CSC readiness scale, which classifies the Irish dairy industry as having a moderate level of readiness for CSC implementation. The implications these findings have for managers and policy makers in terms of the scores obtained in each category as well as the overall industry readiness score is discussed in Sect. 5. Now, each category will be analysed to understand the scores and where improvements could be made to increase their readiness.

4.1 Strong areas of readiness

The Irish dairy industry received a strong readiness score in three areas of readiness as shown in Fig. 7, management & organisation, environmental, and supply chain & operations. The strong readiness score in management & organisation can be explained by the high levels of commitment from leaders to bring sustainable organisational change and the relatively strong managerial support for a circular supply chain. This means they are willing to make decisions that have a positive influence on their sustainability goals and the recent appointment of dedicated sustainability managers is a welcome addition for the industry. However, the industry does not provide a sufficient level of training in terms of sustainable business activity to all management, and this has impacted their level of consciousness for natural resource limitations and the commitment from employees to sustainable practices is not fully in line with organisational goals.

The strong readiness level of the Environmental category is mainly due to the industry's commitment to meeting the environmental standards set for them which they explained is necessary to remain operational. The use of metrics is present internally in dairy industry manufacturers with a focus on efficiency and water usage which is reported to management daily, however there is little attention given to the use of an environmental impact measurement system that goes beyond the boundaries of each organisation and considers the rest of the SC. It is also evident that the industry is focused on ensuring their raw materials are environmentally friendly such as milk at the farm level, though there is a slight disregard for sustainable packaging at the processing stage mainly due to the B2B market demanding that packaging is functional and keeps the product safe (dry) during transportation above all else.

The supply chain & operations strong readiness score is driven by their use of forecasting for supply & demand which is vital for a successful CSC. Most organisations revealed they had an inventory management system in place although it was noted that this information is strictly for internal use only. This explains the sub-par readiness in terms of communication, collaboration, and overall transparency among supply chain partners. Further investigation revealed that information is only provided when requested by customers such as those producing infant formula from their produce for whom it is necessary to be able to track & trace ingredients.

4.2 Moderate areas of readiness

The areas which are classified as having moderate levels or readiness include market & social and government policy. The score of 46.4 for market & social can be equated to a low level of commitment from customers to return used products which can include pallets, packaging and even products themselves which do not meet requirements. It is evident that a market for recovered products does not exist which could explain the low levels of enthusiasm for collecting recovered products/materials. The aspect for which market & social is most ready for CSC implementation is the awareness of consumers on sustainability issues concerning the industry and the associated products which is driving the CE transition. The pressure from NGO's however has not yet been on the same level as that from consumers. The government policy area of readiness is classified as moderate on the readiness scale and should be given particular attention by policymakers due to its significant weighting. The empirical evidence suggests that while the requirement for having a licence to operate is beneficial, government legislation is not supportive enough for the industry to adopt circular practices. The industry also points to a lack of government driven incentives specifically for circular practice adoption such as tax breaks, grants and in particular assistance in the establishment of infrastructure.

4.3 Weak areas of readiness

The area of technology & infrastructure is considered the most important area of readiness in terms of weighting in this study, which is concerning given the weak readiness score of 34.1 obtained. This score is due to several factors, first the products and packaging in the industry are not designed for circularity in terms of reuse, recycling, or remanufacturing, rather they are focused on functionality and transportation considerations. There is a significant gap in terms of information technology adoption which supports a CSC. This partially explains the earlier mentioned low level of communication and transparency among SC partners as there is limited information sharing technology in use across the industry. However, the main reason for the weak readiness of this area is the lack of infrastructure for product recovery activities. There is an absence of collection, sorting, and disassembly centres available in accessible locations for both organisations and society. Finally, the area for which the Irish dairy industry is weakest in terms of readiness for CSC implementation is in the financial & economic category. The industry does not have adequate access to funding or support from the financial institutions to invest in circular practices, this could partially explain the lack of infrastructure and technology. Also, the industry is currently not convinced on the financial feasibility of implementing the CSC and the associated economic benefits of CSC are not clear to organisations. Interestingly, one positive driver of CSC implementation in this area is the increasing price of raw materials which is linked to a positive uptake and interest in recycled and circular materials for packaging and production.

Table 12 Absolute difference comparison of the weighted FIS vs traditional FIS scores

Weight	Category	Traditional FIS (equal weights)	Weighted score	Absolute difference
0.14	Financial & Economic	7.36	5.77	1.59
0.14	Government Policy	7.84	7.92	0.08
0.14	Market & Social	6.81	2.08	4.73
0.14	Technology & Infrastructure	4.73	10.41	5.68
0.14	Environmental	9.56	4.72	4.84
0.14	Management & Organisation	9.49	6.13	3.36
0.14	Supply Chain & Operations	9.16	7.28	1.88
	Total Industry Readiness Score	54.94	44.31	10.63

4.4 Impact of the proposed weighted FIS versus traditional FIS (equal weights)

Another interesting finding is the impact of weighting the measures for the FIS compared to assigning equal weights which the traditional FIS is incapable of doing. To illustrate the impact the weights, the output scores were calculated for a second time only this time they were assigned equal weighting in terms of importance (0.14). It is observable that for most categories, the readiness score does change slightly in terms of absolute difference and although they may appear to be relatively small differences in some cases, these differences have a significant impact on the total industry readiness score which increased from 44.31 to 54.94 (See Table 12). This is a 10.63-point change and results in the readiness measurement “reading high” which could lead to misinterpretation on how ready the dairy industry is to implement CSC. The difference can also be seen in categories which received a low weighting in terms of importance as their score increases when the equal weights are assigned.

For example, the environmental category’s importance weight doubled with an increase from 0.07 to 0.14 and likewise market & social increased from a weighting of 0.04 to 0.14 both of which result in an inflated total readiness score for the industry. The consequences of not considering the weights therefore could mean that industry personnel and policy makers could place disproportionate focus on improving all areas of readiness equally, when in fact, if they were to focus their efforts on the most important areas which received a low readiness score their efforts would result in much better return on investment in terms of increasing their overall readiness score. Specifically, focusing on improvement in the areas of technology & infrastructure, financial & economic, and government policy have emerged as priorities to improve the Irish dairy industry’s readiness to implement CSC.

4.5 Sensitivity analysis

A sensitivity analysis was carried out to examine the impact of varying the weights assigned to the sub-measures on the assessment process and readiness measurement scores. The purpose of this sensitivity analysis was to demonstrate the reliability of the results obtained using the developed FIS. It aimed to illustrate how the proposed approach is sensitive to changes

Table 13 Average inputs to the FIS for the Financial & Economic category

Category	Financial & Economic		
	1	2	3
Sub-measures			
Inputs to FIS	1.37	1.52	2.74

Table 14 Financial & Economic sub-measures with their respective weights assigned for each scenario

Category	No.	Sub-measure	Initial weight	Scenario 1	Scenario 2	Scenario 3
Financial & Economic	1	Clear Economic benefits & Financial feasibility of implementing Circular Supply chain	0.571	0.6	0.2	0.2
	2	Access to funding and support from financial institutions specifically for investment in sustainable business practices	0.286	0.2	0.6	0.2
	3	Raw material price inflation (increase)	0.143	0.2	0.2	0.6

in the sub-measure weights by assigning a higher weight to one sub-measure while keeping the other weights equal to each other. In total 3 scenarios we used to perform the sensitivity analysis experiments. In Table 13 the average inputs to the FIS for the financial & economic category of readiness is shown. Then Table 14 presents the various scenarios we used to conduct the sensitivity analysis experiments. For example, in Scenario 1 a weight of 0.6 was assigned to 'clear economic benefits & financial feasibility of implementing circular supply chain' while a weight of 0.2 was assigned to the other two sub-measures 'Access to funding and support from financial institutions specifically for investment in sustainable business practices' and 'raw material price inflation (increase)' respectively. Then the FIS was altered in MATLAB in line with these changes in weights and rule base. The same readiness sub-measure scores from Table 13 were again used as inputs to the FIS. We then conducted Scenarios 2 and 3 in a similar fashion as illustrated in Table 14.

The results of the sensitivity analysis from all three scenarios are shown in Table 15 and these can be examined to determine if the FIS model is working. For instance, in Scenario 1 we would expect to see only a slight increase in the financial & economic score as we changed the weight of sub-measure 1 slightly from 0.571 to 0.6 and likewise for sub-measure 3 from 0.143 to 0.2. The results confirm this as in Table 15 we observe the score slightly increasing from 32.1 with the initial weights to 34.9 with the altered weights. In another experiment, Scenario 3, we would expect the score to increase significantly as the change in weight is a

Table 15 Sensitivity analysis results for each scenario

Scenario	Financial & Economic Score
Initial weight	32.1
Scenario 1	34.9
Scenario 2	36.5
Scenario 3	53.2

significant increase from 0.143 to 0.6 and this sub-measure having a high input of 2.74. When this scenario is implemented in the FIS through MATLAB this is observed as the financial & economic score significantly increases from 32.1 with the initial weights to 53.2 when the highest weight of 0.6 is assigned to the sub-measure, as expected. From these three scenarios and sensitivity analysis experiments it can be concluded that the FIS model is sensitive to changes in weights of the sub-measures and therefore is working properly which presents reliable results.

5 Managerial and policy implications

In this section, the relevant managerial and policy implications arising from the empirical study conducted for this research are discussed. Having conducted the industry readiness measurement and identified areas in which the Irish dairy industry needs to improve, this study provides several managerial and policy recommendations with particular focus on areas classified as moderate or weak in terms or readiness level. Table 16 provide a summary of the main points for each category in terms of the implications. In order to develop these policy recommendations, the relevant literature on CSC implementation was revisited along with additional policy documents and expert opinions. There are a few documents that were particularly important in the development of these policy recommendations provided here including: The Circular Economy in Ireland (OECD, 2022), Whole of Government Circular Economy Strategy 2022–2023 (Government of Ireland, 2022), Waste Action Plan for A Circular Economy 2020–2025 (Government of Ireland, 2020), and Sustainable Dairy in Europe: Safeguarding our Resources (National Dairy Council, 2019).

5.1 Financial and economic aspects

At present the current level of funding available to the dairy sector for investment in CSC implementation and practices is insufficient. Policymakers need to ensure that adequate levels of funding from various sources are in place to support CE related projects such as CSC implementation (Kühl et al., 2022; Mangla et al., 2018a). First, assistance needs to be provided to local authorities to support and scale up small-scale circular initiatives by setting up local funding schemes. The dairy industry could leverage EU funds such as LIFE, Horizon Europe, Invest EU, INTERREG, and Emission Trading System Innovation fund (OECD, 2022). The dairy industry and policymakers should also look to alternative funding methods as a means of fostering private investments in CSC implementation projects. Alternative examples of funding include crowdfunding, leasing, equity participation, grants, loan guarantees, green bonds and specific loans for circular economy projects and businesses (Government of Ireland, 2022; OECD, 2022).

Table 16 Summary of the main points and implications from each category of readiness

Category	Main points
Financial & Economic	Ensure adequate funding from various sources for circular supply chain (CSC) implementation Support and scale up small-scale circular initiatives through local funding schemes Leverage EU funds such as LIFE, Horizon Europe, Invest EU, INTERREG, and Emission Trading System Innovation fund Explore alternative funding methods (crowdfunding, leasing, equity participation, grants, etc.) to foster private investments in CSC projects Highlight potential savings from transitioning to circular economy (CE) for manufacturing organisations
Technology & Infrastructure	Redesign products for reuse, recycling, and remanufacturing Shift focus from functional packaging to circular design Encourage innovation efforts and collaboration among dairy industry manufacturers Develop smart infrastructure and tracking technology for better reuse and recycling of materials Explore the adoption of blockchain and digital ledger technologies for transparency and traceability in the supply chain
Government Policy	Establish a legislative framework to support the transition to the CE Develop a regulatory framework with specific resource consumption targets Focus on collaborative consumption models and innovative services Invite new stakeholders as advisors (universities, trade associations, local authorities) Address regulatory gaps and improve by-product processes notification Enhance data-informed policymaking through improved data collection and standardisation
Market & Social	Raise awareness of the advantages of CSC among organisations and consumers Highlight potential savings from CSC implementation Develop life-term service relationships with consumers Launch targeted communication campaigns to raise awareness of the CE Develop a circular economy brand and utilise existing labels to incentivise CE adoption Promote transparency and awareness by facilitating access to local CE businesses
Supply Chain & Operations	Obtain real-time and accurate data through sensors and information sharing Restructure the supply chain for better product and information flows Integrate reuse, recycling, and remanufacturing through coordination among supply chain actors Capitalise on data-driven applications and big data analytics for increased information flow and sharing capabilities

Table 16 (continued)

Category	Main points
Environmental	Expand the use of fiscal tools and economic instruments to incentivise CSC adoption Review and adjust environmental subsidies to promote material productivity and reuse Address stakeholders' environmental awareness through a national CE online platform Regularly monitor progress towards CE transition and communicate results to enhance buy-in
Management, Organisation & Human Capital	Address the need for increased numbers of skilled workers in circular manufacturing operations Provide formalised training through government-subsidised courses and lifelong learning programs Strengthen circularity and CE principles in higher education programs Emphasise sustainability in primary and secondary education curricula Foster intra-organisational learning and collaboration among dairy organisations

The extent to which managers in any industry are willing to implement CSC is directly affected by the perceived economic benefits or lack of in the case of Ireland (Agyemang et al., 2019). There is insufficient economic incentives to change behaviour among businesses towards waste prevention and circular models (Kühl et al., 2022). It has also been highlighted that private investment is essential though circular business projects which are not currently attracting venture capital in Ireland, likely due to investors perceiving the CE as risky (OECD, 2022). The government need to highlight the potential savings that can be achieved specifically by manufacturing organisations that proactively adapt their strategy from linear to circular (Mangla et al., 2018a).

5.2 Technology and infrastructure

Most of the Irish dairy industry's products are for the B2B market and are exported globally for use in the production of other consumable products (Hennessy & Donnellan, 2018). For this reason, the focus in terms of product and packaging design is on functionality as the priority is keeping the products safe & dry during transportation by keeping out moisture. The industry now needs to expand its narrow focus on solely functional packaging and redesign its products for reuse, recycling and remanufacturing (Abdul-Rashid et al., 2017; Murali et al., 2019). This problem is inherent in the Waste Action Plan for a Circular Economy which places too much emphasis on recycling and not enough focus on preventing, redesigning and reuse of materials. The government can change and support this by rejuvenating the policies that exist to promote circular design and circular processes which incorporate second-hand material across sectors (OECD, 2022).

Innovative solutions play a key role in implementing the CE at a supply chain level. For example, Carbery Group has already begun to do so by developing the 'Carbery process' which is their way of converting whey permeate into bioethanol. The organisation now produces 12 million litres of bioethanol which is used in the drinks sector and increasingly as a biofuel due to its low carbon intensity (Sustainable Cork Programme, 2020). Other dairy industry manufacturers also need to increase their innovation efforts to tackle some of their more intricate waste issues. The government could encourage this by facilitating local and regional industrial symbiosis and dairy processor clusters which accelerates intra-organisational learning and collaboration.

The development of smart infrastructure and tracking technology would enable greater reuse, recycling and remanufacturing of materials (Mangla et al., 2018a), which could be in the form of by-products in the dairy industry. In addition to modern recovery infrastructure, the dairy industry highlights the need to establish anaerobic digestion chambers to deal with their processing wastes in a CE. Anaerobic digestion is where feedstocks and biowastes are inserted into a large, sealed airless container. In this oxygen free environment, bacteria will produce biogas and digestate through a natural process (Teagasc, 2019). Biogas can then be used to generate heat/electricity or both (Sustainable Cork Programme, 2020). Carbery Group invested in Ireland's first anaerobic digestor which they use to convert stillage or any liquid waste from the bioethanol process which fulfils 9% of the manufacturing sites steam requirements, offsetting significant GHG emissions by doing so (Sustainable Cork Programme, 2020). Similarly, Dairygold, one of Ireland's largest manufacturers treats approximately 27,000 kg of wastewater per day from powder milk and cheese production in this way (Sustainable Cork Programme, 2020). This is converted into energy rich biogas which is then used for heating and a small amount is transferred to renewable energy. This has saved the organisation €871,234 while offsetting 5822 tonnes of CO2 over 29 months and this highlights the need for the entire industry to follow suit (Sustainable Cork Programme, 2020).

Tracking technology for products is often only utilised when requested by purchasers (Neessen et al., 2021). For example, when supplying an infant formula manufacturer, dairy processors are required to track and trace their products throughout their process and the supply chain (Hennessy & Donnellan, 2018). There are opportunities for the industry to upscale this tracking technology which will prove beneficial for product and packaging recovery. Meanwhile, both industry and policymakers should explore the potential benefits of adopting blockchain and digital ledger technologies to improve the overall transparency and traceability in the supply chain which could result in the identification of significant product recovery opportunities (Kazancoglu et al., 2021).

5.3 Government policy

There is currently no legislative framework for the CE in Ireland to support the transition from a linear to the CE, however, the CE bill is expected towards 2023 (Government of Ireland, 2020). A strategic regulatory framework with specific resource consumption targets is essential for the design and implementation of CE policies (Ghosh et al., 2023; Paul et al., 2022). At present, Ireland's policy in relation to the CE has placed too much focus on waste management and not enough attention has been given to developing a collaborative consumption model which generates innovative services to shift from 'owner of products' to 'access to products' among consumers, suppliers and retailers (Neessen et al., 2021; OECD, 2022). To successfully integrate the CE into Ireland's enterprise strategy as a key driver of employment, sustainability and resilience, new stakeholders need to be invited to act as advisors such as universities, trade associations, and local authorities (OECD, 2022).

Regulatory gaps with by-product processes notification are currently hindering the Irish dairy industry's capability to utilise the abundance of by-products that are being produced throughout the SC (OECD, 2022). By-product notification processes enable certain substances to be considered a by-product, which in other words is a secondary product produced as a result of a manufacturing process (Lee et al., 2021) There is a lack of clarity and timeliness in by-product notification processes and this alongside other lengthy regulatory, licencing, and standardisation processes are hindering CSC implementation, practices, and investment (Government of Ireland, 2020).

Data-informed policymaking needs to be improved urgently to facilitate the CE transition. CE data in Ireland at a national level is currently limited to waste data—which itself is fragmented (Government of Ireland, 2022). Moreover, their lengthy time-lapse for data publication is preventing real-time, data-driven policymaking while the reliability of new indicators is insufficient to support informed decisions (OECD, 2022). The food waste stream to which the Irish dairy SC belongs does not currently have a standardised measurement methodology across waste sources. However, policymakers can implement data collection to facilitate CE policy making by: feeding data collection into a national CE information system, enhancing waste-related data collection to include environmental, economic and social data, and collecting locally disaggregated and sectoral data (OECD, 2022).

5.4 Market and social aspects

The main issue that needs to be addressed in terms of market & social readiness is a lack of awareness on the advantages of a CSC among organisations and consumers. This lack of awareness hinders CSC implementation and often stems from organisations viewing circular operations as an additional financial strain that will impact on their competitiveness (Agyemang et al., 2019; Mangla et al., 2018a). There have been efforts in Ireland to close this awareness gap on CE practices such as CIRCULÉIRE, IBEC CE workshops for businesses, MyWaste.ie for consumers and bioeconomy week for farmers. However, these initiatives have been insufficient as there is still limited consensus in Ireland on the costs and benefits of the CE, with only 51% of businesses and only 1 in 4 adult consumers understanding what exactly is meant by the CE (OECD, 2022).

Dairy industry organisations should take a proactive approach to addressing their wastes and raising awareness among their partners of the potential savings to be obtained from CSC. Dairy manufacturers can act as enabler for CSC by developing life term service relationships with consumers as an alternative to one-off transactions (Mangla et al., 2018a). Meanwhile, the government should consider targeted communication campaigns to raise awareness and promote the CE to both businesses and consumers (OECD, 2022). A business communication campaign should focus on the economic benefits of a CSC, guidance and toolkits for applying CE principles to industry, and information on applications for CE related funding. The consumer communication campaign could then focus on economic and environmental benefits of CSC, a dashboard for tracking progress of CE targets, and how to find local CE businesses to enhance transparency and awareness. The government have also outlined their intentions to develop a circular economy brand to raise awareness and build trust in the CE by the end of 2022 (OECD, 2022) and this will be supported by the use of existing labels such as origin green in the dairy industry to incentivise organisations to produce and distribute in line with CE principles.

5.5 Supply chain and operations

The Irish Dairy SC needs to realise the importance of obtaining real-time and accurate data to support their sustainability efforts, reduce food losses and survive in an increasingly competitive market (Kazancoglu et al., 2021). Timely data collection is vital for the dairy supply chain due to the perishable nature and short shelf life of the associated dairy products (Kazancoglu et al., 2021). There are a few options available to the industry for improving the accuracy and flow of real-time data. First, sensors could be implemented to collect data along the supply chain with radio frequency identification systems, cameras, or even temperature gauges placed in vehicles for example (Mangla et al., 2018a). Second, the dairy SC could be restructured to allow for better product and information flows in both forward and reverse directions. This increase in visibility of the entire SC would allow for data to be collected on the by-products that are being generated throughout various processes taking place (Srai & Lorentz, 2019). The integration of reuse, recycling, and remanufacturing in production strategies could then be realised by developing coordination among SC actors in terms of communication and information sharing (Mangla et al., 2018a). In addition, the Irish dairy SC needs to capitalise on data-driven applications for capturing and understanding data generated across the entire SC. Big data is therefore one of these solutions. Big data analytics is a powerful industry 4.0 tool which is capable of coping with large volumes of data in real-time and it is this data which helps CSC implementation by increasing information flow and sharing capabilities (Kazancoglu et al., 2021).

5.6 Environmental aspects

The department of the environment, climate and communications need to expand its use of fiscal tools and economic instruments to incentivise the adoption of CSC practices such as price-based tools, tradeable permits, and extended producer responsibility schemes (Government of Ireland, 2022; Li et al., 2021). The current environmental-related taxes need to be built upon by increasing the existing landfill levy and carbon tax along with expanding the scope of products and materials that it applies to. This drives organisations to seek cleaner solutions in response to certain products becoming more expensive and hence investment in sustainable products and technologies is made more attractive (OECD, 2022).

There is a need for policymakers to review and adjust environmental subsidies as the presence of any subsidies which are promoting the exploitation of resources undermines the efforts of the dairy industry to implement CSC (Govindan & Hasanagic, 2018). A review would involve identifying and removing environmentally harmful subsidies and replacing them with environmentally motivated subsidies which will encourage increased material productivity, reuse, recycling and by-product utilisation (OECD, 2022).

The lack of stakeholders' environmental awareness can also be a hindering factor for the implementation of CSC (Agyemang et al., 2019; Bhatia et al., 2020; Govindan & Hasanagic, 2018). The government of Ireland are keen to develop a national CE online platform which would include; stakeholder profiles, CE projects, initiatives and news, supportive material, directory for finding local CE businesses, and a dashboard showing the progress towards predefined CE targets (Government of Ireland, 2022). According to OECD (2022), it is important to regularly monitor the progress made towards the CE transition and the impact it is having. Tracking such progress can help identify any adjustments that need to be made, and communicate results to stakeholders and society to enhance buy-in.

5.7 Management, organisation and human capital

One of the most pressing concerns that needs to be addressed for the transition to a CE and the implementation of CSC to be successful in the Irish dairy industry is the need for increased numbers of skilled workers in circular manufacturing operations (Mangla et al., 2018a). It appears that training for managers is run internally in each organisation, usually facilitated by the sustainability manager in dairy manufacturing companies. There is an opportunity for more formalised training at higher education institutions through government-subsidised training courses. There is also an opportunity for intra-organisational learning to take place between dairy organisations which could be facilitated by the likes of BordBia or IBEC's dairy industry Ireland association (Hennessy & Donnellan, 2018).

Policymakers in Ireland can support the development of workers, managers, and society's knowledge of CE and CSC management in a few ways. First, CE training and toolkits specifically for workers and businesses should be designed and developed (Bhatia & Kumar Srivastava, 2019; Govindan & Hasanagic, 2018; OECD, 2022). Second, education institutions should be supported to develop lifelong learning programmes with a focus on CE skills such as problem-solving, resource management, and systems thinking skills (OECD, 2022). Finally, the presence of circularity and CE principles in higher education programmes needs to be strengthened especially in the disciplines of SC management, industrial design, and engineering (Government of Ireland, 2022; OECD, 2022). Meanwhile, a greater emphasis on sustainability in primary and secondary education curricula will facilitate sustainable development education and a greater awareness of the benefits associated with the CE (OECD, 2022).

5.8 The impact of COVID-19 on industry readiness for CSC implementation

The global outbreak of the COVID-19 pandemic triggered unprecedented disruptions across industries (Isik & Aktürk, 2022). In the context of the Irish dairy industry's readiness for CSC implementation, the pandemic has introduced significant challenges and opportunities that warrant careful consideration. For example, lockdowns, travel restrictions, and workforce limitations imposed during the pandemic led to SC interruptions, highlighting the need for SC agility (Pujawan & Bah, 2022). Companies relying heavily on linear SC models faced difficulties in sourcing raw materials, distributing products, and maintaining operational continuity (Moosavi et al., 2022). These disruptions have emphasised the importance of CE implementation, as CSCs are inherently more capable of mitigating disruptions by promoting localised sourcing and resource sharing (Yu et al., 2021).

COVID-19 also prompted a shift in consumer awareness, with a heightened focus on health, safety, and sustainability (Yu et al., 2021). As consumers become more conscious of the origin and environmental impact of products, the dairy industry's adoption of circular practices aligns with changing consumer preferences. Companies that demonstrate a commitment to sustainable practices, including CSC implementation, are likely to resonate more with environmentally conscious consumers and enhance their market position (Moosavi et al., 2022; Yu et al., 2021). In addition, governments responded to the pandemic with various regulatory measures aimed at safeguarding public health and maintaining economic stability (Shahed et al., 2021). These interventions may have implications for CSC implementation, such as incentivising sustainable practices or promoting local production (Yu et al., 2021). The Irish dairy industry should explore opportunities to align its CSC strategies with evolving regulatory landscapes, thereby leveraging governmental support for enhanced readiness (Isik & Aktürk, 2022).

As such, the COVID-19 pandemic has added factors which could influence the readiness of the Irish dairy industry for CSC implementation. While it has posed challenges through SC disruptions and resource scarcity, it has also highlighted the need for resilient, adaptable, and sustainable business models (Shahed et al., 2021; Yu et al., 2021). By recognising these impacts and aligning CSC strategies with the evolving post-pandemic landscape, the Irish dairy industry could enhance its readiness and position itself as a leader in sustainable dairy production (Bordbia, 2021).

6 Conclusion

Although several studies exist in the literature on CSC, to date there is a lack of a study which has developed a comprehensive framework for measuring the readiness of the dairy industry for CSC implementation. Some researchers found that not all industries or organisations are successful in their CSC implementation efforts which highlights the need to perform such a readiness measurement before any investment is made (Ada et al., 2021; Kayikci et al., 2022; Kazancoglu et al., 2020; Lahane & Kant, 2021; Ozkan-Ozen et al., 2020). To address this gap in the literature, this study developed a proposed comprehensive framework capable of performing an industry readiness measurement using BWM and FIS. The applicability of this framework was then demonstrated by collecting empirical data from professionals in the Irish Dairy industry. The two main objectives of this study were achieved as follows. Firstly, a comprehensive set of measures and sub-measures was compiled following a review of the literature and a Delphi method approach. These measures and sub-measures were then assigned a weight using the BWM. Secondly, a novel weighted FIS was constructed and utilised to measure the readiness of the Irish Dairy industry using data collected from 34 SC professionals and executives with at least 5 years of experience. The findings from the study suggest that technology & infrastructure and financial & economic categories are the most important measures of readiness from their respective weightings. The empirical study which revealed a total industry score of 44.31 indicates the Irish dairy industry has a moderate level of readiness when mapped onto the CSC readiness scale and therefore must obtain more of the necessary prerequisites to ensure successful CSC implementation.

6.1 Theoretical implications

This study has several theoretical and practical contributions to knowledge. Theoretically, the study contributes to knowledge in the CSC domain by providing a comprehensive set of measures and sub-measures which have been discussed and explained to further understanding of their relevance for successful implementation of CSC. The development of a novel approach for readiness measurement using BWM–FIS adds to the literature on decision making techniques and demonstrates the ability of such methods to deal with tangible and intangible measures along with providing a new application for the BWM–FIS respectively.

6.2 Practical implications

In terms of practical contributions, the Irish dairy industry will benefit from a practical readiness measurement index which they can use at various points in time to track their progress towards CSC implementation. Secondly, managers and policymakers now have a greater understanding of where they stand in terms of being ready to implement CSC facilitated by the use of the accompanying CSC readiness scale from this study. Finally, the implications of this study for managers and policymakers are provided along with recommendations on how the Irish dairy industry could improve in each of the seven areas of readiness.

6.3 Limitations and future research

It is important to recognise that in a similar manner to all research, this study has certain limitations. Identifying these limitations and suggesting how they could be mitigated in the future allows for the suggestion of future research, and an opportunity to build upon the work presented in this study. First, this empirical study focused on the dairy industry in the Republic of Ireland. Therefore, all data collected in the form of opinions from experts is held the context of the Irish dairy industry's unique characteristics. As such, the results and recommendations that arose from them may not be applicable to dairy industries in other regions. It may be beneficial for future studies to apply the proposed CSC readiness measurement framework to dairy sectors in other regions such as outside the EU or developing economies, and then compare the results with this research.

Second, there has been a limited number of studies which identified readiness measures and sub-measures which could be used to measure the readiness of an industry to implement a CSC. Therefore, to gather the readiness measures that would form part of the framework, literature on CSF's, barriers, and enablers of CSC had to be considered. In future, more research focused on identifying readiness measures which can be applied to multiple industries would be useful for academics and practitioners seeking to conduct their own novel readiness measurement and expand the framework presented in this study.

Third, when developing the FIS, the number of rules which need to be coded increases exponentially as the number of the sub-measures (input variable) increases. For example, the supply chain & operations category alone required 729 rules to be coded. In total the proposed FIS in this study requires 1431 rules. This manual coding of rules is both cumbersome and time-consuming. In future studies, neural networks and machine learning techniques could be utilised to reduce the considerable workload and time needed to develop the rule base when coding the FIS.

There is also an opportunity for future research to explore the impact of the COVID-19 pandemic on industry readiness for CSC implementation and how organisations can leverage the government policies that incentivise sustainable practices and encourage local production.

Finally, while this study presents a comprehensive framework for measuring the industry readiness level for CSC implementation, there is an opportunity for future research to expand the framework to include a firm-level analysis. This would enable individual organisations within the dairy sector to identify their specific strengths and weaknesses in terms of CSC readiness. This would enable these organisations pinpoint specific areas within their organisation that need to be addressed for successful CSC implementation to be recognised.

Declarations

Conflict of interest The authors declare no conflict of interest.

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