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Barriers to circular economy adoption are diverse and some are business-model specific: Evidence from the Australian cheese manufacturing sector

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ABSTRACT

Achieving Sustainable Development Goal (SDG) 12.3, aimed at halving food loss and waste by 2030, requires private firms to adopt circular economy practices, which may include different types of circular business models (CBMs). This study examines four interchangeable CBMs—in-house (IH), third party (TP), joint venture (JV), and focal company (FC) models—focusing on the Australian cheese manufacturing sector and its liquid by-product, 'whey'. Through semi-structured interviews with 43 participants from 42 firms, we analysed how barriers differ across CBMs. Some barriers are consistent across all CBMs, such as economies of scale and operational costs. Others are absent in one or two CBMs (e.g., capital costs in JV and competing priorities in TP), while some are unique (e.g., low or inconsistent demand in IH, payment expectations in TP, conflicting values or personalities in JV, and upstream product specifications in FC). Findings indicate that while IH models are feasible for all production scales with sufficient time and resources. TP models are suitable for firms with time constraints, provided there is agreement on compensation with the recipient. JV could work for firms lacking volumes or capital but require local collaboration and transparent business plans. Utilising existing infrastructure of firms already repurposing by-products can be effective but requires upstream firms meeting product specifications. By exploring multiple CBM options, the willingness to explore circular economy approaches increases markedly when considering multiple CBMs (79%) versus IH approaches alone (33%). This highlights the necessity for diverse strategies to achieve SDG 12.3, as a one-size-fits-all approach is insufficient. Firms may need to partner with others for repurposing, and those already repurposing can enhance efforts by enabling others to repurpose waste, though multiple pathways also increase potential barriers.

1. Introduction

The global issue of food loss and waste (FLW) has significant economic, environmental, and social impacts (Hanson and Mitchell, 2017; Lade et al., 2020; Reynolds et al., 2015; Zhu et al., 2023). In response, Sustainable Development Goal (SDG) 12.3 aims to halve FLW by 2030, and this target has been adopted by governments and private firms globally (Commonwealth of Australia, 2017; USDA, 2022; WRAP, 2022). Achieving SDG 12.3 will require effort from private stakeholders to engage in different practices to improve the utilisation of resources across a product's lifecycle. This includes practices that advance the circular economy (CE) by reprioritising resource allocations to reduce, reuse, recycle and recover materials across all stages of the product supply chain (Kirchherr et al., 2017). This will take the form of private firms, among other things, investing in machinery, packaging and staff training to reduce avoidable losses or covering additional operational costs to collect, store and transport FLW to another location (e.g., food charity, secondary manufacturer or livestock farm) (Spang et al., 2019). Complementary frameworks such as the Food Waste Hierarchy (Papargyropoulou et al., 2014) offers useful guidance for managing FLW

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and prioritising possible waste management business models (BMs) —circular or otherwise. Despite there being no universal basis to measure and manage FLW, there is consensus that FLW reduction is concerned with the end destination(s) of food and drink material (e.g., animal feed) and that it does not matter which actor facilitates the reallocation (Boiteau and Pingali, 2023; FAO, 2019; Hanson et al., 2016; Spang et al., 2019; UNEP, 2024). Therefore, various BMs exist offering many options for firms to align with SDG 12.3.

In particular, circular business models (CBMs) are gaining attention for their potential to simultaneously achieve economic, environmental, and social outcomes (Velenturf and Purnell, 2021). CBMs encompass a broad range of actions, and involve individual firms and their broader value networks (Geissdoerfer et al., 2018). There have been multiple attempts to frame CBM typologies. Geissdoerfer et al. (2020) identified cycling, extending, intensifying and dematerialising CBMs, while Bocken et al. (2016) proposed there are CBMs that 'slow' (access and performance models, extending product value, classic long life, encourage sufficiency) and 'close' (extending resource value and industrial symbiosis) resource loops. Within the context of reducing FLW this translates to utilising food and drink materials to the highest possible level throughout a product lifecycle under a preference for human food products via waste avoidance, redistributing surplus stock to food charities, or upcycling unavoidable by-products (EPA, 2023) (discussed further in Section 2.1).

Despite the potential benefits many food businesses have yet to explore CBMs to reduce FLW, reducing the likelihood of achieving SDG 12.3. Many previous studies have examined barriers to these, revealing financial, technological, regulatory, and socio-cultural issues that may prevent adoption (de Jesus and Mendonça, 2018; Mehmood et al., 2021). These broad thematic areas are consistently found across multiple studies but the underlying specific issues are unique (Tura et al., 2019). These barriers occur irrespective of the firm size, industry, and customer segment (Guldmann and Huulgaard, 2020). Other studies have suggested addressing barriers to CBM adoption can be achieved via other BM configurations. For example, joint ventures between firms can achieve sufficient scale (Vermunt et al., 2019). Alternatively, some CBMs that address one problem comes with their own challenges. For example, Geissdoerfer et al. (2022) identified that *'circular start-ups'* faced less organisational inertia but higher investment cost barriers compared with those firms that engaged in '*CBM diversifications*' (e.g., joint venture) models. Therefore, exploring different CBM pathways can be a viable option to reduce the barriers to the same outcome (e.g., FLW reduction). However, there is are some important gaps in the available literature to make it clear how BM options affect CE adoption.

Many studies into the barriers to CBM options have not considered BM that solve the same CE problem, challenging our understanding of the specific role CBMs have in overcoming barriers. First, some studies have found generic CE barriers with no comparison across different BMs (Do et al., 2022; Tura et al., 2019). Second, some studies have analysed cases from different sectors (such as agricultural, textiles, chemical processing, energy or automotive), with vastly different technology options (Oghazi and Mostaghel, 2018; Ranta et al., 2018; Salvador et al., 2022), thus confounding any barriers identified. Third, some treat different levels of circularity equally, such as treating anaerobic digestion (recycling) as having equivalency with repurposing into human food products (repurposing) (Donner et al., 2020; Geissdoerfer et al., 2022), which it does not if CE principles are to be properly applied. Lastly, several studies have not considered CBMs that are unable to solve the same CE problem (Ranta et al., 2018), such as FLW being solvable from Vermunt et al.'s (2019) *'resource recovery'* CBM (capturing materials that would otherwise have been discarded) but not the *'product-as-a-service'* leasing arrangement option. This is because lease arrangements – which can be applied to substitute consumption of some products (e.g., clothing or furniture) – cannot work for food, which needs to be physically ingested. There is no direct comparability between the reported barriers and therefore no real understanding how barriers change when interchangeable CBMs are considered. To truly address these issues a sector-level approach is needed (Do et al., 2022; Vermunt et al., 2019); in particular, one that has many technological options available, emphasising high-levels of circularity.

To our knowledge, only one study investigates barriers to interchangeable CBMs—that of Geissdoerfer et al. (2022). They consider three CBM innovations implemented across 21 European firms (across different sectors) including: (1) *'CBM transformation'* (modification of internal processes to achieve circular outcomes); (2) *'Circular start-ups'* (a third-party firm is created to achieve circularity, with an emphasis on incubators and accelerator programs); and (3) *'CBM diversification'* (joint ventures with the initial firm to solve the circular problem). They find that barriers that implemented in-house (n = 3) processes uniquely faced issues with having to deal with pre-existing investments and lack of internal leadership. Start-ups (n = 9) did not have unique barriers, but experienced high investment costs, lack of legislative support, and immature reverse logistics as highly cited issues. The diversification approach (n = 9) had several unique challenges including heterogenous waste streams, lack of experience, technical trade-offs, and competition with linear streams. However, it is important to note this study specifically looks at the barriers from the perspective of firms that have already implemented the CBM. This could be thought as the challenges occurred post-transition, rather than what is stopping firms from starting the transition process (i.e., pre-transition). This targeting of post-transition firms is common in the extant literature (Do et al., 2022; Donner et al., 2021; Guldmann and Huulgaard, 2020; Ranta et al., 2018; Tura et al., 2019; Vermunt et al., 2019). However, it is important to understand from the perspective of pre-transition firms to determine how barriers differ across equally valid approaches that achieve the same outcome (i.e., FLW reduction). This is most obvious in the number of cases observed in each group. Thus, would we have observed greater similarities or differences between CBMs if there were more than three cases that had implemented in-house approaches?

While there are important learnings from Geissdoerfer et al. (2022), we argue that to better compare and understand differences in the barriers to CBMs it is important to achieve an appropriate cross-section of firms, as past research has largely focused on a very few case studies (e.g. less than 10) (Do et al., 2022; Linder and Williander, 2017; Whalen et al., 2018), or specific segments of firms such as multinationals (Ranta et al., 2018) or start-ups (Guldmann and Huulgaard, 2020; Vermunt et al., 2019). This paper therefore builds upon existing CBM literature, particularly those that contribute to cycling unavoidable by-products from food production/manufacturing to specifically examine options that are interchangeable, as opposed to those that contribute to different CE problems. Importantly, we assess CBM options from a pre-transition perspective (i.e., those firms yet to adopt CBM change), as opposed to a more common approach that assesses and learns from those firms that have experienced the challenges of change and are looking back for insights (i.e., those in a post-transition stage). This identifies two important research questions that this study aims to address.

RQ1: Do firms yet to transition perceive different barriers when presented with various pathways to reduce FLW?
RQ2: How might these barriers to change affect circular business model pathway selection and, ultimately, adoption at sectoral levels?

This study uses the case study of the cheese manufacturing (CM) sector in Australia—focusing on the liquid by-product of cheese production called 'whey'—as a basis for exploring barriers to interchangeable CBM options. This particular sector serves as a pertinent case study to explore the issue for several reasons. Firstly, as prioritising higher levels of circularity is a core principle of the CE, there are various technologies to repurpose whey into human food products in addition to other options that are less circular (e.g., animal feed, spraying out to paddocks) (Gregg et al., 2020; Hetherington et al., 2023). Secondly, the significant investment in processing technologies options to whey

repurposing has meant the dairy sector is considered much more advanced compared to other agricultural sectors in relation to dealing with unavoidable by-products, such as the meat industry and beer brewing (Gregg et al., 2020). However, despite its well-developed status, whey accounts for half of all FLW arising from the Australian dairy sector and costs Australian manufacturers AU$578 million each year in management costs (Dairy Australia, 2023a). This means there are persistent barriers to repurposing whey. Moreover, by taking a cross-section of single industry we are able reduce confounding artefacts when exploring patterns between interchangeable CBMs that occur when comparing different sectors. While, there are specific implications to the Australian cheese manufacturing sector arising from this study, there is some broader relevance to other agricultural sectors in Australia, and globally, in relation to the broader themes identified and general patterns across CBMs.

The remainder of this paper is structured as follows: Section 2 outlines the literature that has informed the study's Conceptual Framework. Section 3 provides the Case Study context, and Section 4 details the Methodology. The Results are presented in Section 5, followed by the Discussion in Section 6 and the Conclusion in Section 7.

2. Conceptual framework

2.1. Circular food loss and waste (FLW) management practices

CBMs achieving high circularity rely on FLW management practices that reduce, repurpose, recycle, or recover materials in food systems (Papargyropoulou et al., 2014). A key CE principle is the prioritisation of management practices according to their level of circularity. This study applies this principle to the management practices that are considered desirable. Therefore, where possible, returning FLW to a human food product is the most preferred option.

Prioritising outcomes involves favouring FLW avoidance, followed by repurposing or donation of surplus stock to food banks. Repurposing (also called 'upcycling') is the act of processing FLW (e.g., a by-product) into another co-product intended for human consumption (Aschemann-Witzel et al., 2023b). Despite requiring additional energy, repurposing is favoured over recycling or recovery alternatives as it displaces the need for virgin agricultural products (EPA, 2023). Although the U.S. EPA (2023) consider diverting FLW to animal feed as similar to feeding humans we adopt the position of others (e.g., see Jones et al. (2022)) that maintaining all food and drink material in the human food supply chain drives higher levels of circularity. This is depicted by the black arrow pointing at human food products in the box on the right-hand side of Fig. 1 (adapted from EPA (2023)), which helps us specify the outcomes our BMs should contribute to.

2.2. Types of circular business models (CBMs) for repurposing FLW

The study of BMs is used at different levels to understand the arrangement and interrelation between organisational elements, value propositions, value creation and delivery, and value capturing (Geissdoerfer et al., 2018; Osterwalder and Pigneur, 2010). Within this, CBMs, a form of sustainable business model (Geissdoerfer et al., 2018), cycle, extend, intensify, and/or dematerialise resource and energy loops (Geissdoerfer et al., 2018) to reduce inputs into, and the waste and emission leakage out of, a production system (Bocken et al., 2016) and include firms and their broader network (Whalen, 2020). As such, the term CBM covers a broad range of product types (technical/non-organic vs biological/organic materials) and resources flows (e.g., energy, packaging and other inputs) (Ellen MacArthur Foundation, 2013).

However, due to the biological/perishable nature of FLW, many CBMs are not applicable. Vermunt et al. (2019) explored a range of CBMs, but many are not compatible with all FLW repurposing—for example, a product-as-a-service BM cannot address FLW because, by definition, it must be consumed to avoid becoming waste. Donner et al. (2021) proposed a new CBM typology for agricultural sector that included six CBMs: biogas plants; upcycling entrepreneurships; environmental biorefineries; support structures; agroparks; and agricultural co-operatives. However, we find this framing to be more a description of six individual cases rather than a simplified representation that identifies distinct conceptualisations at a sectoral level. As such, their typology cannot be applied to a set of practices that achieve the same level of resource circularity (e.g., human food products). Bocken et al. (2016) identified CBMs relevant to FLW, particularly 'extending resource value' (exploiting residual value of waste materials) and 'industrial symbiosis' (IS) (using by-products as inputs for another process, especially as part of collaborations of nearby firms), with the latter being a sub-type of the former (Whalen, 2020). Geissdoerfer et al. (2020) further proposed four CBM strategies, but only 'cycling' (reuse, remanufacturing, and recycling) applies to FLW, overlapping with extending resource value. Multiple CBMs classifications can occur concurrently and all include elements that extend beyond a firm's operational boundaries (Geissdoerfer et al., 2022), emphasising the important role IS will likely have (Neves et al., 2020).

This study expands the four CBMs outlined by Geissdoerfer et al. (2020) (i.e., CBM transformation, circular start-up, CBM diversification, and CBM acquisition) but notably takes a pre-transition perspective

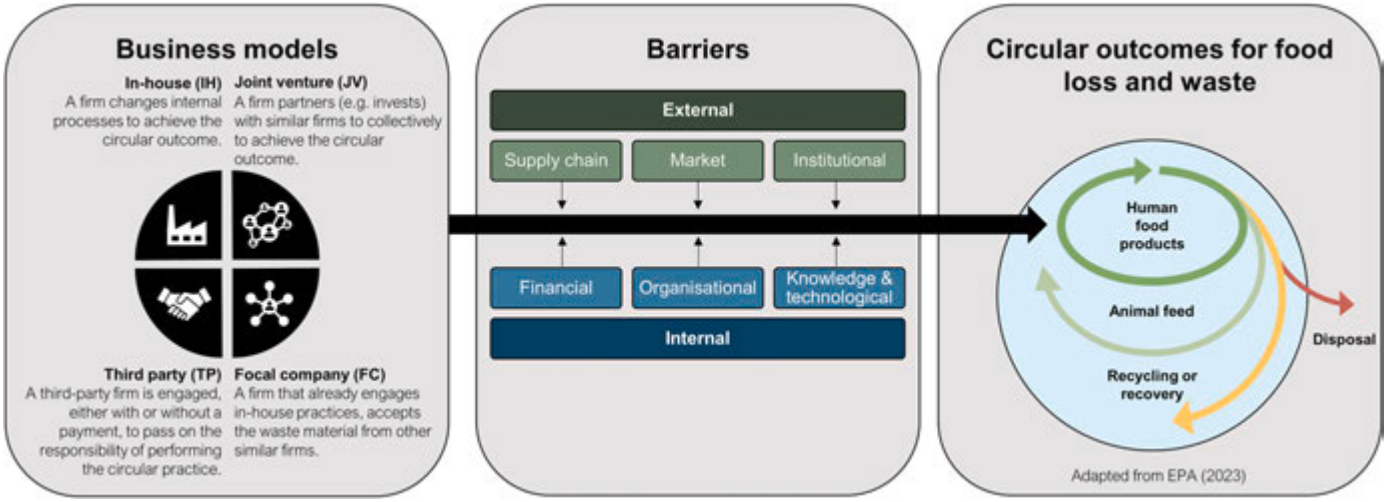

Fig. 1. Conceptual framework for barriers to circular business models.

rather than the post-transition approach in their study to better reflect participants and targeted stakeholders. We consider four types of CBMs in this study: (1) in-house (IH); (2) third parties (TP); (3) joint ventures (JV); and (4) focal companies (FC), each of which is defined below.

2.2.1. In-house (IH) CBM

An IH model refers to processes that occur within a firms' operational control and lead to FLW being maintained as a human food product. It is a common BM, and perhaps the default when studying the adoption of the CE practices. It usually requires investment in infrastructure and human resources in order to produce and market subsequent products. It potentially has high reward but also has a potentially high cost and diverts company resources away from other priorities. This is most similar to the *transform* CBM (Geissdoerfer et al., 2020).

2.2.2. Third party (TP) CBM

Engaging TP arrangements refers to selling the by-product to another firm or gifting it at no (or very low) cost. This approach has the potential to remove some of the responsibility, costs and any resultant benefits from the firm that generates the by-product depending on the specific arrangements between the parties. For example, if the resource stream is of sufficient value the recipient firm might be willing to cover the transportation costs and/or the capital costs associated with collecting and storing the by-product it is collected. It is also feasible, say, for resource streams with relatively low value, the recipient firm would expect the waste-generating firm to cover (some of) these costs. A form of IS, the TP-CBM is similar to the *circular start-up* model (Geissdoerfer et al., 2020), but also includes established firms that can perform the circular processes. Thus, it is similar to Whalen's et al. (2018) *gap exploiter*.

2.2.3. Joint venture (JV) CBM

JVs involve business agreements between two or more stand-alone firms. These firms agree to one or more of the following arrangements: shared investment in infrastructure; shared ongoing operational expenses; shared distribution of revenues; shared liabilities; shared or outsourced management or responsibilities; and/or shared marketing. This is a common practice between firms and involves the agreed allotment of operational aspects (e.g., production, marketing, and distribution). The JV model, which can be considered a form of IS, is closely aligned with the *diversification* CBM (Geissdoerfer et al., 2020) and may include, but not limited to, cooperative structures (Donner et al., 2020).

2.2.4. Focal company (FC) CBM

Within the context of this study a FC is a firm that has already engaged in IH management practices (e.g., repurposing by-products). Such firms have, in theory, the capacity to accept similar by-product resources from other nearby firms to increase their throughput and reduce total processing marginal costs. From a sectoral perspective, this approach is attractive because it may require relatively limited investment compared to establishing new processing sites. It provides space for, say, larger firms to have a sectoral leadership role, which may be appealing for stakeholders (e.g., customers, shareholders). However, it requires the FC to be willing to accept by-product streams of other (potentially competing) firms. Although this approach requires a firm to be engaged in an IH-CBM, it has IS elements as it requires the collaboration of firms. Therefore, the FC-CBM is a distinct, albeit sub-type, of the IH-CBM. The FC model has been superficially discussed in the literature but there is little empirical evidence regarding barriers to adoption (Donner and de Vries, 2023; Pohlmann et al., 2020). Mirroring the *acquisition* CBM (Geissdoerfer et al., 2020), FC models focus on leveraging circular outcomes for other firms.

These four CBMs have overlapping concepts. The FC-CBM is an extension of the IH-CBM as it relies on a firm that has already engaged in internal management practices but is distinct subset due to the interconnectedness with external firms. The FC-CBM will be the recipient of a TP-CBM. Further, a JV-CBM *could* be a FC for firms not formally part of the partnership. For the purposes of this study, these overlaps do not impede our ability to distinguish between the barriers that each of these present. That is because a firm can be asked what is stopping them from processing it IH why they do not engage TPs, or start a JV. In the case of a FC, this was only discussed with those firms already in engaged in IH, because it did not make sense to ask a waste generating firm why they were not accepting the by-product of others, when they had not engaged in practices that dealt with their own FLW. Collectively, these four CBMs offer tangible options for firms generating FLW and will be used in our analysis of barriers to the CE, as displayed on the left-hand side of Fig. 1.

2.3. Types of barriers

As shown in Fig. 1, barriers form the connection between business model options and pathways toward effective waste reduction in line with SDG 12.3—in other words, the issues that may provide a barrier to adoption. An initial barrier to adopting any new technology, regardless of the business model, is having an awareness of its existence. This is different to having a detailed understanding of the technical understanding of how the technology works. The former is referred to as 'knowledge-awareness' (Rogers, 2003). Therefore, we first assess the level of awareness of technology options among stakeholders. Once awareness of the practice exists there are a range of socio-economic factors pertinent to the decision-making unit, and factors related to the new practice that affect the decision to adopt (Rogers, 2003). Some of these factors can act as barriers to adoption and may occur at different levels including within an organisation, across value chains, or at the market- or institutional-level. However, some research indicates firm characteristics such as size, industry and customer segment (business-to-business vs business-to-consumer) had no observable differences on the types of barriers encountered (Guldmann and Huulgaard, 2020).

The subject of barriers to the CE and CBMs has a growing body of evidence to draw upon, including multiple systematic literature reviews (de Jesus and Mendonça, 2018; Mehmood et al., 2021). Notably, these studies have analysed these barriers according to a range of higher level themes that can be considered internal or external to the firm (Hina et al., 2022). This study draws upon these previous studies, and in particular Vermunt et al. (2019) approach to organising and categorising barriers that are identified as part of their study.

Internal barriers include those that factors within a firm that inhibit capacity to engage in the management practice including: (1) *financial*—such as lack of financial resources, capital costs, operational costs (e.g., collection and segregation of components), unclear financial business case; (2) *organisational*—administrative burden, reverse logistics, complex management and planning processes; or (3) *knowledge and technological*—lack of technical know-how and expertise, lack of information/data, ability to deliver high quality products, design challenges to create durable products.

External barriers are those outside of the firm's control and relate to: (4) *supply chain*—lack of partners, higher dependence on external parties, lack of information exchange between supply chain actors, conflicting interests between actors in the supply chain, lack of consideration on circular design from supply chain actors, bad re-use practices/reluctance of third parties; (5) *market*—low virgin material prices, lack of consumer interest/non-acceptance of CBMs, resistance from stakeholders with vested interests in the linear economy; and (6) *institutional*—ineffective recycling policies, incentives that promote material consumption above services, such as V.A.T. (value-added tax), accounting rules creating disincentives, lack of standards and guidelines, and lack of awareness and sense of urgency within society.

These categories and more detailed issues represent a comprehensive analysis of the literature (Vermunt et al., 2019), which is further complemented by the findings of others to ensure consistency with other studies (Do et al., 2022; Donner et al., 2021; Geissdoerfer et al., 2022; Guldmann and Huulgaard, 2020; Ranta et al., 2018; Tura et al., 2019). We also acknowledge that a barrier to adoption can be perceived as

being present, without it actually being present, complicating matters. This is because *'adoption is based on subjective perceptions or expectations rather than on objective truth'* (Pannell et al., 2006, p.1408). We will come back to this in the Discussion section.

3. Case study overview

3.1. Overview of whey challenges and specific focus of repurposing practices

Whey is the liquid by-product of cheese manufacturing. It comprises approximately 50% of the nutrients and between 75 and 90% of total mass from raw milk depending on the type of cheese being manufactured (Tsermoula et al., 2021). While whey is also generated from yoghurt, this study is singularly focused on cheese whey.

There are many options for utilising whey within the CE ranging from repurposing to human food products, feeding it to livestock, using it as a source of nutrients for pasture via composting or irrigation, or disposal (e.g., dumping to sewerage) (Hetherington et al., 2023). There are several opportunities via various technologies for repurposing whey into human food products. These include manufacturing powdered products (e.g., whey protein concentrates), other cheeses (ricotta or brown whey cheeses), fermented beverages (kombucha-style drinks or alcohol), non-fermented beverages (e.g., 'Rivella' in Switzerland), confectionaries, and several niche options (e.g., cooking stock or as a cocktail ingredient) (Dairy Australia, 2023a; Smithers, 2008). While practices such as feeding whey to livestock or using as feedstock for anaerobic digestion are well established for managing whey, they are not considered in the present study as other more, more preferable options exist—i.e., repurposing into human food products.

3.2. Overview of the Australian cheese manufacturing sector

In Australia, 43% of national milk supply (8.1 billion litres each year) contributes to cheese production (Dairy Australia, 2023b). At the time of the study there were 132 firms manufacturing cheese products including from cow, goat, sheep, and camel milk. The industry is characterised by a few large manufacturers (2.1% of firms) and many small manufacturers (89.4%) that are mainly concentrated in the south-east of Australia (see Fig. 2). These firms exhibit diverse business configurations (vertical or horizontal integration), product mixes (exclusive cheese production to a broader array of dairy and non-dairy products) and complex inter-firm relationships (see: https://begagroup.com.au/student-resources/; and https://www.saputodairyaustralia.com.au/en/our-products/joint-ventures).

The global whey protein market was estimated to be US$10.9 billion in 2022 and is expected to experience a 7.9% compounded annual growth rate between 2022 and 2027 (Technavio, 2023). In the 2022-23 financial year, Australian manufacturers produced 58 kilotonnes (kt) of whey powder, with half exported to Asia (Dairy Australia, 2023b) and mainly used in food manufacturing including ice cream, baked goods, infant formula, and health supplements such as Lactoferrin (Fahey, 2023). Major Australian manufacturers (e.g., Bega Group, Saputo Dairy Australia, Fonterra Co-op Group), and mid-scale firms (e.g., Beston Global Food Company) produce whey powdered products such as whole whey powder, concentrates, and protein isolates. There is also a growing market for whey-based alcohol such as vodka and beer, produced by small artisanal distilleries (e.g., Hartshorn in Tasmania) and large-scale producers (e.g., Asahi-owned "Vodka O″ in Melbourne). At the time of this study, consumers are able to buy alcoholic products derived from cow, sheep, goat and camel whey at major retail outlets. Despite these opportunities, whey is still recognised as an underutilised resource by the peak dairy industry body, Dairy Australia, which recently published a commitment to SDG12.3 (Dairy Australia, 2023a). This is because whey accounts for half of the FLW in the Australian dairy sector and is costs manufacturers AU$578 million each year.

4. Method

4.1. Data collection approach

This study explores perceived barriers across various CBMs, an emerging topic in the literature. As this study explores a new framing of CBMs and there are complexities regarding CE practice change (e.g., levels of circularity and different business models configuration options), the methodology needs flexibility to ensure in-depth and nuanced findings where future (ex-ante) pathways are unclear and based on individual business requirements. Although mixed-method approaches combining interviews and surveys are valuable, the small population size (132 firms) and the typical 36% response rate from private firms (Baruch and Holtom, 2008) suggested no additional benefits from a follow-up survey or model analysis of the findings (e.g., econometrics)—at this stage of the research. Instead, seeking a deeper understanding of business CBM options and what may incentivise change across multiple firms resulted in the selection of semi-structured to gather systematic yet explorative data through probing and clarification of responses (Wilson, 2014). Following these interviews thematic analysis was used to identify, summarise, and collate participant responses that are expected to provide comprehensive insights based on all their responses (Braun and Clarke, 2006), which structured quantitative approaches (e.g., surveys) may not allow. Overall, variability amongst sample participants will also be low—even at a high participation rate given low total industry firm numbers—limiting quantitative analysis and supporting the selection of quantitative assessment at this stage.

The interview guide was development based on reviewal of relevant literature and industry reports, pre-testing with candidate businesses, and consultation with experts and industry stakeholders. Interview topics included business characteristics, FLW management (including whey), and factors influencing decision-making regarding whey management. See Fig. S1 in Supplementary Material for specific questions. The study was approved by the University of Adelaide's Human Research Ethics Committee (approval number: H-2022-206).

4.2. Participant selection, sampling and recruitment

There are two aspects affecting the participant selection and recruitment. Firstly, to ensure consistency of views we sought to collect detailed and generalisable information (Palinkas et al., 2015). As firms' organisational structures often differ, the responsibility of whey management could fall across different portfolios of the business such as Production, Operations, or Environment Managers. Therefore, individual's that are '*actively involved in the decision-making process of whey*' were targeted. Secondly, when seeking responses that involve diversity and depth (i.e., rich detail) purposive sampling is a common and appropriate method for interview-based research (Knott et al., 2022). In this context, production scale (tonnes p.a. of finished cheese products) is a major factor that determines the feasibility of different management practices (Juliano et al., 2017). Additionally, in Australia, state governments have a significant role in regulatory oversight regarding food manufacturing including food safety and environmental regulations. A purposive recruitment approach (Palinkas et al., 2015) was thus used to ensure the sample captured a diversity of views based on production scale and state jurisdiction. Participants were recruited from a public database of Australian dairy manufacturers[1] and industry contacts of the research team.

Semi-structured interviews were conducted with 42 Australian CMs during November 2022 to June 2023, accounting for 31% of the cheese manufacturing industry. Ownership changed in one firm during the project, resulting in 43 participants from 42 firms. Most participants

[1] Database of manufacturers: https://www.dairyaustralia.com.au/manufacturing-support/australian-dairy-manufacturers.

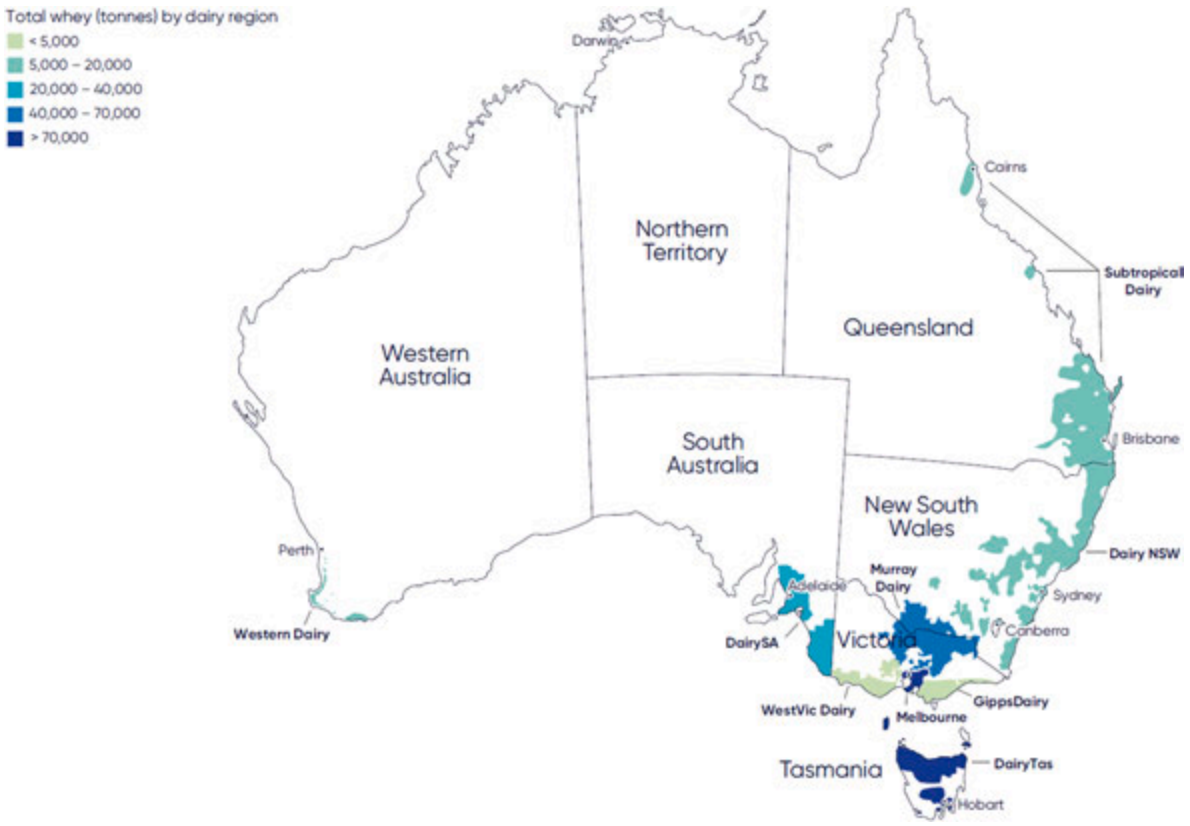

Fig. 2. Total liquid whey generated in Australia. Source: Dairy Australia (2023a).

were heads of organisations (74.4%) (e.g., CEO, General Manager or owner), with others including Production/Manufacturing Managers (9.3%), Operations Managers (7.0%), combined Production and Environmental Managers (4.7%), Environment Managers (2.3%), and Quality Assurance (2.3%). Firms were categorised by production scale: large (>25 kt p.a. of finished cheese products) (2.3%), medium (10-25 kt) (7.6%), and small (<10 kt) (90.2%), reflecting national distribution. State distribution also matched national figures: Victoria (37.1%), New South Wales (28.0%), Queensland (13.6%), Tasmania (9.1%), South Australia (6.8%), and Western Australia (5.3%).

4.3. Data analysis

Interviews (conducted in-person, via phone, or Zoom) were recorded and subsequently transcribed (average 52-min in length). Thematic analysis followed Braun and Clark's (2006) approach, using an abductive coding process to integrate existing literature of barriers (Donner et al., 2021; Geissdoerfer et al., 2022; Tura et al., 2019; Vermunt et al., 2019) and identify new themes (Spens and Kovács, 2006). NVivo (version 12.6.1.970), a common and powerful qualitative research software, was used to thematically code transcripts and meeting notes to identify patterns in the data. This is owing to NVivo's ability to handle large datasets and comprehensively code, (re-)group, interrogate and generate summary reports (Woods et al., 2016) and thematic findings. Codes were grouped into broader themes following Vermunt et al. (2019), namely: internal (financial, organisational, knowledge/-technological) and external (supply chain, market and institutional) barriers.

5. Results

5.1. Description of current uses, awareness, and CBMs

Table 1 summarises the current awareness and uses of alternative whey management practices by participants. More than half of firms are engaged in multiple management practices to utilise whey, and suggest high awareness of the potential uses of whey in human-grade food products. Every participant interviewed could identify at least one alternative.

Table 2 presents the prevailing BMs employed to manage whey in the study sample. Firms use a range of CBMs (IH, TP, JV) across different levels of circularity and more than half engage third parties to feed whey to animals or dispose of it. Three of the four possible CBMs (IH, TP and JV) are currently being implemented by firms at-scale (accounting for 50% of whey by-product) to repurpose whey into human food products. This indicates that repurposing whey and engaging in different types of BMs are not novel concepts to the industry. Practices mostly consisted of manufacturers producing powdered products (e.g., whey protein concentrates) via IH and JV-CBMs across large-, mid- and small-scale manufacturers. Other products included alcohol (e.g., vodka, gin, beer) via IH or a TP (e.g., with a local distillery) arrangements.

5.2. Overview of barrier themes

A summary of the barriers to repurposing whey based on the open-ended questions, regardless of the BM, are presented in Fig. 3 and organised into higher-level categories. As expected, there are a range of internal and external barriers to repurposing whey. These range from: a weak business case for change (e.g., low economies of scale); an increased complexity in managing new processes (e.g., coordinating new processes on-site); incompatibility of new practices within the

Table 1
Current management and awareness of practices of whey (n = 42).

Category	Management practice	Firms that implement practices	Firms that are aware of the practices	Firms that are aware of at least one human food product use
Human food products	Ricotta (from whey)	23.8%	61.9%	100.0%
	Powdered products	9.5%	83.3%	
	Alcohol products	9.5%	81.0%	
	Other human consumption[a]	7.1%	59.5%	
Animal feed	Livestock feed	42.9%	92.9%	
Recycling/recovery	Anaerobic Digestion	2.4%	28.6%	
	Compost	4.8%	9.5%	
	Paddock irrigation	35.7%	69.0%	
	Other products for sale[b]	2.4%	21.4%	
Disposal	Wastewater	35.7%	69.0%	

[a] Includes making non-fermented beverage products, confectionaries, selling to food service as cooking stocks, cocktails, etc.
[b] Includes skin care products and paint.

Table 2
Summary of business models employed to manage 50% or more of whey (n = 42).

	In-house	Third party	Joint venture	Focal company	**Total**
Human food products	9.5%	2.4%	2.4%	0.0%	**14.3%**
Animal feed	11.9%	21.4%	0.0%	0.0%	**33.3%**
Recycling/recovery	21.4%	2.4%	0.0%	0.0%	**23.8%**
Disposal	0.0%	28.6%	0.0%	0.0%	**28.6%**
Total	**42.9%**	**54.8%**	**2.4%**	**0.0%**	**100.0%**

existing setup of the firm (e.g., need for new processing equipment); lack of supply chain partners (e.g., receipts of liquid whey); low or inconsistent demand (for either raw or whey-based products); and/or a range of regulatory hurdles (e.g., food safety or alcohol taxation).

Unsurprisingly, financial (low economy of scale) barriers are highly prevalent. The following quote illustrates this when discussing the potential for processing whey into powdered products:

> *"We've definitely looked at it, but on our scale, it wouldn't be profitable. [We would need to invest in] nano-filters. And the big companies do it. But it's a couple of million bucks to put a filter in. The filters are $34,000 each. They last six months.* ***We just wouldn't have the volume to justify it at this stage.****"* (Participant 27, Production Manager of small-scale manufacturer).

Non-financial barriers also arise with competing business priorities and opportunity cost of the manager's time further affecting capacity to provide adequate attention:

> *"Yes, I'm aware of whey protein stuff. I'm aware of distilling for whey … I would love to see the whey being put to another purpose, but realistically, for the size of my business* ***and my role in it as the head-of-everything, I'm not able to really pursue anything like that. I'm waiting for them to come to me.****"* (Participant 24, Owner of artisanal cheese business).

In addition to competing pressures for attention, some firms reported access issues to information about technology options, limiting choices:

> *"Just, well, for the alcohol,* ***there's special processes you need to do to make it useful and that's very secretive.*** *People who do it are pretty secretive about how they do it."* (Participant 16, Owner of family-run business).

These quotes highlight a range of layered barriers to CE-outcomes, across the four CBMs. Further illustrative quotes for the six themes according to the four CBMs can be found in Table S1 in the Supplementary Material. However, as shown in Fig. 3, there are several barriers that are reported by very few participants. Therefore, as with the dominant final whey handling practices, it is important to consider the most prevalent barriers. Building on this, the next sub-section presents the most prevalent barriers for each CBM.

5.3. CBM-specific barriers

This section summarises the ten most prevalent barriers to repurposing whey across the four CBMs (illustrated in Fig. 4). Following our conceptual framework, the central circle in each diagram denotes the proportion of participants open to CBM adoption, those actively investigating it (i.e., managers have researched, paid for advice, or met with stakeholders), and those facing any barriers. Some participants considered barriers to increasing current repurposing capacity and/or changing to a different repurposing practice. Thus, the proportion that had reported on barriers exceeds the proportion of firms that do not currently repurpose whey (via any CBM) as shown in Table 2. In the outer section of each section of Fig. 4, the ten most prevalent barriers to each CBM appear, organised into external (coloured brown) and internal barriers (coloured blue) as per our framework. Note that the darker the colour of the specific barrier, the more prevalent it was.

5.3.1. In-house CBM

The most reported to barriers to the IH-CBM are illustrated in the top-left of Fig. 4 and were primarily internal barriers. These related to the perceived low economies of scale for new processes (reported by 65% of participants). These are related to, but also distinct from, capital costs (42%) and operating costs such as energy or transportation costs (23%). Interestingly, participants who were already engaged in an IH-CBM made a range of remarks regarding the profitability of the whey-based products.

1. *"****[Cheese is] what the business is first****. The [protein powders], and the other bits are the icing on the cake. You do need icing on your cake these days to survive.* ***But if you don't get the basics right, you don't bother turning up to work.****"* (Participant 1, Operations Manager at a mid-scale operation that manufactures whey protein powders).
2. *"****[Cheese is] a whey-producing factory in terms of the economics of the business.****"* (Participant 34, owner of a small-scale operation making alcohol products).

These extreme examples highlight that, regardless of the size of the firm, it is possible to make the whey-based products marginally to strongly financially viable. Organisational barriers included competing

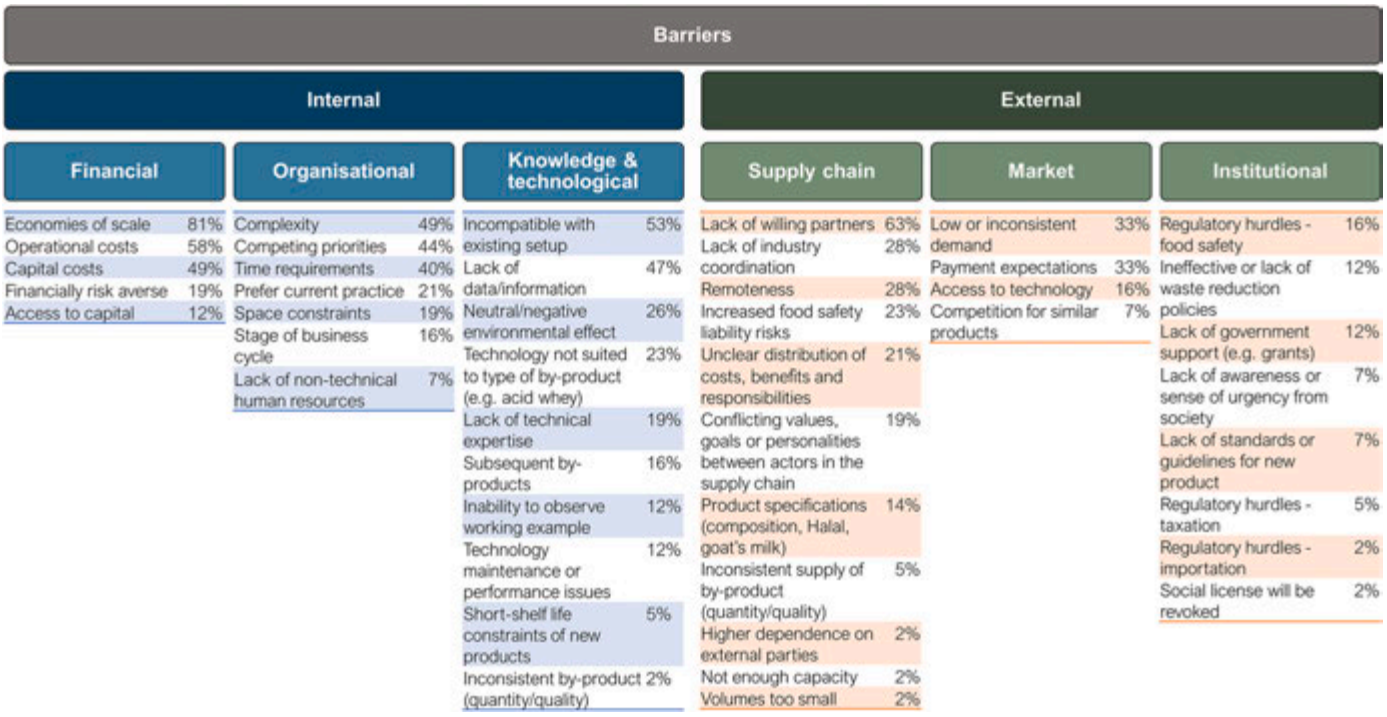

Fig. 3. Prevalence of barriers to implementing any circular business models, based on aggregated coding of open-ended interview responses grouped by broader themes. Percentage based on number of participants (n = 43).

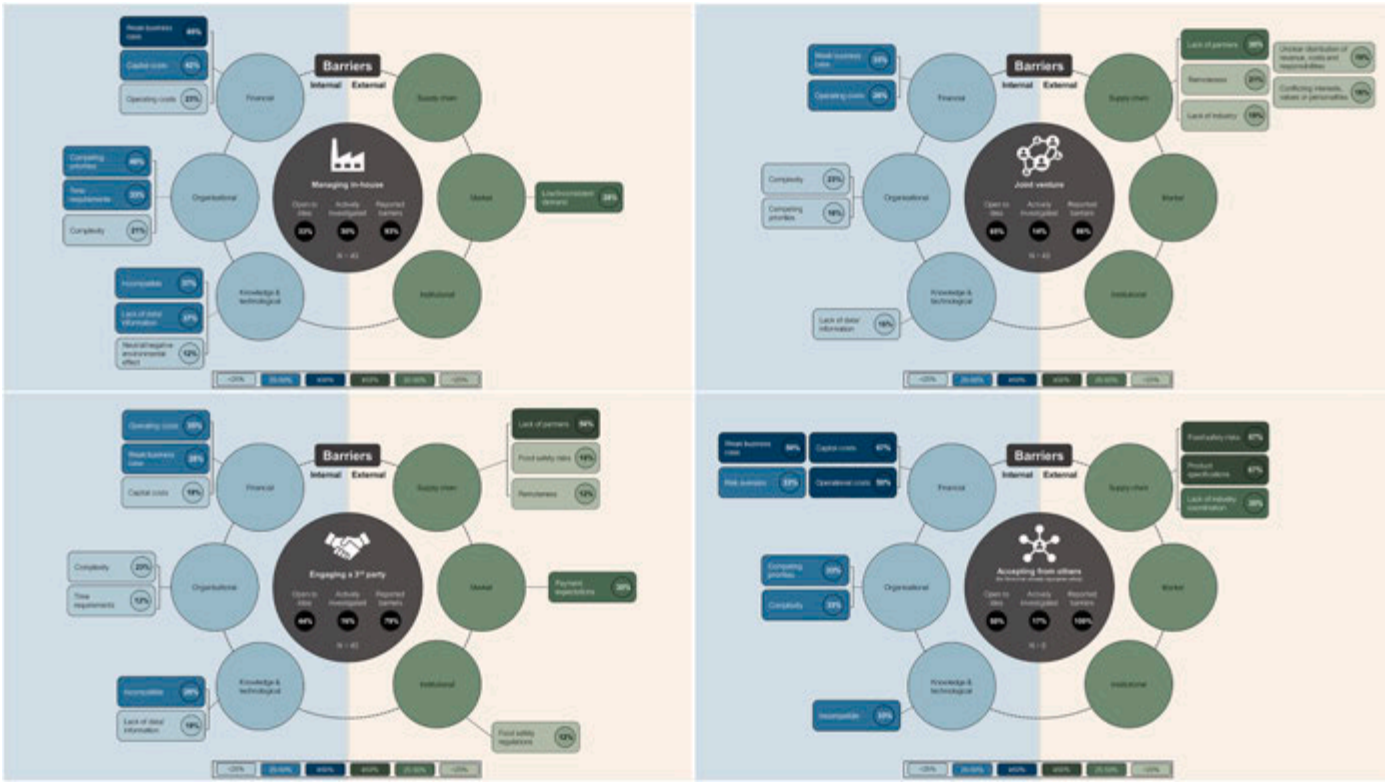

Fig. 4. Ten most prevalent barriers to repurposing whey to four circular business models (CBMs): in-house (top-left), third parties (bottom-left), joint ventures (top-right) and focal companies (bottom-right). Percentages based on number of participants.

priorities (40%) (e.g., current focus on business growth or other sustainability issues), time constraints (33%), and complexity concerns (21%). Knowledge and technology gaps included equipment compatibility issues (37%) and the need for more data and information (12%) such as technical requirements of new processes and associated economic and environmental impacts. Only one external barrier related to low and inconsistent demand (28%). The generally low reporting of external barriers is not shared by the TP-CBM.

5.3.2. Third party CBM

The most prevalent barriers to the TP-CBMs are illustrated in the bottom-left of Fig. 4. By contrast with the IH-CBM there is a greater spread of internal and external barriers. External barriers were led by the lack of potential partners (56%) and downstream food safety risks (12%). Market-related payment expectations (30%) and regulatory hurdles (12%) were also significant. Internal barriers included economies of scale (28%), operating costs (35%), and capital costs (19%). Organisational barriers involved logistical complexities (23%) and time required to manage new relationships (12%). Knowledge and technological gaps featured equipment incompatibility (28%) and information needs (19%).

As with the IH-CBM, internal barriers were common but were, overall, less prevalent. Notably, the barrier related to the economies of scale was reported less than half as much as compared to the IH-CBM (28% vs 65%), with more firms specifically mentioning the operating costs (35%) as a core issue (e.g., transport costs). Capital costs still appeared (19%) primarily due to the need to invest in cooling and storage equipment for the raw whey. Similarly, organisational barriers were still present as there would be significant logistical complexities (23%) and time required to find and manage any new TP relationships (12%). Likewise, knowledge and technological barriers included equipment incompatibility with whey-based products (28%) (e.g., filters or pasteurisers to meet TP's requirements) and more information required to understand the options and requirements of new processes (19%). Generally, there is a greater mixture of internal and external barriers across this CBM (compared to the IH-CBM), which is likewise observed in the JV-CBM.

5.3.3. Joint venture CBM

The most prevalent barriers to the JV-CBM are illustrated in the top-right of Fig. 4. Overall, there was a generally high level of openness to the idea (65%) with several firms (14%) already investigating it as an option. There is a similar pattern of internal barriers to the TP-CBM.

As with the TP arrangements, low economies of scale (33%) and operating costs (26%) were reported. Notably, the capital cost was not a prevalent barrier. Despite this there were general concerns with the complexity of dovetailing the JV with the current operation (23%), making it a low priority for several firms (16%). Once again, there is a general information gaps for some firms regarding the management options that are suited to their operation (16%).

Among the most prevalent barriers external issues were all related to the supply chain. As with TP, lack of willing partners (30%) and remoteness (21%) were reported. However, other barriers also appear. First, many raised concerns regarding the general lack of coordination within industry/among firms (19%), with many noting that they would not be willing to take on any leadership role to coordinate JV parties. Second, many participants reported the need to have a clear understanding of how the roles, responsibilities, costs, and revenues would be distributed among the parties.

Examples of this included whether capital costs would be distributed equally? If Firm A is located farther away from the collection site than Firm B, is Firm B subsidising the transportation costs of Firm A? Will the management be shared among the parties, or will there be a separate executive position/team? Will there be sufficient transparency? Will there be enough separation to partners to not give away any trade-secrets (e.g., cheese recipes). Third, many firms reported there would be some limitations regarding which other CMs they would consider partnering with based on either the types of production interests, organisational values, or clashing personalities (16%). When discussing this CBM many firms spoke about positive relationships, especially similarly-scaled businesses. Therefore, this barrier should be carefully interpreted as something that may limit the potential range of partners, rather than ruling out the CBM completely. Overall, the JV-CBM demonstrated a diverse mix of internal and external barriers, including some unique supply-chain barriers. This is largely due to challenges in establishing and maintaining relationships with similar businesses. Some of these barriers are shared with the final CBM.

5.3.4. Focal company CBM

The bottom-right of Fig. 4 illustrates the most prevalent barriers to the FC-CBM. This question was only asked for businesses that already engaged in IH practices to repurpose whey. Thus, the numbers reported are from a total of six participants. While no participant's firm was currently engaged in a FC-CBM (as shown in Table 2), we were interested understanding what is stopping them from this potentially beneficial approach. Half of these businesses were open to the idea but only one had actively investigated it.

Of the internal barriers, financial barriers were reported the most. Of these, capital costs for, say, cooling and storage infrastructure (67%) was commonly reported. However, when participants referred to these barriers it was not referred to in a manner that would be too difficult to overcome. This is illustrated in the following excerpt:

> Participant: "We might not have an unloading facility of whey coming in. **That will be a couple of $100,000 or $100,000 worth of storage silo and a bit of stainless steel.**"
>
> Interviewer: "Yeah, okay. But broadly you'd be open to it?"
>
> Participant: "***Open to it. The only thing is we won't be able to do 100 L.*** *If someone brings up [a tanker] of 1,000 L of whey a day, we won't be tying up our resources on that. If it is, say, 18,000 or 20,000 L coming in the tanker, happy to deal with it."* (Participant 10, Production Manager of large-scale operation that processes whey into protein concentrates).

This shows that despite there being capital costs to the FC-CBM there was a willingness to explore the approach. In addition, this excerpt highlights the necessity to have appropriate production volumes from partners. Thus, low economies of scale were reported by half of these participants. Likewise, half of these participants noted that the transportation costs was a key limiter in some instances (50%). In two instances, participants referred to being concerned with taking on too much risk with too many initiatives. On the other hand, one participant indicated it their intention to engage local CMs in a FC approach, and it was a matter of '*when*' not '*if*' it would occur pending raising the necessary capital.

As with the previous CBMs, competing business priorities, complexity, and incompatibility challenges with existing infrastructure were reported issues for the FC-CBM (33% of participants reported this issue). Supply chain issues were likewise key barriers. As with the TP-CBM, food safety risks of value chain partners (67%) were a key concern, albeit upstream rather than downstream. As with the JV-CBM, lack of industry coordination was again an issue (33%). A unique barrier to this CBM was the need for whey suppliers to meet the product specification of the focal firm such as nutrient composition, microbial levels, animal source (e.g., cow or sheep), and other certification schemes (e.g., Halal). Overall, the FC-CBM shared many similar barriers to the others described and some unique ones. Even the similar barriers do not necessarily share a similar threshold to overcome these (e.g., capital costs). To help illustrate which barriers are shared and differ among the four CBMs they are summarised in the section below.

5.4. Comparison of CBM-specific barriers

Fig. 5 provides a visual summary of the barriers to the four CBMs, collapsing the four diagrams in Fig. 4 into a single image with an icon to represent for the relevant CBM. Notably, 79% of participants reported being open to at least one of the CBMs, 42% had actively investigated one, and all participants had reported at least one barrier to any of the CBMs considered in this study.

Fig. 5 also illustrates that barriers to repurposing whey cut across all thematic areas. Although there are common barriers across CBMs (e.g.,

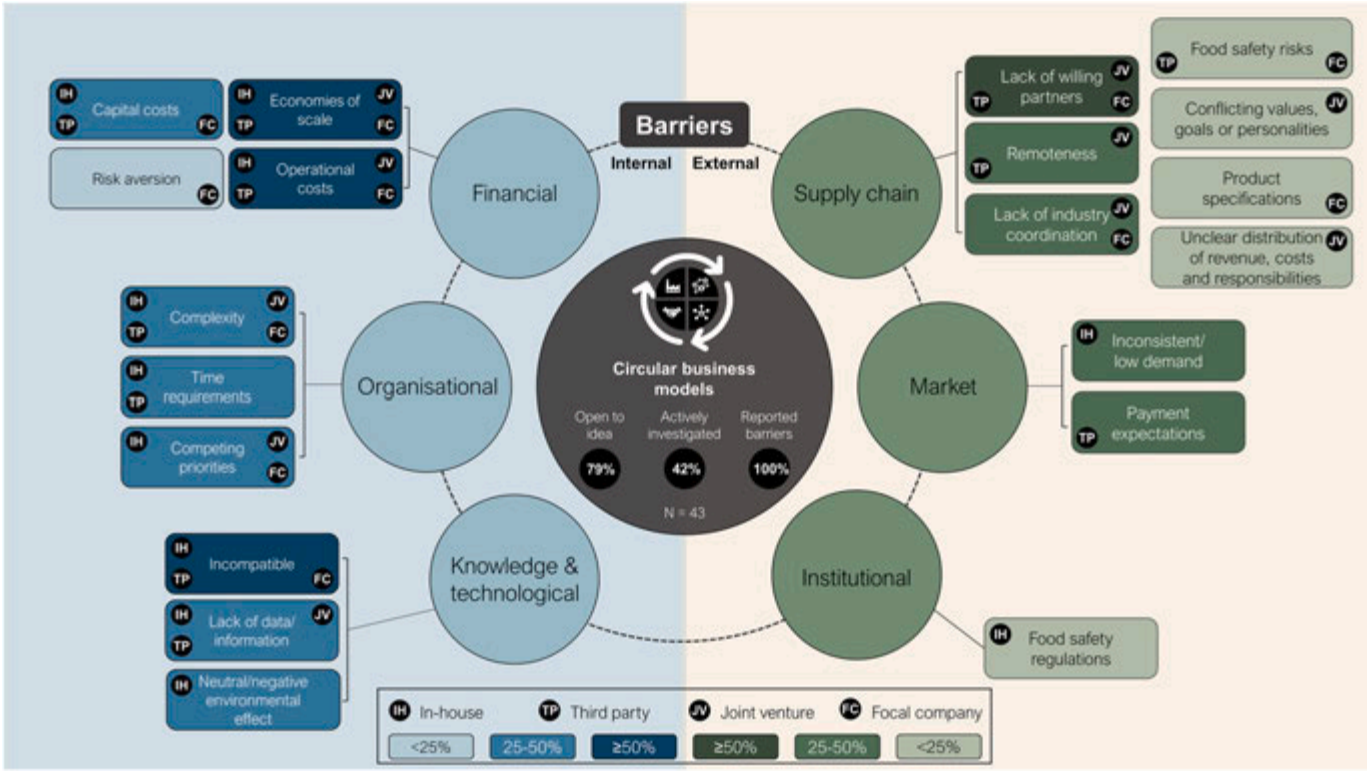

Fig. 5. A visual summary of the prevalent barriers to the four CBMs. Icons represent the CBM/s which were found to be among the ten most prevalent barrier.

economies of scale, operational costs, and increased management complexity) each faces unique barriers. That is, IH models encounter issues related to low demand and perceived environmental impacts. TP models struggle with aligning payment expectations with new recipients (buyers) of the by-product. JVs face challenges in industry coordination and equitable distributions of responsibilities, revenues and costs. Finally, FCs encounter issues with risk aversion and the need for suppliers to meet specific production criteria for the whey by-product. We address these findings in the next section.

6. Discussion

This study investigates CE barriers among interchangeable CBMs for FLW reduction. Building on the existing literature, which has emphasised CBMs that deal with technical/non-organic products (Bocken et al., 2016), we define and apply four CBMs relevant to biological product waste streams that by definition must be consumed/ingested, being a relatively underexplored area in the literature. These were applied to representative firms in the Australian cheese manufacturing sector as a case study. Through semi-structured interviews this study specifically seeks to answer the following research questions: *RQ1: Do firms perceive different barriers when presented with various pathways to reduce FLW; RQ2: How might these barriers to change affect circular business model selection, and ultimately, adoption at sectoral levels?* The novelty of this study lies in the perspective of participants pre-transition and have equally available options to achieve high levels of circularity. Our study design allowed to us to complement the findings of other ex-post analyses by showing what is perceived to prevent future action, rather than what was experienced post-transition. While both are important to understand, the current literature has many studies that only consider the barriers for firms that have already implemented CBMs. By confining the participants to single industry with equal technology availability that all contribute circular outcomes (in particular, repurposing of an unavoidable FLW) we are able better compare the difference in barriers to transitioning to the CE and start to build the evidence-base beyond anecdotes towards some consistent trends. The below paragraphs address the research questions, summarise the key contributions, highlight policy and managerial implications, and limitations before the conclusions.

In relation to RQ1, our study supports the notion there are key differences in perceived barriers when presented with different CBM that achieve the same outcome. The four CBMs considered in this study identified diverse barriers—some consistent and others unique. The economies of scale, operational costs (both financial barriers) and increased management complexity (organisational) were common across all four CBMs. The following barriers were present in some but not all CBMs: capital costs, competing priorities, equipment incompatibility, lack of data, time requirements, lack of willing partners, geographical remoteness, absence of industry coordination, and food safety risks. This highlights that certain CBMs may overcome barriers present in others. Our study identified unique barriers to each of the CBMs. Perceived issues related to the neutral/negative environmental effect, low demand and increased food safety requirements were uniquely prevalent to IH CBMs. Overcoming payment expectations was only a prevalent barrier to TP CBMs. Supply chain issues relating to the unclear distribution of roles, revenue, costs and responsibilities, and finding suitable partners was unique to JVs. The additional financial risks and the need for raw whey suppliers to meet the focal firm's production specification were unique to FC CBMs. The finding of prevalence difference to equally possibly CBM options is unique to this study.

In relation RQ2, by exploring interchangeable CBMs, industries may overcome some (but not all) barriers, but then stakeholders should be prepared for other types of barriers. IH-CBMs have been shown to be possible for all scales of production provided the firm is willing to dedicate sufficient time and resources to the enterprise. For those that have time constraints gifting whey to a TP can work, which was the case in one firm in our study sample (i.e., gifting to a local distillery). However, some firms may wish to be paid for their efforts because there is now greater 'value' in the by-product. So, both parties need to be able to agree on a price. For firms that want to retain some of this value but don't have the volumes or capital to invest in the equipment to dry and fractionate proteins, JVs could be a viable pathway assuming there are similar firms nearby and there is someone willing to take leadership and find a sufficiently transparent and equitable business plans. These complexities might be overcome by utilising the existing infrastructure of firms that already repurpose their by-products (i.e., FCs), especially in regions with a high concentration of CMs. However, this requires all upstream firms (e.g., smaller CMs) meeting the product specifications of the focal firm. The willingness to explore CE approaches increases significantly when considering all possible pathways (79%) compared to IH approaches alone (33%). This underscores the need for multiple approaches to achieve SDG 12.3, as a one-size-fits-all approach may not be effective (Vermunt et al., 2019) and the important role of IS will have in achieving this (Neves et al., 2020). Firms unwilling or unable to increase in-house capacity might partner with others for repurposing, and even those already repurposing can do more by enabling another firms' waste to be repurposed. However, exploring multiple pathways increases the scale/scope of possible barriers.

Our findings fill an important gap by highlighting several important similarities and differences in relation to previous studies. This study identifies several barriers to CBMs that align with findings from previous research. This includes: economies of scale (Do et al., 2022; Donner et al., 2021; Vermunt et al., 2019), financial uncertainty (Geissdoerfer et al., 2022), logistical challenges (Whalen et al., 2018), competing priorities (Geissdoerfer et al., 2022), lack of technical knowledge (Tura et al., 2019; Vermunt et al., 2019), limited evidence for environmental benefits (Guldmann and Huulgaard, 2020), lack of in-house skills (Geissdoerfer et al., 2022), technological incompatibility (Tura et al., 2019), space constraint (Donner et al., 2021), remoteness (Donner et al., 2021), lack of partners (Vermunt et al., 2019), cooperation between partners (Geissdoerfer et al., 2022; Tura et al., 2019; Whalen et al., 2018), sectoral leadership (Whalen et al., 2018), potential conflicts between partners (Tura et al., 2019), and lack of clear responsibilities (Tura et al., 2019). We expand upon this latter point by identifying unclear distributions of revenues or costs as being an additional concern for others. There are parallels with some of the broadly identified barriers in the IS literature, that geographical remoteness and trust are barriers to these (Neves et al., 2020). These similarities help validate our findings.

Despite these similarities, our study also reveals several distinct differences from prior research. Donner et al. (2021), noted barriers specific to anaerobic digestion (odour and customer trust), which we excluded due to focusing on more circular options like repurposing. Unlike Whalen et al. (2018), we did not find a lack of demand for second-hand products significant, likely because whey repurposing does not create an 'old' product. This emphasises a crucial difference between technical and biological materials. While Tura et al. (2019) mentioned raw material scarcity and silo-thinking as barriers, these were not prominent in our study. This may be due to our focus on firms that generate FLW (therefore, no scarcity) and the high percentage of firm heads involved (74.4%) in our sample (therefore a holistic perspective). Vermunt et al. (2019) waste management legislation and market barriers (lower virgin material costs, customer and competitor resistance) as prevalent issues, which were less significant in our context. Instead, we noted food safety legislation and organisational barriers as much more prevalent than in their study. Contrary to Geissdoerfer et al. (2022), we did not find internal pressure to favour 'linear' models or shareholder short-termism as major obstacles. Interestingly, most firms in our sample with shareholders were already repurposing whey. In their study of seafood manufacturers in Vietnam (Do et al., 2022), found that consumer trust in the resultant upcycled product was low. This was not an issue in a sample. Our sector-specific and pre-transition offers a

nuanced understanding that highlights the most prevalent issues to address.

Moreover, many reported barriers may be 'perceived' rather than 'actual'. For example, participants mentioned remoteness or a lack of willing partners as a barrier to TP or JV-CBMs. However, we estimate the maximum distance between any Australian CM to another CM, winery[2] or brewery[3] is less than 100 km (median distance 1.1 km), highlighting that participants might not be fully aware of potentially relevant partners. Whether or not it is an objectively true barrier, the perception of the barrier needs to be addressed (e.g., better access to accurate information through industry or government sources). Supporting greater circularity between agricultural sectors will require more dynamic and integrated business models within and between firms (Donner et al., 2021).

As already highlighted, there is a clear difference between our findings and other studies that we suggest is partly due to the sectoral focus. Our focus on cheese whey in Australia provides limited generalisability. As discussed, FLW presents a biological material, and as such does not have the same CBM options to technical materials (e.g., phones). Also, many other agricultural sectors do not have the same availability or access to technologies to repurpose by-products, at least to the same level of commercial-readiness as whey (Gregg et al., 2020) but these options will become more readily available. Examples include, brewing beer from leftover bread (Goodman-Smith et al., 2023), or making flour from brewers' spent grain (see: https://www.grainstone.com.au/). Additionally, Australia's dairy and broader agricultural sector faces some unique circumstances compared to other regions (e.g., agro-climatic, spatial dispersion, and regulatory idiosyncrasies). This would particularly affect the prevalence of issues reported. However, we would suggest that the broader themes identified, which have been built upon the extant literature, such as some of the high-level patterns across the CBMs (e.g., JVs reducing some challenges like capital costs, but come with unique challenges) may be expected in other regions and sectors, but this requires further analysis. The findings of this study may help broadly inform the analytical approach, themes and general patterns identified for other sectors and regions but requires additional work. Another important contribution is the framing of the four interchangeable CBMs, that could easily be applied to other sectors, in particular, food and agricultural production chains that generate unavoidable by-products. This is an important contribution to the evolve discourse of CBMs that improve *'cycling'* (Geissdoerfer et al., 2020) and *'extending resource value'* (Bocken et al., 2016).

6.1. Policy and managerial implications

Our findings offer some insights to government, industry and individual firms. It highlights that if we can broaden the scope of BMs more firms may be receptive to participating in efforts to reduce waste. We identify specific areas—from internal financial, organisational, and technological areas to broader external supply chain, market and institutional barriers—on which governments, industry organisations and individual firms can act. Additionally, because this is from the perspective of firms that have yet to (and arguably need to) transition to a CE, it shows the perceived factors preventing them from a more circular food system of which whey is one the largest source of FLW across the supply chain, and affected by relatively few decision makers (Dairy Australia, 2023a). The prevalent business model-specific shown in Fig. 5 can help industry bodies (e.g., Dairy Australia), governments, and individual firms that are interested in establishing collaborative CBMs.

At a sector-level, Dairy Australia's FLW action plan outlines a set of priorities to halve FLW in the dairy industry by 2030 (Dairy Australia, 2023a). High impact areas identified include monitoring dairy FLW across the supply chain, establishing industry working groups and assessing the commercial feasibility of diverting waste to third-party processors. Our findings suggest that these industry actions could be useful in reducing some of the barriers. The fact that this strategy has been released (after the interviews were conducted) goes part way to address a key barrier to regarding the lack of industry coordination. Our findings align with these efforts and can pre-empt other barriers. We recommend involving large-scale whey-repurposing manufacturers in discussions to establish FC-CBMs to leverage existing processing infrastructure, rather than focusing only on JV approaches. We suggest this also extends to other sectors outside of CM; for instance, alcohol product manufacturers. As an example, the multi-national alcohol manufacturer Asahi produces a line of a whey-based vodka called "Vodka O″ in Melbourne, Australia (see: https://asahi.com.au/brands/spirits/161-vodka-o). This could focus on partnerships large scale in concentrated locations (e.g., Melbourne) or more local partnerships between artisanal CM and brewers/distillers. Extension of technology options for repurposing whey could also be helpful (e.g. yeast varieties to distil lactose) and promote the benefits of upcycled products to environmental outcomes of whey-based alternatives. A study of whey distillation showed it would emit 8.4 kg less CO_2e greenhouse gases and use 0.44 kg less water per bottle of finished product than conventional malt barley spirits (Risner et al., 2018). These environmental benefits would appeal to environmentally-conscious consumers, as well as those motivated by food waste reduction (Aschemann-Witzel et al., 2023a; Nguyen et al., 2023a,b). They could also play an important role in supporting the development of guidelines and tools to support decision makers in the full consideration of their options relevant to their circumstances. Further efforts to support the increase in demand for whey-based products is assessing the value-proposition of pursuing Upcycled Certification (Upcycled Food Association, 2020) for whey-based food products in the industry, as well as learning from other regions (e.g., whey repurposing in EU) and other sectors. Equally, other peak industry bodies that are strategically aligned with SDG12.3 could likewise learn from some of the higher-level themes from the dairy sector, in particular Australia's horticultural, bakery, food service sectors (FFWL, 2023).

Governments at all levels have a role in shifting waste management practices. Federal alcohol tax regulations, state food safety regulations and local planning development approvals were reported as barriers to changing behaviour. While these regulations serve valid purposes and are unlikely to be relaxed solely for whey repurposing, streamlining compliance processes could facilitate progress. Other efforts of these stakeholders, in conjunction with Dairy Australia, could be to reduce the barriers to CBMs may include the provision of contemporary information about the market potential, financial viability and risks associated with different repurposing options, coordination of the industry to help identify possible collaborative CBMs (i.e., TP, JV and FC) within and outside of the dairy sector, de-risking these opportunities, and better alignment of (dis)incentives to improve the utilisation of resources. These incentives cut across market drivers, regulatory frameworks, and social licences to operate (e.g., improved efficiencies, market demand, government regulation, personal values, social expectations, and broader industry norms) (Hetherington et al., 2024).

For firms considering a CBM, particularly in the Australian CM sector, our study offers valuable insights. Firstly, CBM engagement is feasible regardless of production scale, with diverse technology options available; but it is a matter for individual business objectives and priorities. Secondly, it is not necessary to do everything yourself and there are viable (perhaps overlooked) partners to engage within spatial range (given a median distance of 1.1 km between every CM and a potential partner). Thirdly, while there were notable issues regarding finding suitable partners that share similar values, visions and coming up with an equitable business plan, the overall sentiment of working with others was positive. However, it would seem there is a leadership vacuum.

[2] Location information from: https://www.findawinery.com/, accessed 20 October 2021.

[3] Location information from: https://www.brewsnews.com.au/brewery-database/?view=list, accessed 20 October 2021.

Dairy Australia's recent efforts will help address this and bring forward these discussions. For those firms that are already processing whey, they can play an active role in contributing further to reducing the sector's FLW, and increase their own business's return on capital by processing additional whey from others. While there are many barriers, most (if not all) are not insurmountable.

6.2. Limitations and future research

While the study provides valuable insights into a specific segment of the Australian CM sector, its narrow focus limits its broader applicability and significance. As stated already we recommend exploring other agricultural sectors and regions. Our study may help broadly inform the analytical approach, themes and general patterns. To enhance the validity and generalisability of the findings, future studies could consider exploring or supplementing the current methodology with additional data collection methods, such as; surveys or questionnaires to reach a wider audience, case studies or in-depth interviews to gather more nuanced data, experimental or quasi-experimental designs to establish causality, and mixed-methods approaches to triangulate findings and increase rigour.

The study design allowed us to capture front-of-mind barriers from participants and the scale/scope of relevant barriers. However, this meant that we were not able to quantify the relative intensity of these barriers. Future studies may seek to test the relative intensity of barriers to further assist with prioritisation of government and industry action. We also echo the suggestion of Vermunt et al. (2019) to fully evaluate the effectiveness of policies and programs to incentivise the implementation of CBMs, as well as coping strategies and solutions to overcome subsequent barriers after the CBM is in place.

As stated above, our study deliberately chose to focus on the perceived barriers to CBMs from the perspective of the 'waste generator'. Many of the different technology solutions and circular BMs allow for partnership with firms outside of the dairy sector (e.g., Asahi). While this firm is already in a CBM (as a recipient of the by-product; a 'Gap exploiter') it would be useful to understand the barriers to other potential recipient firms (i.e., other food and beverage manufacturers that can use whey as an input). Our study partially reveals some of these as FCs act are also a recipient firm, but there a likely to be other barriers. Therefore, future studies could investigate the barriers to starting collaborative CBMs from the perspective of other stakeholders.

Finally, this study only focuses on one CE/FLW issue; whey repurposing. Whey repurposing often results in other related by-products that have their own suite of issues (e.g., production of whey permeates from whey protein concentrates). There are some processing options for many of these, and their subsequent by-products, but there comes a point where any lack of technology or economic-feasibility constrain choices. Yet CMs provide opportunities to improve the circularity of the operation (i.e., other FLW issues, energy consumption, packaging use, etc.) and Geissdoerfer et al. (2018) argues *"all elements of a business model need to 'go circular' to achieve the optimal sustainability performance"* (p. 714). Future research may, therefore, consider interconnected and cascading barriers to achieving *'full harvest'* (i.e., utilising all aspects of a food product to its highest potential (Juliano et al., 2022)), whole-of-business, and whole-of-value-chain CBMs. We share the view that more emphasis in the future should be in on cascading and integrated CBM (Donner et al., 2021).

7. Conclusion

Achieving SDG 12.3 will require decision makers across all stages of value chains to change their practices. By embracing a broader set of CBMs we have sought to capture a wider set of firms that are willing and able to participate. However, these new approaches come with unique barriers that need proactive anticipation and identification of solutions. This study highlights how barriers to the CE vary among specific BMs in the context of reducing FLW. Expanding on existing CBM literature, we categorise four CBM types and compare prevalent issues reported by representative firms in the Australian cheese manufacturing sector, used as our case study. This study identifies the specific barriers to the Australian cheese manufacturing sector, providing a basis for future efforts to identify and prioritise barriers to overcome in other sectors and regions.

CRediT authorship contribution statement

Jack B. Hetherington: Writing – review & editing, Writing – original draft, Visualization, Validation, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Adam J. Loch:** Writing – review & editing, Supervision, Methodology, Conceptualization. **Pablo Juliano:** Writing – review & editing, Supervision, Methodology, Conceptualization. **Wendy J. Umberger:** Writing – review & editing, Supervision, Methodology, Conceptualization.

Declaration of competing interest

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

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

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