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# Organic Compost Supply Chain Analysis: A TCE Perspective

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## ABSTRACT

**With the growing attention to Circular Economy (CE), there is a need to develop a waste management strategy to coordinate waste and recycling infrastructure across regional South Australia. The transition into CE needs a clear understanding of appropriate input and output opportunities while aligning the whole supply chain for value creation from waste. The development of the organic recovery industry in South Australia is severely constrained by the lack of suitable processing plants, which are currently operating at their limit. Amidst the challenges of CE adoption, a supply chain for organic compost needs a thorough analysis for capacity expansion. Using transaction cost economics (TCE), this exploratory study investigated the contractual difficulties and logistical challenges of the proposed organic compost supply chain connecting regional organic waste sources with processors and organic compost users. Interviews of organic waste suppliers, processors, and users revealed that while processing appeared to be viable for organic compost, the cost of organising its supply chain might be prohibitively high. Building more processing plants might face supply chain and logistical challenges without support from multi-stakeholders. Practical implications of CE are drawn for the benefits of all partners.**

***Keywords****: Australia, circular economy, circular supply chain management, organic compost, supply chain analysis, transaction cost economics*

## 1. INTRODUCTION

The Circular Economy (CE) initiative is gaining traction because of the increasing focus on better resources and process efficiency at different stages of production and consumption (Patwa *et al.*, 2021). CE has a zero-waste vision where the products go through a restorative and regenerative economic cycle of value addition for further use (Farooque, Zhang & Liu, 2019). The higher emphasis on value creation has gone beyond a traditional view of cost-cutting in a network-centric supply chain. It is a shift in economic behaviour from traditional "cradle-to-grave" practices to the "cradle-to-cradle" paradigm (McDonough & Braungart, 2010). The CE, that focuses on 4R practices (i.e., reduce, reuse, recycle, recovery), aims to reduce the ongoing create-use-discard approach to an innovative sustainable way of creating-use-reuse thinking (Patwa *et al.*, 2021). Although CE has been defined from various perspectives (Kirchherr, Reike, & Hekkert, 2017), we define it simply as an economic activity that focuses on 4R practices that help convert waste into value-added products in addressing the triple bottom lines of sustainability. While waste is inevitable in the supply chain process, CE approach offers ways this waste can be re-purposed into a product for the next round of use. This research on CE further addresses United Nations' sustainable development goal #12, responsible consumption and production (UN-SDG, 2015). Sustainable consumption involves wastage minimisation and reduced consumption of natural resources and energy (McDonough & Braungart, 2010).

Waste management has been part of companies' agenda in the form of lean manufacturing practices (Tortorella, Miorando, & Marodin, 2017), recycling/reverse logistics (Wijewickrama, Chileshe, Rameezdeen, & Ochoa, 2021), closed-loop supply chain (Mishra, Hopkinson, & Tidridge, 2018) and global value chain (Hofstetter *et al.*, 2021). Lean practices and principles aim to reduce waste and variability in processes, add more value to customers, and improve operational performance (Shah & Ward, 2003). For example, lean practices overly target waste minimisation, a preventive measure that reduces waste within the organisation and along the supply chain (Tortorella *et al.*, 2017). The reverse supply chain/recycling/closed loop, once considered a waste stream, has been considered beneficial where products at the end of their life are recycled for further use (Mishra *et al.*, 2018; Wijewickrama *et al.*, 2021). The shift into a circular supply chain extends the boundaries of closed-loop SCM, green SCM, and sustainable SCM into supply chain circularity, where the CE principle uncovers many challenges while working towards a common goal of achieving zero waste (Zhang, Wang, Farooque, Wang, & Choi, 2021). The transition to CE requires reconfiguration of supply chain processes that are likely to prevent waste generation in the first place and enable value recovery across different supply chains with partnering companies.

As CE is believed to reduce, reuse, recycle, and recover materials in production/consumption processes (Kristensen & Mosgaard, 2020), earlier studies have been rhetoric about it. They have created a gap between theoretical research and practical implementation (Zhang *et al.*, 2021). It is not that CE is entirely a new concept; there are global examples of CE in the food, plastics, clothing, and automotive industry where CE goes right back to the beginning of the supply chain as a strategy to "preventing waste from being created in the first place" (EMF, 2021). The current production and consumption practices are central to these initiatives (Hazen, Russo, Confente, & Pellathy, 2020). Despite the growing prominence of CE, the concept has garnered relatively little attention in the supply chain management literature (Hemidat, *et al*., 2018). So far, research on CE is limited to a literature review unfolding the drivers, barriers, and practices of CE and its relationship with sustainability (Bressanelli, Perona, & Saccani, 2019; Geissdoerfer, Savaget, Bocken & Hultink, 2017; Kristensen & Mosgaard, 2020; Patwa *et al.*, 2021; Pieroni, McAloone, & Pigosso, 2019). The research by Patwa *et al.* (2021) empirically validated a CE model highlighting how consumer behaviour and government policies are perceived to affect CE adoption intention significantly. *Zhang et al.* (2021) studied the Ellen MacArthur Foundation (EMF, 2021) that showed real-life cases of CE practices in food, fashion, plastics, and others supported by government policies to fill the current gap in research and industry practices. Using European FMCG cases, Mishra *et al*. (2018) state that creating successful value propositions through CE is complex and requires customer acceptance and business viability. This calls for an analysis of an organic supply chain that applies the CE principles. More on five principles of CE (i.e., closing, slowing, intensifying, narrowing, and dematerialising loops) within SCM processes are available in the study by Hazen *et al.* (2020).

Moreover, uncertainties exist in re-processing, especially for the supply of waste and the demand for re-processed products (e.g., organic compost), and pose big challenges in taking CE initiatives (Zhu & Tian, 2016). According to Chiarelotto, Restrepo, Lorin, and Damaceno (2021), composting has emerged as a mitigation method to waste and for recycling organic waste into agricultural inputs. Composting recycles organic matter into stabilised and sanitary-safe compost. Its application to soil can restore the nutrients in crops. Once done right and with more processing plants introduced, the CE reduces dependence on imported agricultural inputs (inorganic compost), strengthening the local community or specific region as users (Tilman, *et al.*, 2002). Composting applications can contribute to increased agricultural productivity and reduce chemical fertiliser utilisation (Asses, Farhat, Hamdi, & Bouallagui, 2019; Wei *et al.*, 2016). Therefore, evaluating a circular supply chain from the standpoint of waste supply, a potential location of a processing unit, and identifying users of these products can help to resolve many uncertainties surrounding CE adoption. This is a novel approach in this study.

Against this backdrop, this study aims to undertake a supply chain analysis (SCA) to assess the variability of supply sources and demand levels for organic fertilisers. This qualitative research is both exploratory and inductive, meaning that the researchers look for the meanings and insights in a situation (Corbin & Strauss, 2008; Levitt, Motulsky, Wertz, Morrow, & Ponterotto, 2017). Similarly, in this study, the exploratory interviews were applied to build and develop a deeper understanding of the views, experiences, and perceptions of relevant selected stakeholders within the entire organic compost supply chain to achieve the intended research objective. In particular, the study investigates the contractual difficulties and logistical challenges along the triadic supply chain connecting regional material sources, compost processors, and organic compost users. Also, it attempts to identify the sources of high transaction costs along the supply chain and provides suggestions to reduce those costs. To achieve the above-stated objectives, the following research questions are developed.

RQ1: *What comprises an organic supply chain analysis transition to a CE?*

RQ2: *What contractual difficulties give rise to high transaction costs along the triadic supply chain that prohibit stakeholders from investing in organic compost processing?*

Rest of the paper is organised as the context of the study in section 2, literature review in section 3, methodology in section 4, results and findings in section 5, results and implications in section 6, and conclusion in section 7.

# 2. CONTEXT OF THE STUDY

This study on supply chain analysis of organic compost is a subset of a larger ongoing project. The South Australian Regional Organisation of Councils (SAROC) commissioned the Central Local Government Region of SA (trading as the Legatus Group- https://legatus.sa.gov.au/) and secured funding from Green Industries SA (GreenIndustriesSA, 2017) to undertake preliminary work. It has produced two reports: Waste Management Infrastructure for SA Regional Local Government (WasteManagement, 2021); and Regional SA Waste and Resource Recovery Background Report by Rawtec (https://rawtec.com.au/reports/). These reports indicate that composting facilities in regional SA may be viable. The Legatus Group comprises fifteen councils in regional South Australia. Councils own and operate systems for the collection and management of waste for several communities and these are the source of organic materials. **Table 1** provides the list of councils under the Legatus group, and the total estimate of volumes (tonnes) of organic recycling.

**Table 1** Estimated Volume of Organic Feedstock within Legatus Councils

| Legatus Council | Population | Organics kerbside recycling (tonnes) | Organics drop-off (tonnes) | Timber (tonnes) | Total Organics recycling (tonnes) | Cardboard (tonnes) |
|---|---|---|---|---|---|---|
| **Adelaide Plains** | 8,801 | 232 | 29 | 276 | **537** | 196 |
| **Barossa** | 23,560 | 1,475 | 1,798 | 740 | **4,013** | 523 |
| **Barunga West** | 2,542 | 109 | 194 | 80 | **383** | 56 |
| **Clare & Gilbert Valleys** | 9,021 | | 689 | 283 | **972** | 200 |
| **Copper Coast** | 14,138 | 181 | 2,147 | 444 | **2,772** | 314 |
| **Flinders Ranges** | 1,640 | | 175 | 52 | **227** | 36 |
| **Goyder** | 4,134 | | 500 | 100 | **600** | 1 |
| **Light** | 14,733 | 1,228 | 1,125 | 463 | **2,815** | 327 |
| **Mount Remarkable** | 2,861 | | 218 | 90 | **308** | 64 |
| **Northern Areas** | 4,529 | | 346 | 142 | **488** | 101 |
| **Orroroo Carrieton** | 899 | | 50 | 28 | **78** | 20 |
| **Peterborough** | 1,678 | | 50 | 53 | **103** | 32 |
| **Wakefield** | 6,804 | 256 | 519 | 214 | **989** | 151 |
| **Yorke Peninsula** | 11,060 | 1,000 | 150 | 347 | **1,497** | 246 |
| **Total** | **106,400** | **4,481** | **7,990** | **3,312** | **15,782** | **2,267** |

*Source: Bryson (2021, p. 17)*

Some councils accept garden waste and others both garden and food waste in kerbside green bin services. Councils without kerbside bins are anticipated to have large amounts of green organics in their general waste (landfill) bins. Much of this uncollected waste, both from residents and businesses, could potentially be composted if local facilities were available (RawtecReport, 2020). Legatus group anticipates large amounts of commercial organics could be composted if more processing plants are available.

South Australia currently has several commercial compost producers, mainly located in metropolitan Adelaide and the south-eastern regions. Currently, only one compost producer, North Waste, is located within the Legatus council area. Other larger commercial facilities closest to the Mid North and Yorke regions are Jeffries in Wingfield and Peats Soil in Dublin. The limited processing plants justify the need for more organic processing plants. The below list (**Table 2**) shows direct sources of organic waste that process agricultural products. They become potential end users of the compost as well. This prompts more alternative processing plants.

**Table 2**. Direct sources of organic waste in SA *(Bryson (2021, p.26)*

| No | Direct Sources |
|---|---|
| 1 | Forestry SA |
| 2 | Grain Producers SA |
| 3 | Australian Miling Group |
| 4 | Wilson Pastoral |
| 5 | Balco Australia |
| 6 | Meat and Livestock SA |
| 7 | Primo Australia |
| 8 | Samex Peterborough Pty |
| 9 | Abattoirs |
| 10 | Ardrossan Aquacuture Park |
| 11 | Golden North |
| 12 | Clare Valley Wine and Grape Grower |

Australia stands to benefit economically from implementing CE amidst a growing barrier to CE implementation (Farooque, Zhang, Thürer, Qu, & Huisingh, 2019; Govindan, Fattahi, & Keyvanshokooh, 2017; Lahane, Kant, & Shankar, 2020; Tura *et al*., 2019; Vermunt, Negro, Verweij, Kuppens, & Hekkert, 2019). One of the barriers that have not been fully researched is supply chain analysis (demand-supply trade-off), which is critical to successfully implementing the CE. For example, South Australia (SA)'s Glenelg water treatment plant uses food by-products to augment its power requirements. They are also developing a bioenergy roadmap to link biomass suppliers to energy users (JacobsReport, 2015). They are predicting that a CE will reduce greenhouse gas emissions by more than 27% by 2030 (GreenIndustriesSA, 2017). In addition, the SA councils are also incentivising the processing and reuse of wastes, especially organics. As CE has gained momentum toward sustainable development (Bakker, Mugge, Boks, & Oguchi, 2021), CE opens up ways for resilient recovery and a way to economic prosperity by fostering recycled product innovation, reducing resource dependency and environmental impact, and creating new jobs. According to Nandi, Sarkis, Hervani, and Helms (2021), research on CE overly focuses on determining plant facility location, number, and capability with little focus on logistical challenges and cost implications facing the waste supply chain. Thus, supply chain-wide planning and management of CE is quite timely, particularly when uncertainties are swinging between extremes because of the devastating effects of the COVID-19 pandemic.

# 3. LITERATURE REVIEW

## *3.1 Transaction Cost Economics*

Coase (1937) was the first to identify Transaction Cost Economics (TCE) which is fundamental to understanding transaction costs and how those costs determine the economic activities to proceed. The reason is that the transaction costs may not be high as to exceed the net benefits arising from the transactions. TCE in its current form largely owes its existence to Oliver Williamson (Williamson, 1980), the leading figure of TCE, who later, with several other scholars, examined it theoretically and practically. According to Marsh (1998), the TCE approach differs from more traditional economic approaches that emphasise market benefits. It appears to provide a foundation for a critique of the belief that market-based delivery systems are inherently superior.

The logical sequence of the TCE approach begins with the notion that efficiency along the supply chain is guaranteed if competition is effective. If sellers or buyers can switch among their trading partners, they will permanently exclude any inefficient party. While inefficiencies are inevitable, switching is limited because it is expensive to do so. Moreover, competition will not effectively constrain switching behaviour. The source of switching costs is the investments dedicated to each relationship. These are called idiosyncratic investments or the degree of "asset specificity" (Williamson, 1980).

The concepts of transaction cost (Cavinato, 1991), lifecycle costing (Jackson Jr & Ostrom, 1980), product life cycle costs (Shields & Young, 1992), and total cost of ownership (TCO) (Ellram, 1993, 1994), are all similar. One common element is that supply managers take a long-term approach rather than a short-term initial-price approach (Ferrin & Plank, 2002). That insight is essential in analysing future business decisions, for example, organic compost processing. In short, this study focuses on understanding the challenges of processing organic compost and the supply chain that supports this initiative. TCO can be defined as "an innovative philosophy aimed at understanding the 'true' cost of doing business with a particular supplier for a particular good or service (Ellram, 1994, p. 171)". It is critical to include TCO, related to transaction costs, in the analysis of the organic compost supply chain and its cost implications.

### *3.2 Circular Economy Principles Linking Sustainability*

The use of commonly used search words "circular economy", "value creation", and "sustainability" populated 9,230 results, and the addition of "supply chain" to the above offered 6,360 results. The search results indicate a growing research interest among academia, industry practitioners, government, and civil societies in this space. Amidst heightened interest, **Table 3** shows selected studies that have used various methodologies (i.e., mathematical modelling, SEM modelling, survey, and review) and they came up with findings about organic compost from the CE perspective and how does it interface with sustainability or business viability. The list, however, does not preclude other studies on CE.

**Table 3** Selected CE and Sustainability Research

| Author(s) | Methodology | Findings |
|---|---|---|
| Cherki & Kitawaki (2022). | Mathematical modelling in Japan context | Results show that compost supply-demand dynamics display considerable seasonal fluctuation based on the crops planted at each season of the year and on different harvesting periods. |
| Rathore, Chakraborty, Gupta, and Sarmah (2022) | Mathematical modelling in the India context | Cost comparison of centralized and decentralized composting plants for organic Municipality solid waste shows the advantage of decentralized composting plants. |
| Chiarelotto *et al.* (2021) | Literature Review | Review was to discuss the broiler production chain for organic waste composting from a circular economy perspective. |
| Patwa *et al.* (2021) | SEM modelling in the India context | In an empirical study, consumer behaviour and government policies are found to significantly affect CE adoption in emerging economies context. |
| Hofstetter *et al.* (2021) | Conceptual discourse | Linking sustainable global value chain to CE, the study encouraged more transdisciplinary research from business perspectives. |
| Zhang *et al.* (2021) | Real-life cases and literature review | Highlighting the research-practice gap, Ellen MacArthur Foundation cases are referred to indicate that closed-loop, reverse, remanufacturing, recycling, and industrial symbiosis are adopted in CE practices. |
| Kristoffersen, Blomsma, Mikalef, and Li (2020) | Theoretical framework | Presented a theoretical framework to align activities between emerging digital technologies and CE. |
| Kristensen and Mosgaard (2020) | Literature review | Linking CE with sustainability, CE favours economic aspects over environmental and social impacts and may lead to a narrower approach to sustainability. |
| Pieroni *et al.* (2019) | Literature review | Presented an interface between CE-oriented and sustainability-oriented business model innovation. |
| Mishra *et al.* (2018) | questionnaires, and interviews in European FMCG | FMCG use cases from Europe indicate that creating value propositions is complex to ensure customer acceptance and business viability. |

The definition of CE varies in literature and has evolved and depends on the context in which the CE is being used. This study adopts a definition from among 144 analysed by Kirchherr *et al.* (2017). From these definitions, the researchers presented a broad definition of CE as "an economic system that is based on business models which replace the 'end-of-life' concept with reducing, reusing, recycling and recovering materials, thus operating at the micro-level (i.e., products, companies, consumers), meso level (i.e., eco-industrial parks) and macro-level (i.e., city, region, nation and beyond), to accomplish sustainable development (Kirchherr *et al.*, 2017, p. 224)". This study focuses on macro-level (i.e., regional South Australia) supply chain analysis to evaluate the logistical challenges, including the transaction cost element in adopting CE for organic compost.

Traditionally within a supply chain, value can be added in stages by a series of activities and processes from the raw material to its final consumption, known as the value chain (Porter, 1985). The value chain differs from one company to another, and the competitive advantage thereby helps achieve the triple bottom lines of sustainability. In this linear approach, the end of life of products is treated as waste that undergoes the lowest cost disposal options such as landfill or incineration (Mishra *et al.*, 2018), or recycling of the waste for second use (Meric, Selcuk, Onat, & Ongen, 2018). This study extends the value propositions further to the end of life of products by a regenerative and restorative approach which falls within the CE principle. CE concept has gained momentum among businesses, policymakers, and researchers for its potential to contribute to sustainable development (Ghisellini, Cialani, & Ulgiati, 2016; Kristoffersen *et al.*, 2020). The 4R approaches aim to avoid, reduce and negate value loss by lower emissions, reduced pollution levels, and loss of biodiversity and habitats associated with resource extraction (Kumar & Putnam, 2008). CE fosters sustainability and environmental conservation beyond recycling (Tjahjono & Ripanti, 2019).

Circular value creation has been categorised into four archetypes (Mishra *et al.*, 2018, p. 511) (1) Inner value creation loop: Maintaining the integrity of a product at its highest level via service and maintenance (to preserve materials, labour, energy, capital for their original purpose); (2) Extending value creation loops: Using products and materials longer via product durability or design for remanufacturing and reuse (to enable repeat cycles); (3) Cascading value creation loops: Cascading use in adjacent value chains (where the costs of reused products and materials are lower or have superior value compared to virgin or non-renewable materials); and (4) Pure value creation loops: Creating pure, high-quality feedstock at the outset (avoiding contamination and toxicity to allow for reuse and cost avoidance of clean up or purification). The CE connects supply and demand within the supply chain to improve resource efficiency. This aligns with the TCE perspective which translates the supply that meets the demand at a feasible cost. This approach leads to long-term sustainability.

The CE is "a regenerative system in which resource input and waste, emission, and energy leakage are minimised by slowing, closing, and narrowing material and energy loops"(Geissdoerfer *et al.*, 2017). It has recently emerged on the global stage as a principle around which multiple economic, political, and social stakeholders can rally to minimise environmental catastrophe (Hazen *et al.*, 2020). Organisations and businesses are looking towards several initiatives such as compost processing plants and stakeholder engagement and training in that context that primarily rely on government policy that encourages waste reduction and re-purpose waste profitably (Fleischmann, 2019). The concept recognises the importance of the economy needing to work effectively at all scales, for big and small businesses, for organisations and individuals, globally and locally. However, despite its expanding awareness among practitioners and academics, CE has received little attention because of inconsistent engagement, lack of leadership, and missing incentives supporting its adoption (Fleischmann, 2019).

### *3.3 SC Analysis from A TCE Perspective*

While the term "circular supply chain" has been used in some studies by incorporating CE within SCM (De Angelis, Howard, & Miemczyk, 2018; Genovese, Acquaye, Figueroa, & Koh, 2017; Mishra *et al.*, 2018; Nattassha, Handayati, Simatupang, & Siallagan, 2020), a working definition of circular supply chain management (CSCM) has only recently appeared in the literature. CSCM is defined as "the coordinated forward and reverse supply chains via purposeful business ecosystem integration for value creation from products/services, by-products, and useful waste flows through prolonged life cycles that improve the economic, social and environmental sustainability of organisations" (Batista, Bourlakis, Smart, & Maull, 2018, p. 446). In practice, CSCM aims to produce zero waste through system-wide innovations that recover value from what was previously referred to as "waste." Following the integration of CE in CSCM (Farooque, Zhang, Thürer, *et al.*, 2019, p. 884), the SC analysis (SCA) process involves evaluating each stage of a supply chain, beginning with the acquisition of raw materials from suppliers and ending with delivering final products to end-users.

Simchi-Levi, Wu, and Shen (2004) suggest that an accurate SCA is more of a continuous task than a one-time effort which serves several purposes, including mapping the chain to get an overview of product flows, actors' positions, and the interactions between each pair of transactors. Opportunities for innovation can be identified, and investors' investment decisions can be improved through a better understanding of an existing supply chain. An SCA does not only have to capture the correct type of supply chain but should also reflect this in the performance measures to be evaluated (Manavalan & Jayakrishna, 2019). Thus, it is assessed from TCE and TCO perspectives to understand and design a supply chain, in particular, an organic compost supply chain. The previous report, such as Regional SA Waste and Resource Recovery Background Report (RawtecReport, 2020), revealed that there was a mismatch between supply and demand due to failures (incapacitation) of the few current processing plants to fulfil demands for the organic composts. In taking steps towards evaluating compost feasibility in South Australia (SA), SCA is a means to that. In addition, the seasonal variation of compost demand needs is estimated and quantified through a factor defined as Compost Demand Fluctuation Coefficient (CDFC) which allows to determine of the impact of demand fluctuation on other features of the plant, such as stockyard size or optimal plant size.

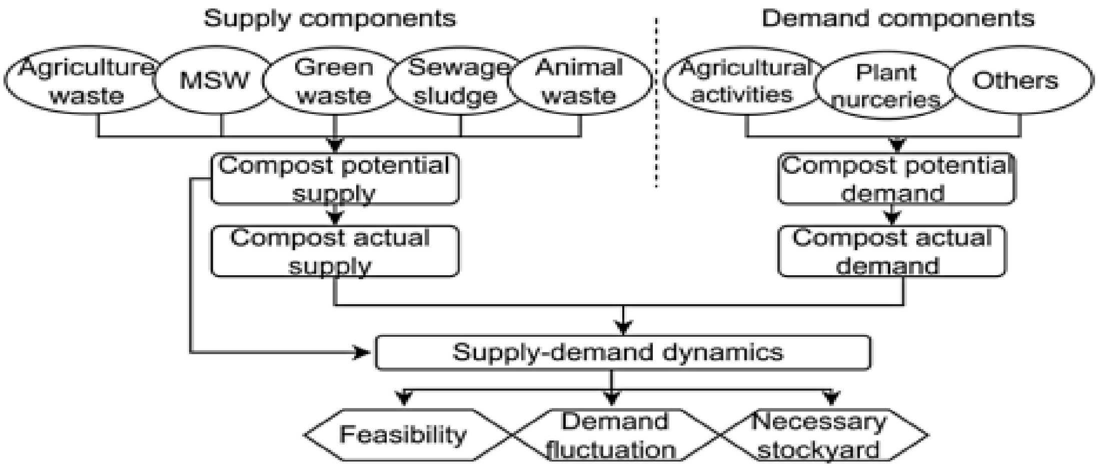


**Figure 2** Flowchart for Compost Supply-Demand Dynamics (Cherki & Kitawaki, 2022, p. 713)

**Figure 2** indicates that the model is built on demand-supply dynamics (CSD). It is estimated based on various agricultural waste being the inputs into the CSD, and agricultural activities that demand the compost. The model is used to assess an appropriate location where another compost processing plant can be conveniently located or established.

In regional South Australia (SA), councils own and operate systems for collecting and managing waste from several communities. These are one of the potential sources of organic waste materials, along with spin-off materials from regional industries. However, this is not free from challenges such as distance from sources to processors and from processors to end-users. Other challenges, from the TCE perspective, include costs of switching from the current use of organics to inorganics compost, costs of resources, disposal, processing, and transportation. Also identified are the lack of stakeholder cooperation, including service provider cooperation, lack of leadership commitment, and a lack of practical, effective standards in waste management (Vermunt *et al.*, 2019). Rathore *et al.* (2022) reveal that decentralised composting plants are more economical than centralised plants. The urgent need for the provision of more new processing plants has been an emerging issue in waste management policy and urban planning in SA. This strategic move would provide more councils with the opportunity to participate in the CE and reduce organic matter being used in low-cost ways of being sent to landfills. To achieve this objective, this study has used academic literature on supply chain analysis along with TCE to investigate the contractual difficulties as the challenge in the supply chain and offered some essential practical solutions.

### *3.4 Composting Process*

Composting is the biological decomposition of organic waste under controlled conditions to a state where storage, handling, and land applications can be achieved without adversely affecting the environment (Kadir, Azhari, & Jamaludin, 2016). According to Epstein (2017) and Smith and Collins (2007), the term used in this definition implies that the process is managed or optimised to achieve desired results. Composting is linked to the ideas of reclamation, recycling, treatment, and disposal (Hansen, Mancl, Keener, & Hoitink, 1995). Reclamation and recycling are both aspects of resource stewardship that involve saving and reusing natural resources. Constituting various physicochemical and biological processes, composting is a sustainable technology for organic solid waste treatment (Bernal, Alburquerque, & Moral, 2009). The compost products application mitigates adverse environmental outcomes (Onwosi *et al.*, 2017) and improves waste management (Chiarelotto *et al*., 2021). According to the audits conducted by ECSustainable (2022) in Australia, approximately 33% of the waste material collected by Councils is food organics, and 10% is garden vegetation. Surprisingly, such a large amount of organically active material is currently buried anaerobically in landfills, contributing more than 3% of Australia's total greenhouse gas emissions each year through methane gas production (which has 25 times the global warming potential of carbon dioxide) (ICAW, 2021).

Compost quality is determined by several variables, including raw material particle size, aeration, moisture, temperature, pH, carbon to nitrogen ratio (C: N), and pathogen elimination. If these are not monitored correctly during the fermentation process, it results in the compost of low quality. For example, an assessment of some composting plants in the area of Souss Massa in Morocco proved that the lack of regulation relating to the composting activity in Morocco caused problems of inadequate process monitoring and low quality of compost (Cherki & Kitawaki, 2022).

Composting, however, has several advantages. According to Chen, de Haro Marti, Moore, and Falen (2011), composting typically reduces manure volume by 30 to 50%, making the material significantly more affordable to transport and other benefits. Diverting urban solid waste organic material from landfills to composting has environmental benefits, such as lowering greenhouse gas (GHGs) emissions from landfills. Using compost on land reduces the need for water by an average of 30% and dramatically improves soil quality, helping grow vegetables and fruits.

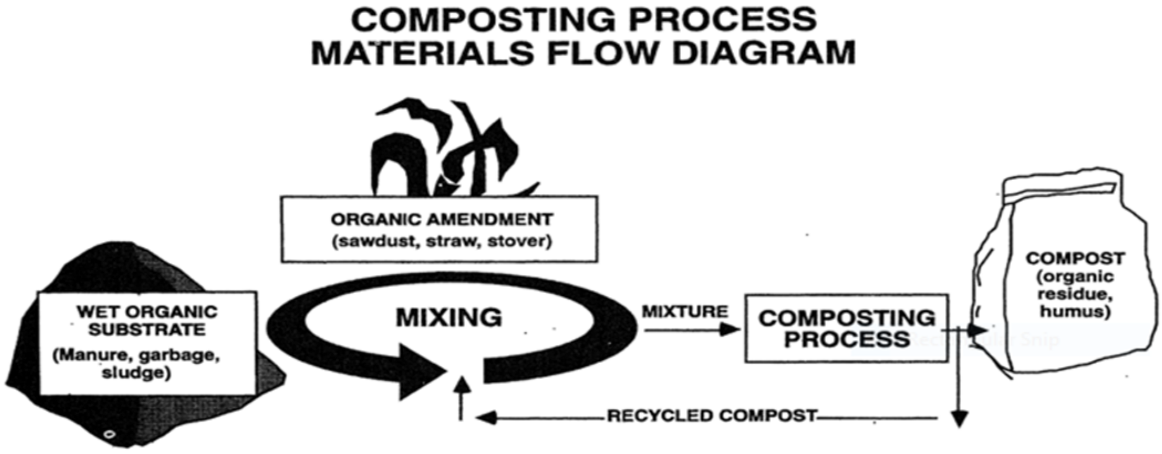


**Figure 3** Composting Process (Hansen *et al.*, 1995)

The composting process is depicted in **Figure 3**. The process begins when the inputs such as manure, sawdust, sludge, etc. are gathered. The degradation of organic waste is a natural process that begins soon after the waste mixture is generated. Organic materials continue to decompose and are eventually converted to biologically stable humic substances, the mature or finished compost, once optimal physical conditions are established (such as microbes that require "food," suitable moisture, pH, temperature, and oxygen).

One of the significant downsides of using compost is that there are risks with the composting processes, such as physical, chemical, and biological contaminants and negative direct/indirect environmental impacts (Pergola *et al*., 2020). Contamination reduces the value of the material, and while it can be reduced by monitoring and screening technologies, it reduces consumer confidence in the quality of the product being supplied and can impose significant costs on users (EPA, 1999). While using food-driven compost, the main concern is loading the soil with metals, resulting in increased metal content in the crops (Hargreaves, Adl, & Warman, 2008). Against this background, contamination and other risks associated with composting are essential aspects of this study to examine in detail how best the current situation can be improved and suggest possible solutions to the potential risks.

# 4. METHODOLOGY

This study used semi-structured interviews with suppliers, processors, and end-users in South Australia. Interview approach elicits descriptive qualitative responses that help address research objectives (Gajendran & Oloruntoba, 2017). As the existing knowledge drawn from literature is limited, the interview approach offered an opportunity to study the phenomenon in its natural setting where complex links and underlying meanings could be explored through participants enabling the researchers to analyse the whole supply chain (Mohajan, 2018).

The questionnaire used 12 items with open-ended interviews. With study objective(s) in mind, the questionnaire was self-developed based on literature knowledge of waste stream, logistics challenges in supply and demand, contractual agreement among stakeholders, transaction cost economics, and switching costs of doing business in an organic compost supply chain. The questionnaire was pre-tested within the research team comprising a supply chain academic and an industry mentor who corrected the clarity and logical flow of items. Interview protocol comprised: (1) demographic information, (2) a summary of business, (3) a questionnaire covering circular economy, supply chain challenges, contractual arrangement, and transaction cost. Human Ethics was approved (Victoria University, HRE21- 008 16/02/2021) to conduct interviews with primary suppliers, processors, and end-users.

**Table 1** (section 2) provides a potential volume of organic feedstock from various sources of councils within Legatus Group, and **Table 2** (section 2) is a list of business sources of organic waste. Interview participants were recruited through the Legatus group and followed a snowball sampling technique for more contacts from this list. Senior managers and owners of small and medium enterprises (SMEs) in SA engaged in businesses having various waste processing plants, and end-users of compost were interviewed. Five interviews were conducted in regional SA, although a minimum of nine were intended for validity and generalisation of findings (Hennink, Kaiser, & Marconi, 2017). The low number of interviews can be attributed to the COVID-19 pandemic that restrained the potential participants as businesses operated under multiple lockdowns and restrictions. However, despite the limitations, the smaller sample in this study can be justified in line with Boddy (2016), who asserted that smaller cases could also provide a new, deep and nuanced understanding of previously unexplored phenomena. Furthermore, qualitative researchers have noted that often a researcher can (unknowingly) have all the data they need from their first piece of data collection (Sandelowski, 1995). The small number of interviews were analysed manually, which was time effective.

**Table 4** below provides SMEs (coded as C1 to C5 for confidentiality) as either sources or users or both where the participants have been engaged in waste management for the last five to 12 years. Only one processor, from the existing two, was interviewed. These SMEs are sources of chicken manure, cattle and sheep feed, and mill waste, and mostly compost users for agriculture cropping and wine vineyards. The processor receives and processes metropolitan Adelaide's green organics.

**Table 4** Respondent Demography

| No | SMEs | Category | Description | Experience with compost (Yrs.) | Waste/Compost material types |
|---|---|---|---|---|---|
| 1 | C1 | Source | Family farm | 8 | Chicken manure& biosolids |
| 2 | C2 | Source/ User | Family Farm | 6 | Cattle feed and sheep, agricultural cropping |
| 3 | C3 | Source/ User | Family business | 12 | Mill wastes |
| 4 | C4 | Source/ User | Grape growers and winemakers | 5 | Viticulture |
| 5 | C5 | Processor | Processor | 1 | Receive and process metropolitan Adelaide's green organics |

### *4.1 Reliability and Validity*

Following the recommendations by Venkatesh, Brown, and Bala (2013), Yin (2018), and Simpson *et al.* (2021), we addressed the reliability, construct validity, internal validity, and external validity of this study. Interviews were carried out with selected participants representing suppliers, processors, and end-users who are engaged in organic compost and shared their lived experiences. The authors carried out the coding independently and then verified with each other. This satisfies the data completeness and source reliability. Construct validity was measured by a self-developed questionnaire that was based on literature knowledge as no prior qualitative studies were available in the context of the organic compost supply chain. The content validity was assured by pilot testing, and comments were assimilated that ensured the alignment with the study objective. Internal validity (credibility) in the qualitative study means the extent to which data are plausible, credible, trustworthy, and defendable (Venkatesh *et al.*, 2013). In the organic compost triadic supply chain, the choice of interview participants within a triad appears appropriate. The interviews that explored the benefits, as well as challenges, appeared credible and trustworthy. A review of academic literature, the latest industry, and government reports confirmed the validity. External validity (or transferability) was confirmed as the findings would remain the same amidst the challenges and practical difficulties experienced by each case context. The findings would likely hold well with other triads engaged in organic compost activities within Australia.

## 5. DATA ANALYSIS AND FINDINGS

### *5.1 Sources of Organic Waste*

The sources of organic materials include green waste, kerbside collected green waste, untreated timber, sawdust, straw, paper, cardboard, manure and sludge, waste from meat and fish preparation, etc. From this list, a small number of sources within regional SA have been chosen from kerbside collections, broadacre farming, timber processing, and animal meat production. Three participants from sources were interviewed about their companies' organic waste management practices. Recognising this as a small sample, interviewees were invited also to comment on trends and practices within SA's Mid-North broader agricultural industry. Each participant was employed within a target industry for locally produced compost.

The interviewees (C1, C2) indicated that raw materials/waste was currently being repurposed rather than discarded. Consequently, "*organic waste is not waste but rather a resource that is already in use*" (C1). The current uses are low-cost and value options that require almost no specialised, idiosyncratic investment. Furthermore, the sources are complex, diverse, and unorganised in business associations. Current uses are simple and often informal, and processors will need to attract these materials to the higher-value option of composting by offering an attractive total cost of ownership.

With regards to participating in a future organic processing supply chain, the interviewee (C5) indicated that "*suppliers do not need to make significant, dedicated investments*". Their role is to deliver materials/waste meeting specifications to the processor, who will then prepare them for processing and charge a fee for doing so. This means that sources of organics are largely insulated from the potential for opportunism. If the processors were "*to impose significant costs on the suppliers, they could return to current arrangements at little or no cost*" (C5).

The supplier will need to monitor performance against the supply specification and will incur TC in doing so. It will require constant control of the organic material, which adds complexity and some uncertainty, hence increasing TC. However, that control is unlikely to be expensive as it concerns the core business of the supplier. For example, a wheat grower must, in any case, monitor their crop (for chemical residues, contamination, etc.) and that monitoring will extend to any residue sent for composting. In terms of failure costs, by incurring the costs to specify and monitor arrangements, its likelihood can be effectively constrained for sources. The expected cost of failure is the product of the likelihood and the consequences. But, in this case, the consequences are primarily having the material returned and having to revert to the original low-cost use. So, they are not thought to be prohibitive.

The implication is that, while by no means a simple matter, the logistical challenges confronting potential suppliers appear to be minor. Thus, transaction costs are unlikely to be a significant impediment to suppliers' involvement. As a result, the barriers to participation in the organic compost supply chain are relatively low for sources. We now turn to processors with the same analysis.

### *5.2 Processors of Organic Compost*

The interviewee (C5) indicated that the processor created a wide range of products (about 300 potential products in the range), with six to seven as primary products. Regarding asset specificity, the small-scale composting relevant to regional processing is, in general, not capital intensive, which limits the dedicated investments required for processing. For example, trucks and front-end loaders are used, but they are generic machines that can easily be switched to other uses. This is unlikely in large processing facilities which use rotating equipment to aerate the materials/waste. Processors do need to invest in shredders and aerating equipment, but it is possible to service small-scale plant with mobile equipment. The last point implies that the actual product specification will need to be agreed upon with the local users in advance or, in some cases, they will have to process the products on a make-to-order (MTO) basis. Either option will incur significant transaction costs (TC).

Contamination of inputs has been identified as a critical issue by all. This is particularly so when the user wants a clean and green environment (Semple, Reid, & Fermor, 2001). Contamination poses costs of rejection and claims for damages, as well as costs in terms of reputational health, and safety risks. For private farmers, there is a challenge in of disposing large volumes of agricultural waste. One participant (C5) mentioned that "*Sometimes they must pay a penalty fee of disposing of these wastes if the waste is rejected by processors due to contaminations or non-conformance to specifications required*".

The processor stated that, on occasions, he rejected some feedstock due to high levels of contaminants and manual and/or mechanical sorting is necessary for the removal of physical contaminants. All that adds to the TC. Furthermore, it has emerged that the agreements that processors reach with users will have ramifications for the arrangements that processors make with suppliers. This implies that users want to specify the product and processors will need to balance that specification with those agreed to by the sources.

The problem of contamination and user specifications complicates the situation. Given the difficulties and frequency of the transactions, specification and monitoring costs are likely to be significant. Enforcement of specifications is also a component of TC. Processors will need to write contracts that can be enforced through the legal system. However, experience from the interviews suggests that informal agreements enforce specifications which are expected. Small and regional transactions are often supported by community-based, informal practices, making enforcement relatively inexpensive, albeit somewhat uncertain. That reduces TC in some respects, although it can also increase the expected cost of failure.

Overall, SC analysis indicates that processors face high transaction costs, especially in monitoring and dealing with the consequences of contamination. These transaction costs are high and are likely to outweigh those faced by suppliers. Reducing transaction costs for processors is expected to boost the development of these organic compost supply chains significantly.

### *5.3 Users of Organic Compost*

Turning now to regional users of organics (C2, C3, C4), they are mostly farmers. Farmers are currently using a combination of synthetic fertilisers, biosolids, and manure to improve soil productivity. Most farmers currently source synthetic, inorganic fertiliser through long and distant supply chains. Some have reported that they use chicken manure; both pure and a blend of manure with straw bedding mostly collected from farms.

According to the analysis, current supply chain logistics are problematic because the entire season's fertiliser is ordered at once, posing cash flow and storage issues. This implies that switching to organics will be a major change for many broadacre farmers and major changes are subject to uncertainties and apprehension, adding to TC. Furthermore, when it comes to switching costs, interviews revealed that "*the current supply of synthetic fertiliser is in pallet form, but the organics might be incompatible with the spreader equipment currently used, requiring users to make financial commitments by purchasing new equipment, exposing them to the potential for opportunism on the part of the processors*" (C3). Asked whether they have used organic fertiliser: "The interviewee responded, "*We prefer synthetic fertiliser because it gives more return on Investment"* (C4). Asked about whether they use standards as a compliance requirement (AS 4454:2012) for their products, he responded*" I think they're probably a little bit vague potentially and therefore need to be improved*" (C5).

Soil additives are applied in an integrated and seasonal process. It means that a failure in some future local supply chain will result in additional TC because the right, complementary alternative must be sourced, or, more likely, users will hold sufficient stockpiles to complete the season. Similarly, different crops will necessitate different composts, so users must specify the qualities required for the processor. This procedure will be time-consuming and costly, as it will include soil testing and other methods. Adding to the complications is that it seems likely that inorganic fertilizers will be used in conjunction with any organic compost, making specifications more difficult.

Finally, the last element of TC, the expected costs of contractual arrangement failure, are expected to be high for users. As with processors, the likelihood of failure for users can be constrained by incurring TC in specification and monitoring but the consequences can be severe. The overall conclusion is that users face high transaction costs, particularly the expected costs of failure.

## 6. DISCUSSION AND IMPLICATIONS

### *6.1 Discussion*

The study aims to analyse a supply chain that adopts CE to achieve a sustainable economic future by following 4R practices (i.e., reduce, reuse, recycle, recovery of waste) *(*Kirchherr *et al.,* 2017), and preserves natural resources by restoring value from waste (Farooque, Zhang, & Liu, 2019). Despite the growing importance and benefits of CE, implementing CE in a supply chain is not free from challenges (Ghisellini *et al.,* 2016). Logistical, contractual, and industrial application challenges for organic compost are likely to result in high transaction costs (TC). Moreover, organic compost adoption depends on how competitively it is priced compared to inorganic fertiliser (Chen, Zhang, & Yuan, 2020). **Table 5** below summarises the challenges facing the supply chain partners when it comes to CE practices within the chain. Transaction costs are high in many cases as discussed within the table below.

**Table 5** Challenges Facing Organic Compost Supply Chain

| Actors | Issues | Explanation of issues |
|---|---|---|
| 1. Suppliers | Organic waste sources | Sources are complex, diverse, and unorganised in business associations. |
| | Organic waste specification at source | Materials/waste need to meet specifications (contamination free) for processing. |
| | Control of organic waste | Complexity and uncertainty may increase transaction costs (TC). |
| | Participation in the organic compost supply chain | Relatively low for suppliers because of low logistical challenges and low TC. |
| 2. Processor | Depends on either a small or large processing plant | For small-scale composting, the processing is not capital intensive. But large processing facilities need rotating equipment to aerate the materials/waste. |
| | Actual product specifications need to be agreed upon. | Product specifications need to be agreed upon in advance or, agreed to products on a make-to-order (MTO) basis. Either option will incur significant transaction costs (TC). |
| | Rejection due to waste contamination | Processor rejects the waste due to contamination and involves disposal cost paid by the suppliers. |
| | Contractual difficulties and high transaction cost | Monitoring and dealing with the consequences of contamination is high for processors even if a contractual agreement is in place. |
| 3. End-users | Inorganic fertilisers are commonly in use | Synthetic and inorganic fertiliser are acquired through long and distant supply chains. |
| | Logistical problem | Because the entire season's fertiliser is ordered at once, posing cash flow and storage issues. The major changes are subject to uncertainties and apprehension, adding to TC. |
| | Specification issues | Specification varies for crops. The right specification includes soil testing and other methods. Mixing inorganic fertilizers with organic compost will make specifications more difficult. |
| | High transaction cost | Users face high transaction costs, particularly the expected costs of failure. |

## *6.2 Suggested Remedies for the Issues*

First, it is to create more substantial, stronger organisations (e.g., economic institutions) that provide a framework in which transactions might be organised competitively. TC is reduced by organisations with membership rules and procedures that address the logistical challenges by reducing the costs of specifying, monitoring, and enforcing contractual arrangements and the risk of those arrangements failing. Coalitions of Councils can deepen participation in the CE. Consider Regional Composting Cooperatives (RCC), formed by all participants along the supply chain. The RCC could establish membership rules that help reduce TC. For example, we have identified quality control as a key issue. The cooperative might have membership rules which require participants to use only accredited testing laboratories or to meet a checklist of criteria. Along the same lines, an alternative would be to establish a council-led institution such as the Organic Waste Management Authority (OWMA). It would be a trusted organisation that could act as a broker among participants and provide targeted assistance.

Second, the suggested remedy is to take specific action to address the anticipated problems identified in the interviews. This will necessitate the state government's involvement (Fleischmann, 2019), and may include, for example, providing a sampling and testing service to reduce monitoring costs or introducing a joint scheme to underwrite the costs of failure. Other suggested strategies include activities to increase trust in the composting industry by training and educating supply chain participants, particularly about contamination, via roadshows and other activities.

Third, in terms of logistics needs, it is recommended that the number of third-party logistics (3PL) providers be increased. A 3PL provider is a specialised company that provides customers with distribution, storage, transportation, and fulfilment services. They offer full-service management of specific services. In this study, they either collect and deliver materials from sources to processors or collect and deliver organic compost products to end users. The practice of increasing the number of players in logistics services will increase competition among service providers. This will result in lower transportation costs because suppliers, processors, and users will be able to negotiate transportation costs and choose who will provide the best service, resulting in cost savings and increased efficiency.

## *6.3 Theoretical Implications*

The study contributes to developing a convincing discussion and providing a better understanding and insights into the supply chain and logistical challenges of connecting all three stakeholders so that they make judicious decisions. Understanding the ground reality, as highlighted in this study, will reveal more knowledge than theorising, as evidenced by most cases in the literature. The literature remains oratory on the challenges and opportunities for partners to embrace CE in the circular supply chain (Hofstetter *et al*., 2021; Kristensen & Mosgaard, 2020). But the shift from a linear economy to a complex CE requires a transformation in the supply chain (Zhang *et al.*, 2021) where this study has contributed by analysing in detail a triadic supply chain involving suppliers, processors, and users to reveal the ground-level difficulties with CE. Compost processing faces difficulties when it comes to waste quality, supply volume, processing equipment and asset specificity, and organic compost specification. While authors discussed the lack of collaboration/support from supply chain actors and stakeholders as the most prominent barrier to CE adoption (Farooque, Zhang, & Liu, 2019), this study has identified that suppliers require no investment as compared to processor and end-users who need to invest on processing plants/asset specificity and spreading equipment for mixing organic with inorganic compost respectively. Thus, transitioning from a linear economy to a complex CE, this study highlights that TCE plays a critical role. Incorporating TCE in the contractual agreement between the partners shows the likely success of CE practices in a supply chain. Extending TCE into the CE environment is a unique contribution.

### *6.4 Practical Implications*

The initiatives proposed in the study reveal that to develop regional processing, councils need a tool supported by supply chain analysis and TCE for assessing the impact of such an investment. Moreover, it implies that responsible authorities can initiate community skill development and training in areas such as material source separation, disposal pathways for materials, reduction of waste, minimisation of contamination, where to dispose of materials, etc. These solutions will necessitate a stronger collective voice for the Councils aiding the development of policies and acquisition of funding to address the issues. More relevant and coordinated research in feasibility studies increased community participation and government interventions to improve composting processes, handling, and efficiency are required. These solutions can be implemented by enlisting the help of more supply chain professionals, consultants, and researchers. On the same note, providing ongoing education can help to reduce contamination and increase landfill diversion, reducing supply chain costs for councils.

## 7. CONCLUSION AND LIMITATIONS

The research established the fact that raw organic material is currently repurposed rather than discarded and is therefore not waste per se. But current uses are simple and low cost, which also means that they are low value uses. Regarding regional sources of organics, their logistical challenges appear to be minor and, thus, transaction costs are unlikely to be a significant impediment to suppliers' involvement. Processors face high transaction costs, especially in monitoring the process in line with the specifications of each region’s user requirements and managing the consequences of failing to eliminate contamination. Reducing these transaction costs by addressing the logistical challenges is expected to boost the development of these supply chains significantly. The challenges facing users also constitute a significant impediment to the emergence of the proposed organic compost. The study, therefore, revealed that, while organic waste processing appears to be viable for organic compost, the cost of organising its supply chain might be prohibitively high. Building more processing plants is unlikely in the absence of additional initiatives from the councils and industry bodies in the locality.

In terms of limitations, this research focused solely on potential sources, processors and end-users, and industrial applications which hampered the inclusion of community-level sourcing and applications. The impact on the environment and social well-being was beyond its purview. The SC analysis can include these dimensions in any future research. Furthermore, many industry members were largely unavailable at the time of the interview because it was the season of peak activity. COVID-19 lockdowns and restrictions meant that the target number of interviews could not be met. Future research can involve more participants at each stage of the supply chain. Other research efforts that address odour control, toxic contamination, materials handling, and other methods for demonstrating new compost handling methods could be explored. A mixed methods study could reveal more details of the organic compost supply chain challenges that might have been missed through these interviews.

## DATA AVAILABILITY STATEMENT

*The data that support the findings of this study are available from the corresponding author, [BKC], upon reasonable request. We have no conflicts of interest to disclose.*

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