Barriers to sustainable food consumption and production in China: A fuzzy DEMATEL analysis from a circular economy perspective

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Abstract

The global agri-food sector is in a dire need of transitioning into sustainable consumption and production patterns. The circular economy concept offers a viable pathway to improve resource efficiency and recover value from food loss and waste. Although China has made circular economy a strategic component of its national development strategy, it has faced multiple barriers which persisted in the full-scale implementation of sustainable food consumption and production. We aimed to empirically investigate these barriers, based on data from three key stakeholder groups in the food supply chains: the food processors, sales and distribution firms, and consumers. We quantified the cause-and-effect relationships among barriers by the fuzzy decision making-trial and evaluation laboratory analysis (Fuzzy DEMATEL) technique. All groups identify weak enforcement of environmental regulations and lack of environmental education and accountability as key cause barriers in China. Our results suggest that policy level changes include enhanced regulatory attention, and new educational initiatives will be required in China. Managers should focus on waste separation and gaining economies of scale. Together, these initiatives will help promote sustainable consumption and production for a paradigm shift to a circular agri-food supply chain system.

Keywords: *Circular economy; Circular supply chain; Food loss and waste management; Sustainability; Sustainable consumption and production*

1. Introduction

To ensure sustainable consumption and production (SCP) patterns is one of the 17 Sustainable Development Goals of the United Nations. "Sustainable consumption and production is about doing more and better with less. It is also about decoupling economic growth from environmental degradation, increasing resource efficiency and promoting sustainable lifestyles" (United Nations, 2020). The food sector has been one of the focus areas for making the transition to SCP patterns because the sector is responsible for about 30% energy consumption and 22% greenhouse gas emissions of the world (United Nations, 2020). According to the Food and Agriculture Organization (FAO), about one-third of the food produced for human consumption (approximately 1.3 billion tons worth around $1 trillion) is lost or wasted in food production and harvesting, sales/distribution, and consumption stages every year (FAO, 2011). On the one hand, the world needs to reduce food loss and waste along the supply chain to meet the increasing consumption needs of a growing population (Parfitt et al., 2010; Toop et al., 2016). On the other hand, the current food waste management systems need an overhaul to maximize value recovery. Taking multiple European countries as an example, food waste accounts for about 60% of the total municipal bio-waste, which is collected separately and treated by composting or anaerobic digestion with biogas production (European Environment Agency, 2020). However, the rate of separated bio-waste collection averaged about only 43% in 2017, and the remaining bio-waste was not separated from other municipal waste and thus lost for value recovery (European Environment Agency, 2020). In many other countries including China, food waste recycling is much less developed and food waste is often disposed of together with other municipal waste and sent to landfills.

The circular economy (CE) concept can support systemic changes required to increase implementation of SCP measures and recover value from valuable food waste resources. In recent years, CE has been increasingly recognized as a more sustainable alternative to the dominant linear (i.e., take, make, and dispose) economic model (Ghisellini et al. 2016) which offers a new and compelling sustainability perspective (Farooque et al., 2019a). CE finds its root in the concepts of industrial ecology, biomimicry, and cradle-to-cradle (Yuan et al., 2006; McDonough and Braungart, 2008; Mentink, 2014). It is an innovative industrial ecosystem that is restorative and regenerative by design (Ellen MacArthur Foundation, 2014). In CE, technical materials (e.g., metal and plastics) are designed for recovery (remanufacturing, refurbishing, and recycling), and biological materials (e.g., fruit peels and chicken bones) are safely returned to the biosphere to enhance natural capital. By circulating the use of materials, CE aims to improve resource efficiency with virtually no creation of waste (Ellen MacArthur Foundation, 2014), in a way that will reduce costs of both resources and energy as we shift towards SCP (Broadbent, 2016). In a fully circular economy, forward supply chain operations, recycling activities, and value recovery from waste are powered by renewable energies, so that materials circularity is achieved without creating negative environmental footprint. Such a vision, although far from being a reality, inspires the world to move in the right direction.

Policymakers and business leaders worldwide have started to embrace CE as an innovative and more sustainable economic model. Several major economies, including the European Union, China, and Japan, have made CE part of their regional/national development strategy. Organizations including Apple, Philips, Coca-Cola, and IKEA are committed to CE to enhance their sustainability performance to create value for their customers and other stakeholders. In the agri-food sector, taking the U.K. as an example, it could save annual landfill cost by USD 1.1 billion if organic food wastes were kept out of landfills. Other benefits include a reduction of greenhouse gas emissions by 7.4 million tonnes each year, electricity generation of up to 2 GWh each year through waste-to-electricity technologies, and organic compost to restore soil fertility (Ellen MacArthur Foundation, 2013). The world is in a dire need to fight environmental degradation and to reduce greenhouse gas emissions to combat climate change. Therefore, it is of strategic importance to implement CE principles in food waste management.

Despite these potential benefits to SCP in the agri-food sector, it is not clear how progress can be made in developing and embedding CE principles into the industry due to the presence of multiple barriers. These sustainability barriers are often intertwined, so it is difficult to divide and address them sequentially (Han et al., 2008, Jurgilevich et al., 2016; Ghisellini et al., 2016). In addition, studies of food waste management have mainly focused on the consumption stage (Schanes et al., 2018). Similarly, studies of barriers to sustainable food waste management have also focused on the consumption stage, for example, do Carmo Stangherlin and de Barcellos (2018) and Lazell (2016). Although substantial environmental impacts from food loss and waste also occur in the food processing and sales/distribution stages (United Nations, 2020), no study has systematically investigated sustainability barriers in these stages along with those in the consumption stage in the context of China. It has been widely acknowledged that supply chains should be studied as systems as a supply chain player's behavior and performance are influenced by those of other players, which is evidential in the bullwhip effect (Lee et al., 1997). SCP require collaboration and close coordination among multiple supply chain actors (Borrello et al., 2016). Therefore, it is essential to employ a systems approach to investigate its implementation barriers.

Our results narrow the knowledge gap by investigating barriers across multiple stakeholders in the forward supply chain, including food processors, sales/distribution channels, and consumers. It provides a more holistic and systematic view to help overcome the barriers to sustainable food consumption and production from a CE perspective focusing on value recovery from food loss and waste. In contrast to earlier works which tended to study challenges as isolated ones at the consumption stage, this research investigates sustainability barriers in the context of the larger supply chain system in which an actor is embedded in.

Applying such systems thinking can help uncover the interdependency among system actors and provide deeper understanding in the root causes of complex problems. Therefore, it can better predict behaviors and, ultimately, adjust their outcomes (Richmond, 1993). Given that waste disposal behaviors vary in different cultures, there is a need to study barriers in specific regional and cultural settings to take into account the effect of regions/cultures.

The context of this study is China, the largest developing country that has both great need and commitment to implement CE. The insights offered from the research are not only applicable to agri-food businesses and their supply chain operations in China but also shed light on similar operations in many other economies that struggle with a transition to sustainable food consumption and production. The research addresses the following research questions:

- What are the key barriers hindering sustainable food consumption and production for transitioning to a CE in China?
- How can the interdependency between the barriers be uncovered for identifying and overcoming the root cause barriers?

This research answers the first question by identifying a list of important barriers based on literature and insights from the Chinese agri-food sector. The multiple barriers influence decision-makers and suggest that a multi-criteria decision-making model (MCDM) would be valuable (Çelikbilek and Tüysüz, 2016). It addresses the second question by utilizing the Fuzzy decision-making trial and evaluation laboratory technique (Fuzzy DEMATEL), to systematically analyze the complicated interdependency between barriers. Fuzzy DEMATEL is a fuzzy set extension to the standard DEMATEL technique (Gabus and Fontela, 1972). In comparison with standard DEMATEL, Fuzzy DEMATEL is more advantageous because it can address the inherent vagueness, bias and uncertainty in human judgments which are part of the concerned research phenomenon (Wu and Lee, 2007; Lin, 2013). Its methodological procedures are similar to grey-based DEMATEL, another widely used variation to the standard DEMATEL (Si et al., 2018). We used Fuzzy DEMATEL because it has greater capacity than grey-based DEMATEL in handling vagueness. Fuzzy DEMATEL uses three-dimensional triangular fuzzy numbers (TFNs) (e.g., 0, 0.25, 0.75) (Kumar et al., 2013), while grey-based DEMATEL uses two-dimensional grey numbers (e.g., 0, 0.75) to represent the linguistic variables. Based on the findings from the Fuzzy DEMATEL analysis, we discuss managerial and policy implications on how the barriers can be addressed.

The rest of the paper is organized as follows. Section 2 reviews relevant literature. Section 3 describes the methodology and data collection procedure. Section 4 presents the results and analysis. Section 5 discusses managerial and policy implications. Section 6 concludes the research.

2. Literature review

2.1. Food waste management and sustainable consumption and production

The United Nations Environmental Program (UNEP, 2020) defines SCP as “the use of services and related products, which respond to basic needs and bring a better quality of life while minimizing the use of natural resources and toxic materials as well as the emissions of waste and pollutants over the life cycle of the service or product so as not to jeopardize the needs of future generations”. FAO (2011) defines food losses as “the decrease in edible food mass throughout the part of the supply chain that specifically leads to edible food for human consumption” (p. 2), which take place at production, postharvest and processing stages in the food supply chain. Food waste is defined as “food losses occurring at the end of the food chain (retail and final consumption)” (p. 2). Food loss and waste reduction is the major global economic and political agenda as one third of globally produced food is lost or wasted in the food chain (Corrado et al., 2019). This is especially becoming imperative amidst the call for exploring the connection between food waste generation and waste management under the broader framework of sustainable production and consumption (Alexander et al., 2013; Lehtokunna et al., 2020). In the food systems, SCP face many issues due to complex interdependency in a web of political, institutional, and technological factors (Heller and Keoleian, 2003; Papargyropoulou et al., 2014). It is also closely linked to their value chain governance patterns (Messner, et al., 2021). It is also imperative to recognize the food categories with high environmental intensity (Beretta & Hellweg, 2019). Some of the other unique challenges that food supply chains face include frequent production setups, strict regulations, perishability, storage condition requirements, transport damages, processing loss, contamination, and recycling issues (Al-Ansari et al., 2015; Behzadi et al., 2018; Sonesson et al., 2018; Matzembacher et al., 2020). These challenges are further escalated by widespread growth and structural shift in the food consumption pattern of urban and rural consumers and more challenge is to have the conceptual understanding on the nature of food wastes and their treatment (Dobermann and Nelson, 2013; Matzembacher et al., 2021). Hence, there is a growing need to theorize sustainable food supply chains (Sala et al., 2016; Zhu et al., 2018; Matzembacher et al., 2021).

Food waste management is one of the key challenges in sustainable food consumption and production (Garcia-Herrero et al., 2018). As mentioned earlier, food loss and waste account for about one-third of the global food production, equal to 1.3 billion tons per year. A few studies reported the magnitude of food losses and wastes in the production and consumption stages with respect to developed and developing countries (Smil, 2004; Parfitt et al., 2010; Gustavsson et al., 2011). Their causes are diverse (Buzby and Hyman, 2012; Girotto et al., 2015; Luo et al., 2021). Some product wastes are not suitable for consumption; they need to undergo re-processing for value recovery (Sonnino and McWilliam, 2011). Some even pose environmental threats and hygiene problems (Gustavsson et al., 2011). Besides, it is difficult to track or separate the costs from the perspective of organization that generates the waste (Eriksson et al., 2017). In the meantime, new technologies (e.g., Industry 4.0) and enhanced collaboration may support firms to address these threats and recover more value (Rosa et al., 2020). Lately, literature shows interest in developing strategies to manage those products (wastes) effectively, as they are recognized as an alternative way to food supply (Stancu et al., 2016). However, the available studies appear to be biased towards the quantification of wastes and losses by projecting them as a negative phenomenon (Eriksson et al., 2018). Amidst this, researchers demand the need for fresh perspectives of food waste generation studies from multi-stakeholder perspectives (Corrodo et al., 2019).

In China alone, the annual food waste is in the range of 200 billion Chinese Renminbi (RMB) (Chen et al., 2015). The loss of grains (or *liangshi* in Chinese) in the entire supply chain is about 19.0±5.8%, with the consumption stage being the single largest source of food waste (7.3%). The estimated loss in storage, processing, and distribution is 8%, 2.6 %, and 3%, respectively. This level of waste is equivalent to about 135 billion m^3 of water footprint, and about 26 million hectares of land being cultivated in vain (Liu et al., 2013). Besides, the post-harvest stage contributes around 35 million tons wastage in storage mainly due to fungi, rodents, and insects (Zhao et al., 2011; SAG and NDRC, 2011; Liu et al., 2013). Additionally, there are some significant processing, transportation, and distribution losses in the system (Liu et al., 2014).

2.2. CE oriented food loss and waste management

The CE concept offers a new perspective to sustainable food loss and waste management as it considers wastes as resources for value recovery (Ciacteillo et al. 2016). As mentioned earlier, diverting organic food wastes from landfills could generate tremendous economic and environmental benefits (Ellen MacArthur Foundation, 2013). In a recent study, Santagata et al. (2020) summarize the challenges and opportunities of food waste recovery in CE. The research on food value chain primarily on the production, business and industry trends. The focus on transition towards a circular economy is topical on food value chain and waste literature, till recently the focus has been mostly on consumers (Lehtokunnas et al., 2020). At the policy level, it is the part of Farm-to-Fork strategy proposed by the circular economy package as a part of global initiative (Corrado et al., 2018). However, such a mission requires a systems approach because food loss and waste occur at multiple stages along the supply chain including agricultural production, postharvest handling and storage, processing, distribution, and consumption (Liu, 2014). The multiple sub-systems and components mean that integrated decision making is crucial (Lechner and Reimann, 2020; Jabbour et al., 2019). Therefore, CE oriented food loss and waste management requires close coordination of supply chain actors including farmers, bread producers, retailers, compostable manufacturers, insect breeders, livestock farmers, and consumers (Borrello et al., 2017). Its first step is to collect and sort a large variety of food wastes efficiently from spatially dispersed sources. Afterwards, food wastes are treated by appropriate value recovery options. Efforts should be made by managers to reduce resource use and waste by carefully assessing supplier capabilities and their supply network to ensure waste is not only avoided at their facilities but also at other facilities along the supply chain (Bai et al., 2020). Throughout these efforts, there remain challenges for firms that wish to transition to a profitable CE business model, with many barriers (e.g., customer behavior or financial limitations and constraints) that are outside of the managerial control (Loon and Wassenhove, 2020). In a study, de Sadeleer et al. (2020) analyzed the performance of transition into CE and waste prevention through recycling and energy recovery.

2.3. Barriers to CE implementation in China

Despite of a promising vision, CE implementation faces a variety of barriers. Govindan and Hasanagic (2018), Tura et al. (2019), and De Jesus and Mendonça (2018) provided general classifications of CE implementation barriers. Given that CE implementation barriers are context specific, most barrier studies focused on a specific region/country. For example, Kirchherr et al., (2018) investigated barriers in the European Union, and Mont et al. (2017) focused on the Sweden context. This subsection reviews barriers to CE implementation in China which is the context of this study.

CE implementation in China has been driven by government agencies such as the National Development Reform Commission (NDRC) and Ministry of Environmental Protection (Mathews and Tan, 2016; Geng et al., 2014;). However, China's progress in CE implementation has been modest due to the persistence of many barriers (Mathews and Tan, 2016; Pesce et al., 2020). Further, Su et al. (2013) analyzed CE implementation barriers including lack of incentive schemes for CE projects, absence of high-end technology towards CE practices, complex institutional structures and issues of local administration coordination, less financing options, lack of transparency, and absence of region-wise customized performance monitoring system. Ranta et al. (2017) discussed barriers including the absence of a holistic vision, overemphasis on recycling, and underuse of reuse and reduce methods. From institutional perspectives, Liu and Bai (2014) recognized a gap between awareness about CE practices and its implementation due to structural, contextual, and cultural issues. These issues are unique to organizations and regions (Gedam et al., 2021).

Yuan (2017) identified that inadequate regulatory environment, multiple stakeholder involvement, absence of basic data, and low level of attention to waste management caused obstruct the CE projects in a significant way. This also appears to be a major issue of production and consumption stages. In a recent study, Zhang et al. (2019) reported that the key barriers to smart waste management for a CE in China were the lack of regulatory pressures and the lack of environmental education and culture of environmental protection. Focusing on the holistic supply chain management, Farooque et al. (2019b) identified the key barriers to circular food supply chains in China were “weak environmental regulations and enforcement”, “Lack of market preference/pressure” and “Lack of collaboration/support from supply chain actors”. Extending this insight, Ranta et al. (2018) elucidated and compared the institutional barriers of CE economy in China, the US, and Europe. The study recognized the difference of the normative behaviour of the Chinese environment than other regions and attribute CE performance in China to its large informal sector and low-level regulation with less enforcement. On the other hand, it argued that the US lacks nation-wide stringent regulation supporting CE and Europe supports CE with high level source-separation activities and clear institutional environment. In a specific study with respect to Norway, Jaegar & Upadhyay (2020) identified product design and production and high start-up costs are key barriers to CE environments. In Sweden, the CE activities show less incentive alignment and lack profit focus (Eriksson et al., 2016; Johannson and Henriksson, 2020). In addition, complexity of procedures and high legal/regulatory compliance costs appear to be the significant barriers in Europe (Garcia-Quevedo et al., 2020). On other hand, China considers recyclables as valuables instead of waste; yet, their region-specific CE norms appear to be a potential barrier to CE implementation.

Weak legal enforcement (Farooque et al., 2019b) in China has continued. Despite rapid economic expansion, the deteriorating environment has undermined the local standard of living. China’s Environmental Protection Law was updated in 2015, including stricter punishments on polluters. Related initiatives have yielded significant results, especially in air, water, and soil pollution. However, food loss and waste is not a heavy polluting sector so it has been excluded from the environmental protection related laws. Similarly, while China's Circular Economy Promotion Law was amended in 2018, there are no provisions on food loss and waste. While food loss and waste reduction can contribute to the carbon emission, food sector was not included in China's carbon neutrality strategy. The most related law is the Anti-food Waste Law (issued in April 2021), intended to enhance food security. However, many citizens are not aware of the newly enacted law, the fines are not high, and the measurements are not clear, suggesting there will be weak enforcement.

Agri-food products face unique challenges for transitioning to a CE (Leite et al., 2014). Overall, the food recycling system in China is weak due to poor infrastructure for collection and inadequate treatment facilities. Unsorted food wastes are mainly sent to landfills. Only in large cities like Shanghai and Beijing, a small portion of food waste is separated at sources and treated by biochemical processes (Thi et al., 2015). In recent years, interest in food waste recycling has been growing (Wen et al., 2016). Zhang et al. (2012) advocated the use of waste cooking oil as an energy resource. Converting food waste to energy is in line with the interest of the government to reduce the demand for petroleum products and natural gas (Liang and Zhang, 2012, Li et al., 2012). Woon and Lo (2016) proposed the use of general food wastes as a potential resource for generating electricity and city gas in Hong Kong. Some agri-food wastes such as potato vines, peanut shells, wild plants, and household wastes are converted into useful products such as biomass, biodiesel, and animal and fish feed as they are nutrient-rich with organic matter (Ma et al., 2010; Chen et al., 2015). All these studies on food waste recycling focused on technologies and practices. They offer little insights into the related implementation barriers, which are crucial for understanding why they not been commercialized in the domestic market.

2.4. Theoretical background

The research draws on the combined perspectives of stakeholder theory and theory of reasoned actions (TRA) at the firm level to explore the challenges of food waste management. The stakeholder theory underscores the responsibility of fulfilling both internal and external participants' expectations (Freeman,1984). In the current context, it helps explain the reasons for barriers to sustainable food consumption and production that involve actors or stakeholders of varied characteristics and behaviors such as processors, wholesalers, traders, distribution channel partners, e-retailers, and consumers. The theory offers deliberations on multi-stakeholder engagement and governance that are imperative to the food processing industry and contribute to designing and co-creation processes in ensuing sustainability across food chains (Schröder et al., 2019). Besides, it provides normative explanations of why and what ways firms should consider stakeholder views in implementing sustainable and production-consumption strategies. The theory also supports incorporating the stakeholders' views for visioning and participatory exercises that lead to decision making within the CE and waste management system (Vergragt and Quist, 2011).

The power of TRA is befitting to explain the firm's readiness for adopting CE principles in waste management (Fishbein and Ajzen, 1975). The theory helps to find out the reasons of behavioural attitudes of stakeholders towards particular phenomenon, as it is recognized as the moral responsibility of stakeholders (Sayer, 2015; Lehtokunna et al., 2020). TRA helps to understand the individual actions and consumption patterns to design policy and promote the sustainable waste management practices integrating CE elements. Specifically, it helps to explore the attitude under the conditions of volitional control and predicts the intentions, which explicates willingness or readiness to engage a specific task in environmental sustainability (Han and Kim, 2010). Besides, it decodes interactions between barriers of SCP focusing on inter and intra organizational subjective norms, which is about the specific behavior under external stakeholders' pressure (Fishbein and Ajzen, 1975). Thus, it is helpful to study the commitment and readiness to CE through the fitting production and consumption processes.

2.5. Barrier study techniques

In complex environments, effective decision-making is highly dependent on the analysis of interdependency between the decision variables interacting within the system. The DEMATEL technique (Gabus and Fontela, 1972) has become increasingly popular in analyzing those interactions (Shao et al., 2016). Other relevant multi-criteria decision-making tools include Interpretive Structural Modelling (ISM), Analytic Hierarchy Process (AHP), Analytic Network Process (ANP), and Structural Equation Modelling (SEM). (Refer Table 1).

Table 1. A comparison of DEMATEL with ISM/AHP/ANP/SEM

DEMATEL	ISM	AHP	ANP	SEM
DEMATEL uncovers the causal interactions among the variables, classifying them into cause and effect groups.	ISM uncovers the contextual interactions among variables based on their driving potential and dependencies.	AHP does not reveal interdependencies between and among the variables.	ANP uncovers interdependencies between and among the variables. It is less accepted for barrier studies due to its complexity.	SEM is mainly used for theoretical development and it requires a large sample size.

Source: Adopted from Venkatesh et al., (2017) and Mangla et al. (2018).

The DEMATEL technique not only establish relationships but also elucidate the overall degree of influence of the study factors (Gabus and Fontela, 1972). Centered on graph theory, the technique can accommodate heterogeneous factors (Li and Wan, 2014; Benyoucef et al., 2014) and does not require a large amount of data. It visualizes the causal relationships through the impact-relations map or causal-effect diagram, where the techniques differentiate causal and effect groups separately (Venkatesh et al., 2017). The DEMATEL technique was judged to be most suitable to address the research questions proposed earlier because it is a good fit for uncovering the causal relationships between system variables (He et al., 2021). As mentioned earlier, we employed Fuzzy DEMATEL, an advanced variant of the standard DEMATEL technique to address the inherent vagueness, bias and uncertainty in human judgments (Wu and Lee, 2007; Lin, 2013). There is a wide range of research reports that applied fuzzy logic studies with DEMATEL (Keskin, 2015). Some of the recent DEMATEL studies in the sustainable production consumption domain include Deng et al. (2015), Sivakumar et al. (2018), Bhatia and Srivastava (2018), Kumar and Dixit (2018), Liu et al. (2020), Singhal et al. (2020), etc.

Summarizing the literature review, food waste management is a key challenge in SCP. The CE concept offers a viable pathway to sustainable food consumption and production by treating wastes as resources for value recovery. A wide range of barriers to CE implementation have been identified in the extant literature, but there is a lack of study of specific barriers in food waste management in China. This significant knowledge gap will be addressed in the following sections. Besides, DEMATEL technique has not been widely applied in the CE studies, although it has been widely used and reported in closed-loop or conventional reverse supply chain, and energy studies in recent times (Büyüközkan and Güleryüz, 2016; Çelikbilek and Tüysüz, 2016).

3. Methodology

The study follows a two-step process. The first step is to elucidate the barrier list. In the second step, these barriers are subjected to fuzzy DEMATEL technique in the following step to draw causal-effect maps. The following sub-sections describe the methods in detail.

3.1. Finalizing the study barriers

Based on the recent literature, the researchers compiled a list of thirteen barriers to sustainable food consumption and production in China with a focus on value recovery from wastes from a CE perspective. The list was reviewed by three senior government officials who were in charge of municipal waste management and new government initiatives in sustainability, four business managers who had responsibilities over supply chain operations in food processors and retailers, and two scholars in the field (with in-depth knowledge of the agri-food sector in China). They were asked to comment on the validity of the barriers in the Chinese context and whether any important barrier is missed out. A concern was raised that practitioners may have difficulty to distinguish several barriers in the initial list, because they were regarded as too closely related to each other. Based on their feedback, the thirteen barriers were merged into nine barriers that are distinctively different from each other. For example, low margin in value recovery from food waste was considered as intertwined with high collection and transportation cost, and therefore they were combined as cost barrier. According to their suggestion, a new barrier was added into the list which was lack of benchmarking and relevant standards in China. The resulting final list of ten barriers is described as follows.

B1 - Weak legal enforcement: Like many other developing countries, China lacks a comprehensive and effective legal system for environmental protection and the enforcement of laws is weak (Borrello et al., 2016; Govindan and Hasanagic, 2018; Li and Yu, 2011). Despite China's ambitious CE vision and current environmental laws, the implementation end enforcement has faced many difficulties which are intertwined with resource implications, monitoring mechanisms, and potential impacts on business operations and economic development.

B2 - Inadequate infrastructure: Waste sorting at source is a precondition for maximizing value recovery from food waste (Wang et al., 2021). Unfortunately, most Chinese cities do not have adequate infrastructure to support refuse classification. In July 2019, Shanghai, the largest city in China, started to implement compulsory waste sorting. However, it is lagging in food waste processing capacities. Overall, there is not enough separated bins for diverse types of garbage and the waste management system is weak in China (Zhang and Wen, 2014), especially in its less developed regions.

B3 - Behavioural barrier: Most Chinese do not have the habit of rubbish sorting due to various cultural and historical reasons. They are used to mixing all garbage types and throwing them away altogether for convenience (Liu et al., 2009). In addition, it is part of the traditional Chinese culture for a host to prepare/order more than enough foods, which is perceived as a symbol of prosperity. Many Chinese hosts feel embarrassed if their guests finish all the served foods, because they feel "losing face" if their guests do not get enough to eat. Therefore, food waste is commonplace at social events in China.

B4 – Lack of investment in advanced equipment/technologies: Value recovery from food loss and waste requires significant upfront investment in advanced equipment/technologies. Lack of financial resources is widely acknowledged as a barrier to support CE implementation (Govindan and Hasanagic, 2018). In China, food processors and municipal waste management departments often employ contractors to manage waste collection and further processing activities. Such contractors are often small and medium sized enterprises which do not have a lot of financial resources to invest in advanced food waste processing equipment/technologies.

B5 - Lack of expertise: CE is a relatively new concept, so there is a lack of expertise to support its implementation (Kaur et al., 2018; Borrello et al., 2016). Food waste as a bio-based resource requires specialized competence and knowledge for value recovery operations. At present, there are very limited training courses and study programs in China on CE and sustainable food waste management. Consequently, there is a shortage of expertise for a variety of sophisticated food waste treatment options.

B6 - Lack of cross-sector collaboration: Lack of support/collaboration from other sectors can be a serious obstacle to a transition to CE (Mangla et al., 2018), because it is often not realistic for a same sector to reuse all its wastes. For example, some food wastes can be used to produce animal feeds, compost, or energy, but they require substantial initial investments and long-term cross-sector collaboration between food waste producers/collectors and potential users to be economically viable. Unsurprisingly, lack of cross-sector collaboration is a barrier which hinders the implementation of CE principles in food waste management.

B7 - Cost barrier: There is a low margin in value recovery from food wastes and a high cost for food waste collection and transportation (Borrello et al., 2016; Govindan and Hasanagic, 2018). Therefore, food waste management is not necessarily profitable depending on whether the operating costs can be fully offset by the economic gains or not. Due to cost considerations, a waste management business may not want to take certain types of food wastes which have lower economic benefits. Apparently, there exists a cost barrier to achieving maximum environmental benefits by collecting and processing all food wastes.

B8 - Lack of economies of scale: There is a lack of the economies of scale in collecting and processing food wastes for value recovery (Borrello et al., 2016; Govindan and Hasanagic, 2018; Sauvé et al., 2016), especially for household food wastes. Household food waste is spatially dispersed and the amount collectable from each residential community is usually not much. Such a lack of economies of scale disincentivizes sustainable food waste management for value recovery.

B9: Lack of environmental education and accountability: In the past few decades, there was very limited education on environmental protection in China. Consequently, many Chinese citizens have little care or awareness about the environmental impacts of food loss and waste (Geng et al., 2009). In recent years, the Chinese government stepped up environmental education, but the effect of the old mindset is persistent, especially among the older generations. The current environmental education system focuses more on professional education and relatively ignores the non-professional education that would influence day-to-day consumption and business-oriented behavior relating to food wastes (Tian & Wang, 2016). In addition, there is often a lack of accountability for environmental damages except for major environmental disasters.

B10: Lack of benchmarking and standards: There are difficulties in finding benchmarking enterprises or practices for sustainable food loss and waste management as China's progress toward a CE is still modest (Mathews and Tan, 2016). There is also a lack of national and industry standards for collecting and processing food wastes. Overall, food waste management as a sector is still at an early stage of adopting sustainability practices in China.

The researchers designed a questionnaire in English to capture the opinions of evaluators for Fuzzy DEMATEL analysis. The questionnaire was then translated into the Chinese language, including an explanation of each barrier to guide the evaluators. Two researchers who are bilingual in English and Chinese checked the translation to ensure accuracy. The researchers conducted two rounds of pilot tests with nine expert evaluators to get feedback on the questionnaire design. Based on their feedback, the researchers revised the questionnaire to ensure content validity by eliminating ambiguity and possible confusion.

The finalized questionnaire was distributed by email or post to be anonymously completed by potential evaluators in three groups: food processors (food processing/manufacturing companies), sales and distribution channels (supermarkets, import/export businesses, e-retailers, and wholesalers), and consumers. Each group had 100 potential evaluators received the questionnaire, so in total the questionnaire reached 300 potential evaluators. For the evaluators from the industry sectors, we employed a purposive/judgmental sampling approach (Saunders et al., 2019) to target those who are most knowledgeable on the subject. We only invited participations from senior executives/managers/supply chain heads and business owners. This was to ensure the quality of the data and the validity of the results. The data collection was supported by three branches of a regional government in northern China, namely, the Development and Reform Commission, the Bureau of Commerce, and Food Safety Committee. For responses from consumers, a convenience sampling method was adopted. A total of 210 questionnaires were returned from three groups of evaluators, among which 117 complete responses were considered valid for the Fuzzy DEMATEL analysis. Tables 2 & 3 show the profile of these 117 evaluators.

Table 2. Evaluator demographics

Evaluator Group		Frequency	Percentage	Annual Revenue (million RMB)					
				<5	5-9.9	10-49.9	50-100	100-300	>300
Food Processor		34	29.1%	6	2	8	8	4	6
Sales/ distribution channel	Supermarket (10)	39	33.3%	1	1	2	3	2	1
	Importer & Exporter (9)			2	0	1	2	1	3
	E-retailer (11)			6	2	2	0	0	1
	Wholesaler (9)			2	1	3	2	0	1
Consumer		44	37.6%	-	-	-	-	-	-
	Total	117	100%						

Table 3. Evaluator profiles

Evaluator Group	Industry Experiences (years)				Designation	
	1-3	4-7	8-12	⩾13	Middle Level Manager	Owner/Senior Manager
Food Processor (34)	0	14	8	12	20	14
Supermarket (10)	0	3	6	1	6	4
Importer & Exporter (9)	0	2	3	4	4	5
E-retailer (11)	5	5	0	1	6	5
Wholesaler (9)	0	3	2	4	3	6
Consumer (44)	-	-	-	-	-	-

3.2. DEMATEL Analysis

In this research, we apply the fuzzy DEMATEL technique using the following steps to analyze the barriers to sustainable food consumption and production. Venkatesh et al. (2017) explained in details the technical procedures of the Fuzzy DEMATEL technique.

Step 1: Constituting the expert panel / focused group and finalizing the decision variables

Step 2**:** Structuring a pairwise comparison matrix

In this step, each decision-maker was asked to finalize the degree to which a factor *i* affects factor *j* using the scale from 0 to 4 (0= no influence, 1= very low influence, 2=low influence, 3= high influence, and 4-very high influence). A sample of pairwise comparison is shown in Appendix A.

Step 3**:** Finalizing the fuzzy initial direct relation matrix (A)

The TFN is represented by a triplet, i.e. (e_{ij}, f_{ij}, g_{ij}). Suppose $x_{ij}^{k} = e_{ij}^{k}, f_{ij}^{k}, g_{ij}^{k}$where 1 ≤ k ≤ K, to be the fuzzy evaluation that the k^{th} expert gives about the degree to which barrier *i* have an impact on barrier *j*. If 'K' is the number of participants in our study to estimate causality between the identified n study barriers, inputs given by the participants result in a n×n matrix i.e.$X^{k} = x_{ij}^{k};$ where, k = 1, 2, 3 4...n (number of experts in a decision panel). A sample of fuzzy initial direct relation matrix is shown in Appendix B.

$$a_{ij} = \frac{1}{k\sum x^{k}{}_{ij}} \tag{1}$$

Followed by that, the defuzzification process is used to convert the fuzzy numbers to crisp numbers, as those fuzzy numbers are not appropriate for the matrix operations. We defuzzify the fuzzy initial direct relation matrix using the below equation (2)

$$I_T = \frac{1}{6}(e + 4f + g) \quad (2)$$

A sample average initial direct-relation crisp matrix (A) for the food processor group is shown in Appendix C.

Step 4: **Constructing normalized initial direct relation matrix (D)**

$$m = \min \left[\frac{1}{\max \sum_{j=1}^{n} |a_{ij}|}, \frac{1}{\max \sum_{i=1}^{n} |a_{ij}|}\right] \quad (3)$$

$$D = m \times A \quad (4)$$

As a sample, the normalized direct-relation matrix (D) for food processors is shown in Appendix D.

Step 5**:** Obtaining the total-relation matrix

$$T = D(I - D)^{-1} \quad (5)$$

Where, I: Identity matrix; T: Total relation matrix

$$T = \left[t_{ij}\right]_{n \times n}$$

Step 6: Calculating the sum of rows (R) and the sum of column (C)

$$R = \left[\sum_{j=1}^{n} t_{ij}\right]_{n \times 1} \quad (6)$$

$$C = \left(\left[\sum_{i=1}^{n} t_{ij}\right]_{1 \times n}\right)^{T} \quad (7)$$

R represents the overall effects of barrier (i) on the barrier (j), and C stands for the overall effects experienced by a barrier (i) from barrier (j).

Step 7: Finalizing the cause-effect graph

This step is done by using the data set of (R+C; R-C), where (R+C) and (R-C) are the horizontal and vertical axes, respectively. (R+C) depicts the measure of the significance of study barriers and represents the influenced and influential power. (R-C) explains the cause and effect relationship between the barriers. A factor falls into the causal group if it shows a positive (R-C) value. A barrier is classified into the effect group if its (R-C) value is negative (Lin, 2013).

4. Results and analysis

The following section presents Fuzzy DEMATEL analysis results. The total-relation matrices for three evaluator groups are provided in Tables 4, 6 and 8 respectively and they quantify the impact relationships between all the barriers. The R+C and R-C scores for each evaluator category are presented in Tables 5, 7 and 9 respectively along with the evaluators' importance rankings and Fuzzy DEMATEL based rankings. Moreover, cause-effect diagrams are developed for each evaluator group separately and presented as Figures 1, 2 and 3. The significant relationships between barriers are also mapped on the cause-effect diagrams by arrows to highlight their interdependence. We mapped the significant relationships (highlighted as bold values) above a threshold value (Ø) calculated by adding 1.5 standard deviations to the mean of the total-relation matrix (T), following Li and Tzeng (2009)'s recommendations on using appropriate threshold levels.

4.1. Fuzzy DEMATEL results of the food processors

Fuzzy DEMATEL analysis results of the first evaluator group (i.e., food processors) are presented in Table 4, Table 5 and Figure 1. From these results, we observe that weak legal enforcement (B1), lack of investment in advanced equipment/technologies (B4), lack of expertise (B5), lack of economies of scale (B8) and lack of environmental education and accountability (B9) are identifiable as the cause barriers from the food processors' perspective. However, by looking at the interrelationships of the barriers presented in Figure 1 and Table 6, B1, B8 and B9 appear to be the key cause barriers, while B1 has a directly significant impact on B10 and B2 respectively. Similarly, B4, B5 and B2 have a high R+C score, respectively, suggesting these are the most influential barriers to sustainable food loss management from the food processors' perspective.

Table 4. Total-relation matrix of food processors

Barriers	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10
B1	0.84	**1.08**	0.96	0.98	0.99	0.91	0.98	0.88	0.98	**1.02**
B2	0.81	0.86	0.86	0.90	0.87	0.82	0.89	0.80	0.82	0.89
B3	0.81	0.91	0.74	0.84	0.85	0.79	0.85	0.75	0.82	0.88
B4	0.89	**1.05**	0.90	0.88	0.96	0.89	0.99	0.89	0.88	0.95
B5	0.88	**1.02**	0.90	0.97	0.87	0.88	0.97	0.88	0.89	0.98
B6	0.76	0.88	0.78	0.84	0.85	0.70	0.84	0.77	0.79	0.84
B7	0.85	**1.02**	0.88	0.97	0.95	0.89	0.86	0.88	0.85	0.92
B8	0.83	0.97	0.84	0.91	0.90	0.85	0.94	0.75	0.84	0.90
B9	0.89	0.99	0.90	0.92	0.92	0.86	0.92	0.83	0.80	0.95
B10	0.87	0.99	0.89	0.92	0.92	0.84	0.92	0.83	0.89	0.85

Note: $Ø_1$= 0.99; Significant relationships greater than $Ø_1$: B1-B2, B1-B10, B4-B2, B5-B2, B7-B2

Table 5. Rankings of barriers (Food processors)

Barriers	R+C	R-C	Evaluator's Ranking	DEMATEL Ranking by R+C value	DEMATEL Ranking by R-C value
B1	18.06	1.20	1	6	1
B2	18.30	-1.28	2	3	10
B3	16.86	-0.39	7	9	8
B4	18.39	0.16	6	1	5
B5	18.30	0.18	3	2	4
B6	16.48	-0.41	9	10	9
B7	18.22	-0.09	5	4	6
B8	16.99	0.47	10	8	2
B9	17.52	0.43	4	7	3
B10	18.07	-0.26	8	5	7

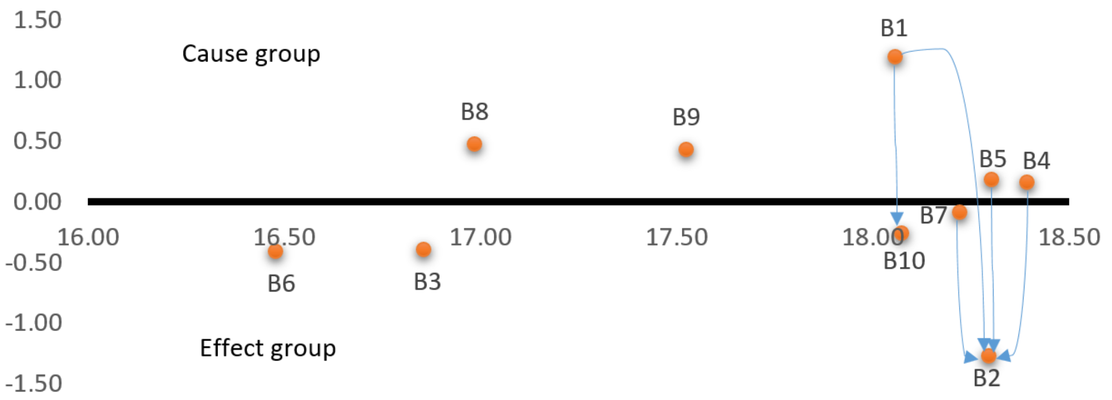

Figure 1. DEMATEL casual-effect diagram (Food processors)

4.2. Fuzzy DEMATEL results of the sales & distribution channels

Similarly, Tables 6 and 7 and Figure 2 present the Fuzzy DEMATEL analysis results of the second evaluator group (i.e., sales and distribution channels). Weak legal enforcement (B1), lack of investment in advanced equipment/technologies (B4), lack of cross-sector collaboration (B6), cost barrier (B7), lack of environmental education and accountability (B9) and lack of benchmarking and standards (B10) are identified as the cause barriers from distribution channels' perspective. However, by looking at the interrelationships of the barriers presented in Figure 2 and Table 8, B1, B9, and B7 are identified as the most significant cause barriers, while B1 and B7 have a significant direct impact on B3 and B2 respectively. Similarly, B2, B7 and B1 have a high R+C score, respectively, suggesting these as the most influential barriers to sustainable food loss and waste management from sales & distribution channel's perspective.

Table 6. Total-relation matrix of sales & distribution channels

Barriers	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10
B1	0.54	**0.75**	**0.69**	0.64	0.66	0.60	0.64	0.64	0.64	0.65
B2	0.56	0.60	0.64	0.60	0.61	0.53	0.62	0.62	0.52	0.59
B3	0.56	**0.67**	0.52	0.56	0.59	0.51	0.58	0.58	0.55	0.57
B4	0.57	**0.72**	0.64	0.54	0.64	0.57	0.65	0.64	0.52	0.58
B5	0.57	**0.69**	0.62	0.61	0.54	0.56	0.63	0.63	0.54	0.59
B6	0.53	0.64	0.58	0.58	0.58	0.45	0.58	0.58	0.49	0.53
B7	0.58	**0.74**	0.65	0.67	0.67	0.59	0.57	0.67	0.54	0.60
B8	0.55	0.68	0.60	0.61	0.60	0.55	0.61	0.52	0.51	0.56
B9	0.58	0.67	0.62	0.56	0.57	0.52	0.56	0.57	0.45	0.58
B10	0.58	**0.69**	0.62	0.58	0.61	0.55	0.59	0.59	0.55	0.50

Note: $Ø_2$= 0.68; Significant relationships greater than $Ø_2$: B1-B2, B1-B3, B4-B2, B5-B2, B7-B2, B10-B2

Table 7. Rankings of barriers (Sales & distribution channels)

Barriers	R+C	R-C	Evaluator's Ranking	DEMATEL Ranking by R+C value	DEMATEL Ranking by R-C value
B1	12.09	0.81	5	3	1
B2	12.74	-0.95	1	1	10
B3	11.89	-0.49	10	6	9
B4	12.02	0.13	3	5	4
B5	12.06	-0.10	4	4	7
B6	10.98	0.10	9	10	6
B7	12.33	0.24	2	2	3
B8	11.84	-0.24	6	7	8
B9	11.02	0.39	7	9	2
B10	11.61	0.11	8	8	5

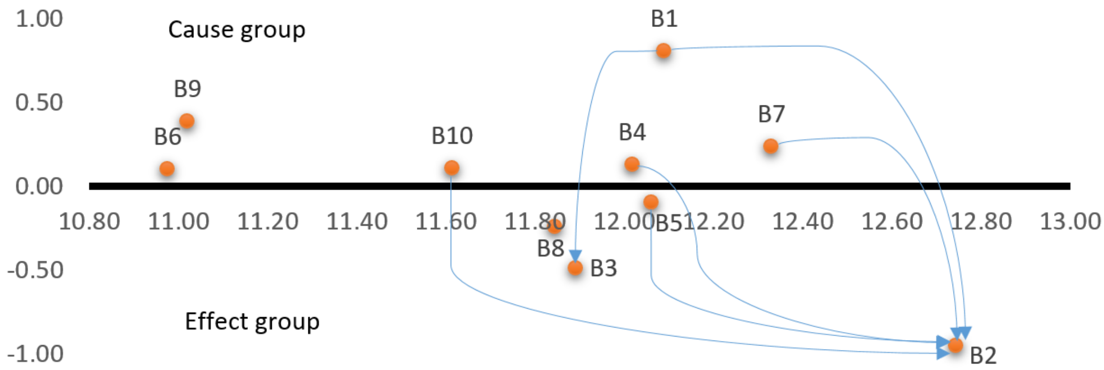

Figure 2. DEMATEL casual-effect diagram (Sales & Distribution channels)

4.3. Fuzzy DEMATEL results of the consumers

Tables 8 and 9 and Figure 3 show the Fuzzy DEMATEL analysis results of the third evaluator group, the consumers. Weak legal enforcement (B1), lack of investment in advanced equipment/technologies (B4), cost barriers (B7) and lack of environmental education and accountability (B9) are identified as the most significant cause barriers from consumers' perspective. However, by looking at the interrelationships of the barriers presented in Figure 3 and Table 9, B1 and B9 appear to be the key cause barriers, while B1 has a directly significant impact on B3 and B2 respectively. Similarly, B4, B7 and B8 have the highest R+C score, respectively, suggesting these as the most influential barriers to sustainable food waste management from the consumers' perspective.

Table 8. Total-relation matrix of consumers

Barriers	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10
B1	0.43	**0.77**	**0.72**	0.66	0.68	0.65	0.63	0.64	0.66	0.70
B2	0.37	0.50	0.57	0.52	0.53	0.52	0.52	0.52	0.46	0.50
B3	0.38	0.55	0.44	0.48	0.53	0.49	0.48	0.48	0.46	0.51
B4	0.44	**0.75**	0.61	0.56	0.68	0.65	0.66	0.67	0.55	0.61
B5	0.39	0.60	0.54	0.56	0.50	0.57	0.56	0.56	0.48	0.56
B6	0.40	0.61	0.54	0.57	0.59	0.48	0.56	0.58	0.48	0.55
B7	0.44	**0.73**	0.62	0.67	0.67	0.65	0.55	0.67	0.55	0.61
B8	0.43	0.68	0.58	0.64	0.63	0.62	0.63	0.53	0.51	0.58
B9	0.49	0.66	0.69	0.60	0.64	0.60	0.58	0.59	0.48	0.64
B10	0.44	0.62	0.61	0.56	0.61	0.58	0.55	0.57	0.53	0.49

Note: $Ø_3$= 0.70; Significant relationships greater than $Ø_3$: B1-B2, B1-B3, B4-B2, B7-B2

Table 9. Rankings of barriers (Consumers)

Barriers	R+C	R-C	Evaluator's Ranking	DEMATEL Ranking by R+C value	DEMATEL Ranking by R-C value
B1	10.74	2.32	3	9	1
B2	11.49	-1.47	4	4	10
B3	10.71	-1.12	1	10	9
B4	12.02	0.38	9	1	4
B5	11.37	-0.74	6	5	8
B6	11.17	-0.47	10	7	7
B7	11.88	0.43	5	2	3
B8	11.62	0.02	8	3	5
B9	11.09	0.82	2	8	2
B10	11.31	-0.18	7	6	6

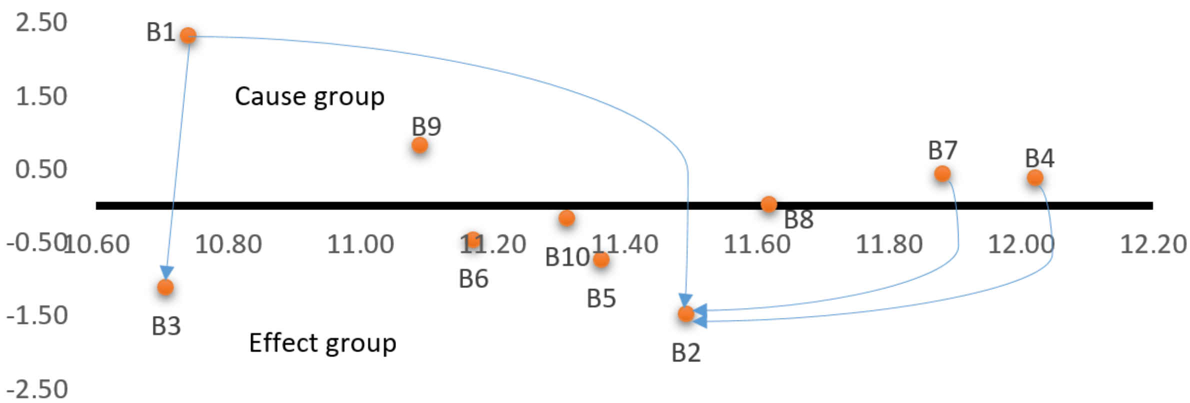

Figure 3. DEMATEL casual-effect diagram (Consumers)

5. Discussions

Barriers that have the highest net causal-effect (R-C) values, therefore, have the greatest long-term impact on the system, so long-term efforts should be made to address these issues. Similarly, the barriers with the highest prominence values have the potential to affect and/or be affected by other barriers. Therefore, managers and policymakers should prioritize addressing or circumventing these in the short-term, presenting a practical approach to the otherwise complex web of political, technological, and institutional structures (Papargyropoulou et al., 2014). The interdependencies and interrelationships highlight the previously noted importance of integrated decision making in CE activities and design (Lechner and Reimann, 2020).

Table 10. Barriers with the highest prominence and net cause-effect values

Barriers Description	**Key cause barriers**			**Most prominent barriers**		
	FP	**SD**	**CS**	**FP**	**SD**	**CS**
B1: Weak legal enforcement	✔	✔	✔		■	
B2: Inadequate infrastructure				■	■	
B3: Behavioural barrier						
B4: Lack of investment in advanced equipment/technologies				■		■
B5: Lack of expertise				■		
B6: Lack of cross-sector collaboration						
B7: Cost barrier		✔				■
B8: Lack of economies of scale	✔				■	■
B9: Lack of environmental education and accountability	✔	✔	✔			
B10: Lack of benchmarking and standards						

* Note: FP = Food processors, SD= Sales & Distribution Channels, CS= Consumers

Table 10 summarizes the overall results and provides a comparison of key cause and high prominence barriers. The results reveal many similarities in the responses of the three evaluator groups. For example, weak legal enforcement (B1) is identified as a key cause barrier by all three evaluator groups. This finding is in line with that of Farooque et al. (2019b) which focused on barriers to circular food supply chains in China. All three evaluator groups also identify the lack of environmental education and accountability (B9) as a cause barrier, which confirms the finding of Zhang et al. (2019) on the barriers to smart waste management in China. The strength of legal enforcement is a societal element that will affect all evaluator groups. These results enable us to assess barriers beyond those that may be identified with institutional perspectives (e.g., as in Ranta et al., 2017). While there may be separate legal requirements that affect a given industry or evaluator group more than another, there is a consensus that the weak enforcement of the legal framework in this area reduces the need for action; this result is different to the identification of Yuan (2017) of an inadequate regulatory environment. Similarly, the low levels of environmental education would influence individuals acting within each of the evaluator groups; long-term changes to a national curriculum would lead to positive changes within each evaluator group (Zhang et al., 2019). Greater education will enable firms to enhance their awareness (addressing concerns identified by Liu and Bai (2014)), collect better data (Yuan 2017), and develop improved performance monitoring systems (Su et al., 2013).

In the same way, there is a consensus among the study evaluators on the role of barrier B8 (lack of economies of scale). Food processors consider it as key cause barrier, whereas sales and distribution channels and consumers view it as the most prominent barrier. The relatively small scale that many food processors operate on will mean that their lack of economies of scale will lead to and contribute more to other barriers; in contrast, the scale of many sales and distributions firms will mean that this is less likely to be a cause, however, given its high prominence score, it will be one the short term challenges for the sales and distribution channels to address.

Moreover, both the food processors and sales and distribution channels identified B2 (inadequate infrastructure) as the prominent barrier. This is reasonable as these firms would rely on the provision of sufficient infrastructure to support their efforts in sustainable food loss and waste management. The influence of infrastructure aligns with previous discussions on the need for more firms along the supply chain (Boons and Lüdeke-Freund, 2013) and higher numbers of firms involved (Veleva et al., 2017). Lastly, B4 (lack of investment in advanced equipment/technologies) is identified with high prominence by food processors and consumers. The barrier has similarities to the financing options in general CE studies in China (Su et al., 2014); however, it is not considered as a barrier by sales and distribution channel members. The reason they do not perceive it as a barrier is likely due to the size of the firms; many food producers will be smaller firms and they, along with consumers, will be less endowed with financial resources required to make or invest in sufficient changes to improve food loss and waste management processes. The sales and distribution firms tend to be larger and will tend to have sufficient slack resources that can be redeployed to support sustainable food loss and waste management activities.

Despite these similarities, there are some differences as well. For example, the cost barrier (B7) was identified as the key cause barrier by sales and distribution channels. This identification may relate to the relatively small margins and level of intensity in many retail and distribution environments; such tight margins would preclude investments with indefinite payoffs. This suggests opportunities for the design and implementation of improved incentivization schemes (Su et al., 2013). Lack of expertise (B5) was identified by food processors as the most prominent barrier in their case. The lack of capability and expertise in the staff will be related to the low levels of general capabilities in society (partly driven by low levels of education in this area) and the sudden need for the firm to gain this expertise. A general need for expertise means such expertise will be hard to acquire, and it will be challenging to overcome the skill shortage. Without the right skills, it will be difficult to use new technologies, and this may relate to the previously identified issue of a lack of high-end CE technologies (Su et al., 2013).

The study results also reveal that the key cause and prominent barriers are different from barriers rankings based on the evaluators' importance rankings across the three evaluators (see Tables 5, 7 and 9). These differences demonstrate the importance of how techniques such as Fuzzy DEMATEL allows us to perceive the hidden interrelationships between the evaluators' responses that they are unable to perceive themselves.

5.1. Theoretical contributions

The study design was based on both stakeholder theory and TRA. The results provide evidence that there are different barriers as perceived by each of the stakeholders. It also provides firms with a mechanism to identify which barriers are important to other stakeholders; as the barriers are addressed/resolved, a specific and tailored communication plan can be developed to communicate this to the other two distinct stakeholder groups that were included in the study, addressing the areas of greatest importance to the other stakeholders and increasing inclusivity in the management of supply chain processes (Boons and Lüdeke-Freund, 2013).

The analysis of relationships between barriers provides new insight into TRA in the applications within CE. The results provide an analysis of the interactions between the barriers and these are implicitly addressing both inter- and intra-organizational subjective norms (Vergragt and Quist, 2011). As a result, future work that seeks to develop mechanisms to influence behaviour under pressure from external stakeholders, can use these results to analyse the potential for the co-creation of sustainability processes and food loss and waste management (Schröder et al., 2019). Future research might extend the TRA analysis by providing perspectives from government policy makers, as a key influencer of subjective norms in the country. Understanding the relationship between barriers also enhances decision-making for managers, as they can isolate and address barriers in a systematic approach, addressing challenges to the transition to a CE business model that is profitable (Loon and Wassenhove, 2020). Governing bodies and Boards of Directors may also implement measurement models and metrics that force greater managerial consideration of the CE requirements (Bai et al., 2020).

5.2. Implications for Practice and Policy

The results and findings presented above provide insights from three different types of representative stakeholders: food processors, sales and distribution channels, and consumers. The identified barriers and their interdependencies indicate a strong role for both managerial decision-makers as well as government policy makers to work in unison to develop frameworks, metrics, and industrial structures to systematically address the barriers. From the results presented in section 4, we develop the following implications for policy and practice.

First, **weak legal enforcement** is one of the fundamental reasons behind the largely absent/ineffective food loss and waste management mechanism in China. This weak enforcement remains distinct from the presence of regulations (Yuan, 2017; Farooque et al., 2019b) but may be related to the complexities of localized administration and coordination (Su et al., 2013). The complexities of the agri-food systems also make it difficult to enforce legalisation as CE implementation requires infrastructure support along the whole supply chain, from farmers to food processors, wholesalers, retailers, logistics service providers, consumers, and waste management organizations. However, specific examples exist of enhanced enforcement. For instance, in Shanghai City, from 01 July 2019, they have begun to enforce the new "Regulations on the Management of Household Waste" (Xinhaunet, 2019). This includes both requirements for individuals and organizations to comply, with fines of 50-

200 RMB for individuals and up to 50,000 RMB for organizations. The first tranche consisting of 623 fines were applied after inspecting 1588 communities, 406 enterprises & institutions, 1853 firms and other groups. At this time, the first batch of social supervisors for domestic waste management were employed. Other legal requirements include the Environmental Protection Law, recently enhanced to make punishments stricter. However, they focus on the most polluting industries rather than food loss or waste. While the Circular Economy Promotion Law was amended in 2018, there are no provisions specific on food loss or waste. The Anti-food Waste Law (April 2021) focuses on food security and has unclear measurements and weak punishments, generating what will likely be weak enforcement. From these measures, specific initiatives should include fines sufficiently high to deter undesired actions, food waste and loss should be acknowledged as a key driver in the environmental protection and CE promotion laws, and the measurements and requirements for compliance should be clear and simple for citizens to understand.

Second, the **lack of environmental education and accountability** is a major contributor to the lack of food waste management culture throughout the food systems/food supply chains. The issue is complicated by the need to involve multiple stakeholders in the industry (Yuan 2017; Zhang et al., 2019). As it often takes years and even generations to change a culture, the journey to a CE in China is likely to be a marathon for achieving SCP. Industry groups will need to include multiple stakeholders and develop joint systems and metrics that can be agreed on and applied widely to improve accountability. Officials can also be employed in roles that directly hold organizations accountable such as in Shanghai in 2019 (Xinhaunet, 2019).

Third, the **Lack of economies of scale** in collecting and processing food wastes for value recovery is a primary concern of food supply chain stakeholders, and this inhibits investments in food waste management. Greater inclusion of firms over the supply chain (Boons and Lüdeke-Freund, 2013) and moving beyond the efforts of an individual firm (Veleva et al., 2017) will be necessary. In cities like Shanghai and Beijing where there is infrastructure for household waste sorting, consumers need to separate food wastes at source to allow them to be collected and consolidated for value recovery. The barrier in the economies of scale is likely to be overcome when there is increased participation by firms and consumers in sustainable food waste management. Measures, such as the use of Industry 4.0 technologies, may help smaller firms to collaborate in a way that they can overcome some of the scale-based challenges (Rosa et al., 2020).

Given the results, further attention by food processors and distribution firms in the supply chain must be placed on developing solutions to the source separation challenge. Through careful re-design of collection processes, the waste management processes for firms can recover value from food wastes. When this waste is separated from the waste that is directed to landfill, firms will be able to support their transition to a circular supply chain in the food industry while maintaining profitability (Loon and Wassenhove, 2020).

Consumer separation of waste is also necessary, and as much of household waste is food waste, there is increasingly the need for firms to invest in source separation but also the subsequent waste treatment facilities and associated capabilities. Such infrastructure may use food wastes to create organic fertilizers, generate biogases, and feedstock. New technology platforms and Industry 4.0 may enable this collaboration within the sector (Rosa et al., 2020). These initiatives may require wider collaboration outside of traditional collaboration within the sector and may require developing cross-sectoral initiatives to tackle waste management challenges. Lessons from pilots in China and elsewhere suggest that technologies can improve separation of waste efforts (Wang et al., 2021), improve consumer understanding and behaviors (Li et al., 2020), and monetary subsidies can influence behaviors (Owusu et al., 2013).

Firms should work to enhance their capability and expertise in CE (Sehnem et al., 2019; Subramanian 2017) and food waste management. Large firms may implement training programmes. The prominence of this barrier also suggests a role for third-party training organizations to provide certification and training both for existing staff (able to leverage the expertise immediately) and for job seekers who will be able to apply their developed expertise to benefit employers.

These results have clear implications for policymakers in addition to managers. First, there is a role for the Chinese government to take a more active role in their involvement in food waste CE and add additional regulatory pressures on participants. All evaluators have identified the need for regulatory change as a crucial barrier that policymakers are best positioned to overcome. The fundamental problem here is not the lack of CE legislation in China, but its lack of enforcement caused by a variety of reasons. The legislation process in China is top-down and usually involves very limited public participation or consultation. Consequently, many laws are not widely known or supported by the public. Furthermore, a piece of legislation may be passed when the required physical and institutional infrastructure is still not in place, making it practically infeasible to be enforced. Overall, the legal system in China is still underdeveloped and the court system is not independent from the government administration as in the Western countries. Therefore, a well-intended CE legislation is not necessarily in the priority list of local government officials when there are more urgent matters competing for their attention.

Second, the government should offer financial supports to sustainable food loss and waste management activities. In comparison with many developed countries, the population density in most Chinese cities is much higher which creates an advantage for achieving the economies of scale in food waste collection and processing. Nevertheless, the economic value that can be recovered from most food wastes is low, so there is a lack of economic incentive among food waste management organizations. To overcome this issue, the government may consider offering and increasing subsidies to the involved organizations. Experiences in Ghana suggest that direct incentives to households can improve participate in waste source separation initiatives (Owusu et al., 2013). The government may also consider increasing investments in the essential infrastructure required for source separation of food waste, food waste collection, and value recovery operations such as composting, anaerobic digestion, and waste-to-energy conversion. Such green investments are justifiable as sustainable food loss and waste management has substantial environmental benefits in reducing greenhouse gas emissions which helps combat climate change. It also helps restore soil fertility which enables more sustainable farming.

An additional policy role is the improvement of educational investments in improving food loss and waste management. There is a clear need for both business professionals and consumers to have greater insight into the importance and mechanisms for sustainable food loss and waste management, and changing the nature of national educational systems and national curricula would address this concern. Specific education initiatives could include advertising and promotional material. Initiatives could also consider the use of social supervisors for domestic waste management, which was introduced in Shanghai in 2019 (Xinhaunet, 2019). While China first implemented environmental education in 1973, to enhance awareness, in 2003, two curriculums were updated in primary and secondary schools. In 2011 and 2016, two national action guidelines for environmental communication and education (2011-2015; 2016-2020) were promulgated. The current environmental education system focuses on professional education and less emphasis is placed on the general citizenship (Tian & Wang, 2016). Whereas, the outcomes of the education are not clear, there are challenges in how to change attitudes and behaviors. For instance, there is no detailed accountability system and so there seems to be little incentive for behavior change relating to food loss and waste.

A final element that policymakers may consider is the importance of separating waste streams. Wang et al. (2021) reported multiple successful cases of using internet of things (IoT) technologies to enable accountability in household waste source separation in China. The implementation pilots proved the feasibility of inducing a behavioral change by providing incentives to split and separate waste streams clearly. They also showed the practicality of using IoT technologies to achieve accountability, which directly overcame one of the key cause barriers to promote effective waste management. Similarly, the techniques outlined by Li et al. (2020) can help households to understand the composition of waste and begin to influence their behaviors towards waste source separation. A primary outcome of these changes would be to enhance the economies of scale of waste management. Improved economies of scale should overcome the hesitation and reluctance of business managers to make necessary investments to enhance their waste management processes.

6. Conclusions

The level of food loss and waste globally appears to spark concern, but the problem is driven by different stakeholder groups, each with different perspectives and concerns. The existing studies mainly investigated food waste management in the consumption stage. Despite food processing and sales/distribution stages have substantial environmental impacts, no study has systematically investigated sustainability barriers in these stages along with those in the consumption stage. This study narrows this knowledge gap in the research context of China, the world's largest developing country which has an ambition toward a transition to a CE.

This study makes several key contributions. First, we use expert panel data drawn from three supply chain stakeholder groups (food processors, sales & distribution firms, and consumers) and we believe that this research is the first to address the barriers to food loss and waste management for CE. The study has a significant contribution in identifying major barriers, from the perspectives of three supply chain stakeholder groups and highlighting the causal relationships between these barriers.

Second, the study results make significant contributions to practice and the transition towards CE. The results provide a pathway for a structured approach to addressing the barriers along the supply chain to improve sustainable food consumption and production in China. The causal nature and relationships suggest sequences of changes that can be made to maximise outcomes, by addressing the key cause barriers with the first initiatives. We identify 'weak legal enforcement' and 'lack of environmental education and accountability' as key cause barriers that are consistently identified along the food supply chain by all the food processors, sales and distribution channels, and consumers. Such a cause barrier suggests that a transition would be enhanced by careful policy making to enhance the food production sector, with stricter measurement, enforcement of regulations, and provision of household subsidies. Technologies can be used to improve compliance and enhance education and household understanding of waste separation. Applications of subsidies and direct monetary incentives can also influence household behaviors. Also, food processors perceive the lack of economies of scale as a critical cause barrier and the inadequate infrastructure, lack of investment in advanced equipment/technologies, and lack of expertise as prominent barriers. Sales and distribution firms perceive the cost barriers as a key cause barrier and the infrastructure and lack of economies of scale as prominent barriers. The consumers see the lack of investment in advanced equipment/technologies, cost barriers, and the economies of scale as prominent barriers. Together, these findings should support government and business decision-making in supporting a transition to a more sustainable, circular economy, and targeting the development of new policies and investments in appropriate infrastructure to reduce food loss and waste.

Last but not the least, this study makes strong theoretical contributions. This study employed dual theoretical lenses of the stakeholder theory and TRA at the firm level to explore the barriers to sustainable food consumption and production. The study findings affirm the explanatory power of these two theories; therefore, provide guidance to further studies on sustainable consumption and production.

Future research should conduct similar studies in other countries, to enable us to understand the role of culture in influencing these barriers. Some barriers (e.g., legal enforcement and education) will be driven by the specifics of the countries studied. A cross-national study may support the identification of barriers that will be more generalizable to other settings. Future research will also need to be conducted on how to overcome these barriers; while these results present a causal connection between the barriers additional exploratory research may uncover solutions to managing the barriers grounded in leading industrial practices and through the development and implementation of effective metrics. Sector-specific studies that may be qualitative or based on action research may enable mechanisms to be determined that support firms in overcoming barriers such as the key cause barriers of cost, economies of scale, and improving internal accountability.

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Appendices

Appendix A

A sample of pairwise comparison

Barrier	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10
B1	0	4	2	0	2	0	0	0	3	0
B2	1	0	3	0	0	0	0	0	3	4
B3	1	0	0	0	4	0	0	0	2	3
B4	0	3	0	0	0	1	0	2	0	4
B5	1	0	0	2	0	0	0	3	0	4
B6	1	0	0	0	2	0	0	3	0	4
B7	1	3	0	2	0	4	0	0	0	0
B8	0	4	0	1	3	0	2	0	0	0
B9	1	2	3	0	0	0	0	0	0	4
B10	0	0	4	0	0	0	0	1	3	0

Note: 0 = no Influence, 1 = very low Influence, 2 = low Influence, 3 = high Influence, and 4 = very high Influence

Appendix B

A sample of fuzzy initial direct relation matrix

Barrier	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10
B1	0,0,0.25	0.75,1.0,1.0	0,0.25,0.5	0,0,0.25	0.25,0.5,0.75	0,0,0.25	0,0,0.25	0,0,0.25	0.5,0.75,1.0	0,0,0.25
B2	0,0.25,0.5	0,0,0.25	0.25,0.5,0.75	0,0,0.25	0,0,0.25	0,0,0.25	0,0,0.25	0,0,0.25	0.5,0.75,1.0	0.75,1.0,1.0
B3	0,0.25,0.5	0,0,0.25	0,0,0.25	0,0,0.25	0.75,1.0,1.0	0,0,0.25	0,0,0.25	0,0,0.25	0.25,0.5,0.75	0.5,0.75,1.0
B4	0,0,0.25	0.5,0.75,1.0	0,0,0.25	0,0,0.25	0,0,0.25	0,0.25,0.5	0,0,0.25	0.25,0.5,0.75	0,0,0.25	0.75,1.0,1.0
B5	0,0.25,0.5	0,0,0.25	0,0,0.25	0.25,0.5,0.75	0,0,0.25	0,0,0.25	0,0,0.25	0.5,0.75,1.0	0,0,0.25	0.75,1.0,1.0
B6	0,0.25,0.5	0,0,0.25	0,0,0.25	0,0,0.25	0.25,0.5,0.75	0,0,0.25	0,0,0.25	0.5,0.75,1.0	0,0,0.25	0.75,1.0,1.0
B7	0,0.25,0.5	0.5,0.75,1.0	0,0,0.25	0.25,0.5,0.75	0,0,0.25	0.75,1.0,1.0	0,0,0.25	0,0,0.25	0,0,0.25	0,0,0.25
B8	0,0,0.25	0.75,1.0,1.0	0,0,0.25	0,0.25,0.5	0.5,0.75,1.0	0,0,0.25	0.25,0.5,0.75	0,0,0.25	0,0,0.25	0,0,0.25
B9	0,0.25,0.5	0.25,0.5,0.75	0.5,0.75,1.0	0,0,0.25	0,0,0.25	0,0,0.25	0,0,0.25	0,0,0.25	0,0,0.25	0.75,1.0,1.0
B10	0,0,0.25	0,0,0.25	0.75,1.0,1.0	0,0,0.25	0.25,0.5,0.75	0,0,0.25	0,0,0.25	0,0.25,0.5	0.5,0.75,1.0	0,0,0.25

Appendix C

A sample of average initial direct-relation matrix (A)

Barrier	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10
B1	0.04	0.61	0.56	0.44	0.49	0.41	0.41	0.37	0.72	0.59
B2	0.39	0.04	0.54	0.52	0.40	0.41	0.49	0.39	0.38	0.50
B3	0.50	0.43	0.04	0.38	0.43	0.39	0.41	0.28	0.52	0.53
B4	0.45	0.65	0.40	0.04	0.51	0.47	0.62	0.55	0.33	0.43
B5	0.44	0.48	0.43	0.56	0.04	0.44	0.51	0.51	0.44	0.57
B6	0.33	0.40	0.35	0.44	0.53	0.04	0.42	0.45	0.43	0.41
B7	0.37	0.60	0.39	0.64	0.55	0.53	0.04	0.55	0.30	0.36
B8	0.38	0.51	0.35	0.48	0.46	0.51	0.63	0.04	0.37	0.41
B9	0.62	0.49	0.53	0.42	0.43	0.46	0.43	0.35	0.04	0.54
B10	0.50	0.50	0.51	0.43	0.50	0.38	0.42	0.42	0.55	0.05

Appendix D

A sample of normalized initial direct-relation matrix (D)

Barrier	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10
B1	0.01	0.13	0.12	0.09	0.10	0.09	0.09	0.08	0.15	0.13
B2	0.08	0.01	0.12	0.11	0.08	0.09	0.10	0.08	0.08	0.11
B3	0.11	0.09	0.01	0.08	0.09	0.08	0.09	0.06	0.11	0.11
B4	0.10	0.14	0.09	0.01	0.11	0.10	0.13	0.12	0.07	0.09
B5	0.09	0.10	0.09	0.12	0.01	0.09	0.11	0.11	0.09	0.12
B6	0.07	0.08	0.07	0.09	0.11	0.01	0.09	0.10	0.09	0.09
B7	0.08	0.13	0.08	0.14	0.12	0.11	0.01	0.12	0.06	0.08
B8	0.08	0.11	0.07	0.10	0.10	0.11	0.13	0.01	0.08	0.09
B9	0.13	0.10	0.11	0.09	0.09	0.10	0.09	0.07	0.01	0.11
B10	0.11	0.11	0.11	0.09	0.11	0.08	0.09	0.09	0.12	0.01