Interrelationships between mechanisms of Rebound Effects in a Circular Economy in the agri-food industry

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Master Thesis

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Abstract

A Circular Economy (CE) is seen as a strategy to achieve sustainable development and is perceived as a substitute for the current take-make-waste linear economy. However, the sustainability potential of the CE can be limited by the occurrence of Rebound Effects (REs). The implementation of a CE requires several traditional actors, expands the number of network nodes, and increases material and information flows in various directions. Addressing REs in a CE needs, therefore, a more thorough understanding than REs in linear economies, given the complexity of a CE. Research combining REs with CE is mostly based on reviews rather than research. Additionally, the majority of studies are explored on the micro-level, did not address the causes of REs, and focused on specific types of REs. Therefore, this research encompasses multiple research gaps by determining REs at the micro- as well as meso level, identifying mechanisms behind REs (causal connections between variables from implementing CE initiatives to REs), and by including the interaction between different REs in a complex CE context. Based on a literature review on the mechanisms of REs in a CE and a multiple-case study within the agri-food industry, a Causal Loop Diagram (CLD) is developed to capture the interrelationships between the mechanisms and REs. The findings emphasize the importance of the interconnectedness of REs and their mechanisms at different levels within a complex CE system and show the need for interdisciplinary research. In addition, the findings require an integrated approach in the management of applying CE principles, highlighting the need for a strong collaboration between various stakeholders.

Key words: Circular Economy, Rebound Effect, Mechanisms, Agri-food industry, Causal Loop Diagram

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1 Introduction

The natural ecosystems, human health, and well-being are threatened by the adverse effects of the current linear economy. This model is based on the take, make, and waste of resources and goods where insufficient attention to pollution is given (Bruel *et al.*, 2019). In other words, the linear economy does not consider environmental impacts from recourse consumption and waste disposal. This results in an unsustainable earth with perhaps irreversible environmental changes. Also, global resources are limited and planetary boundaries are exceeded by this linear economy (Lüdeke-Freund *et al.*, 2019). Therefore, shifting from a linear economy to a Circular Economy (CE) is essential.

A Circular Economy (CE) is perceived as a substitute for the take-make-waste linear economy. It can be seen as a driver toward a truly sustainable economic system (Mies & Gold, 2021). A CE aims to minimize resource utilization and emissions by slowing, closing, and narrowing material and energy loops which can be achieved through, for instance, reuse, remanufacturing, or recycling (Geissdoerfer *et al.,* 2017). In addition, a Circular Business Model (CBM) promotes the transition toward a CE (Castro *et al.*, 2022). However, the sustainability potential of a CE can be limited by Rebound Effects (REs) (Metic & Pigosso, 2022). This means that implementing CE principles results in fewer economic, environmental, and social benefits than expected, i.e., less sustainable than expected (Zink & Geyer, 2017). REs occur due to behavioral and systemic responses (Zink & Geyer, 2017). In a more systemic understanding, RE is defined as the initial stimulus of external variables in sustainability and organizational strategies, which partly or entirely negates the intended effects (Cezarino *et al.*, 2020). For instance, organizations make an improvement towards CE which can reduce production costs, consequentially increasing the profit, which in turn results in re-investing in other production factors. Finally, this increases resource utilization (Metic & Pigosso, 2022).

REs have been widely discussed in the context of linear economies (Figge & Thorpe, 2019). In a CE, however, its dynamics manifest differently due to the interplay across the value chain (Metic & Pigosso, 2022). This means that the implementation of a CE requires several traditional actors, expands the number of network nodes, and increases material and information flows in various directions (Castro *et al.*, 2022). Consequently, addressing REs in a CE requires a more thorough understanding than REs in linear economies. Therefore, to determine REs in a CE, it is crucial to consider the interconnectedness and complexity of the system due to the interaction between different actors.

Nevertheless, despite the extensive literature on REs in various disciplines, including theoretical and empirical studies, research regarding REs within a CE context is still limited (Metic & Pigosso, 2022; Makov *et al.*, 2018). The majority of studies combining RE with CE took place in the context of review rather than research (Font Vivanco *et al.*, 2022); hence, a need was identified for more empirical studies. Furthermore, CE studies are mostly explored on the micro-level and usually focus on specific cases examining a limited number of types of REs (Metic & Pigosso, 2022). For instance, Makov *et al.* (2018) focused on only two types of REs (Imperfect Substitution RE and Re-spending RE) within a case study of smartphone reuse. Similarly, Warmington *et al.* (2020) examined the same REs (Imperfect Substitution RE and Re-spending RE) within an online peer-to-peer boat sharing case study. Therefore, these studies do not fully address the complexity of CE and do not explain the adverse result obtained (Castro *et al.*, 2022). Moreover, a broader focus on the meso level within CE would allow for a more in-depth understanding of REs that occur due to the complexity of the system, given its interconnectedness (Metic & Pigosso, 2022). This research will broaden the scope by adhering to both micro- and meso levels.

Furthermore, there is limited understanding of what causes REs (Galvin, 2021), while a deep understanding of the causes is crucial to mitigate REs in CE strategies (Guzzo *et al.*, 2023). This means that more clarity on the causes of RE within CE is needed (Metic & Pigosso, 2022). This research therefore sets out to identify causal mechanisms behind REs that occur within a CE system. Hence, RE mechanisms can help explain why and how REs occur (Metic & Pigosso, 2022), including the causes of the REs. This research uses the mechanisms to describe causal connections between variables from implementing CE initiatives to REs.

This research encompasses multiple research gaps by determining REs at the micro- as well as meso-level (Metic & Pigosso, 2022) and by including the interaction between different mechanisms of REs in a complex CE context (Castro *et al.*, 2022). The aim of this research is to investigate the mechanisms at micro- and meso levels that lead to a RE in a CE, including their interactions. Therefore, the research question addressed is "*What mechanisms help explain micro- and meso level Rebound Effects (REs) and how is the interaction between those mechanisms in a CE?"*. This empirical research of mechanisms of REs within CE was designed as exploratory research and organized as a multiple-case study. The research contributes towards the development of a circular system that brings true sustainability.

The remainder of the research is structured as follows: section two reviews the literature on REs within CE, indicating the complexity of the CE system and the interconnectedness of REs. Section three describes the methodology, including the research setting. The research question is discussed in section four, presenting the mechanisms of REs. Section five points out the main contribution of this research, and the lessons from the findings are discussed. Future research and the limitations of this research are described in section six.

2 Theoretical framework

The transition from a linear economy to a CE involves several changes within the system since the CE entails a shift throughout the supply chain, increasing the system's complexity. Accordingly, REs in CE behave differently than REs in systems with a linear economy and are highly dependent on the system's complexity (Castro *et al.*, 2022). Traditional REs from energy economics particularly relate to energy efficiency improvements that are outweighed by consumption growth and new energy demand (Chen, 2021). This means that traditional REs look into the difference between input and output only (Wang *et al.*, 2016). However, REs within CE are concerned with broader changes in the system due to the interplay across the value chain (Metic & Pigosso, 2022). Hence, REs have shifted from single causality to multiple causal relationships within a CE (Chen, 2021). Therefore, REs within a CE go beyond simplistic linear REs due to the interaction between several actors, which means that various REs occur and might interact at different levels in the system.

First, the mechanisms of REs within the CE system must be understood to be able to determine REs. Next, it is essential to understand the difference between the levels at which REs occur and how REs are interconnected with each other and across levels.

2.1 Mechanisms of REs

Several side effects brought by implementing CE principles can cause a RE. These side effects can be seen as unintended consequences of applying CE principles (Laurenti *et al.*, 2016). This research identifies mechanisms behind REs which arise from side effects within a CE system. Mechanisms can be understood as a set of interdependent variables that can initiate an activity or process to occur (Castro *et al.*, 2022), such as REs. Therefore, the mechanisms help explain why and how REs occur (Metic & Pigosso, 2022), including the causes of the REs. It is essential to clarify what side effects brought by CE will lead to a RE mechanism to understand the different mechanisms of REs in a CE. Therefore, Table 1 summarises potential side effects from CE with the associated mechanisms of RE and the corresponding RE definition.

Table 1. Potential side effects with associated mechanisms of RE and the RE definition in a CE

Side effect from CE	Mechanisms leading to RE	Definition RE	References
Implementing sufficiency strategies by an organization	Organization does not offer more of the products/services, which will be offset by an increase in supply from another organization	Sufficiency RE	Metic & Pigosso, 2022
Reduced productions costs due to applying CE-principles	More profits, invest in more production, leading to more resource utilization	Re-investing RE	Santarius, 2016; Metic & Pigosso, 2022
Need for more transportation	Further distances have to be driven, increase in emissions	Environmental RE	Chen, 2021; Castro *et al.*, 2022
New policies or regulations for CE systems	Biased policies widen the gap of resources between small and dominant organizations, resulting in economic impact; also, local RE without collaboration between governments	-	Chen, 2021; Castro *et al.*, 2022
CE products compete with linear products	CE products do not avoid demand for linear products, increasing overall production	Imperfect Substitution RE	Zink & Geyer, 2017; Metic & Pigosso, 2022; Siderius & Poldner, 2021
Lower costs of CE products (e.g., due to recycled materials)	Substitute towards CE products rather than others with lower resource consumption, leading to more resource utilization	Substitution RE	Metic & Pigosso, 2022
Cost savings due to more efficient production	Increased profit, which is used to further the production, leading to more resource consumption	Output RE	Metic & Pigosso, 2022
Non-monetary policies, such as green labels	CE strategies lead organizations to overstate their environmental performance, including greenwashing, and thereby undermine the economic prosperity and sustainability	-	Zerbino, 2022

2.2 Levels of REs

The REs can occur on micro-, meso- and macro level and are linked forward and backward between those levels. A connection between the micro- and meso levels is necessary for a CE since the CE requires interactions across organizations (Nikolaou *et al.*, 2021). The *micro* level refers to an individual consumer or an organization/producer (Metic & Pigosso, 2022).

Mechanisms towards REs at the micro level emerge by an improvement towards a CE (e.g., reuse, recycle, and reduce) in an organization and are restricted to that single organization. The *meso* level refers to the level of single sectors or markets (Metic & Pigosso, 2022). The mechanisms towards REs that take place in a sector or market and do not involve just one actor occur at the meso level. Those mechanisms can occur due to the cooperation among organizations to promote CE principles, such as the exchange of waste streams. Hence, mechanisms at higher levels can impact a RE at a lower level and the other way around (Lange *et al.*, 2021). For example, organizations make an improvement towards CE which increase profits and expand production (mechanism at the micro level), which may lead other organizations to follow and thereby leads to price competition and higher sales (mechanism at the meso level). Therefore, this mechanism at the meso level would not have taken place without the mechanism at the micro level (Lange *et al.*, 2021). This means it is essential to consider the interconnectedness between REs at both micro- and meso levels, which enables recognizing different dynamics and REs (Guzzo *et al.*, 2023).

2.3 The interrelationship between various REs

Furthermore, the mechanisms of REs are interconnected since REs interact at different levels. Two or more REs can occur in combination, such as the Output RE, where organizations use their increased profit to further the production of the same product/service, in combination with the Re-investing RE, where organizations use their increased profit to expand production in other production factors (Santarius, 2016; Metic & Pigosso, 2022). This means a systemic linkage exists between direct REs and, subsequently, additional indirect REs. Moreover, since the REs are combined, the different mechanisms for REs might also interact. Therefore, it is essential to identify not only the stand-alone REs, but also how they are interconnected and interact to develop meaningful strategies to mitigate REs.

After discussing the literature on the mechanisms of REs and their interaction between and across different levels, it is clear that a complex problem exists around REs in the transition to a CE. Relevant stakeholders dealing with implementing a CE were consulted to shed light on this problem and discuss how REs unfurl in practice.

3 Method

This section addresses the methodological approach for the research. First, the research design is presented. Subsequently, the research setting is explained, and thereafter, the data collection method is presented along with an overview of the participants. Lastly, a detailed description of how the data is analyzed is given. Data analysis comes just after data collection; however, it is essential to continue to collect and iterate on data at multiple levels during data analysis to verify the data (Gioia *et al.*, 2013).

3.1 Research design

Because RE within a CE is still a novel phenomenon in early development, an inductive research design is adopted. The inductive design approach explores new or emerging phenomena by viewing existing phenomena from a new perspective and does not require preconceived ideas or theories (Thomas, 2006). Mechanisms of REs, and specifically their interactions, within a CE is an emerging and new research topic that is relatively neglected in both research and practice. Therefore, an inductive research design is suitable for exploring this emerging topic and generating new insights, theories, and research direction.

Furthermore, the lack of literature combining CE and REs signals a lack of understanding of the mechanisms for potential REs. Therefore, because of the mainly exploratory nature of the research, the research design involves a qualitative methodology for identifying REs in CE (Siderius & Poldner, 2021). Qualitative research can be described as the study of the nature of phenomena and is especially suitable for answering questions about why something is observed, assessing complex interventions with multiple components, and focusing on intervention improvement (Busetto *et al.*, 2020). Given the complexity of the CE and the interrelationships of the mechanisms of REs on the micro- and meso level, the qualitative data is achieved from multiple cases. A multiple-case study provides a strong base for theory building by integrating new empirical insights derived from real-life cases (Eisenhardt & Graebner, 2007). Moreover, compared to single case studies, multiple case studies provide the development of more robust, generalizable, and testable conclusions (Eisenhardt & Graebner, 2007). Therefore, the multiple-case studies suit the investigation of the proposed research question well. To conclude, the research design allowed for the examination of REs as they emerged and the collection of rich data on the mechanisms of these REs (Yin, 2009).

3.2 Research setting

For this research, in particular, the agri-food industry is chosen as a specific sector. The agri-food industry faces unsustainable problems (due to the linear economy), such as resource scarcity, food loss, and waste generation throughout the supply chain (Esposito *et al.*, 2020). Hence, adopting CE principles in the agri-food industry is imperative for overcoming these problems and reaching sustainable development goals (Esposito *et al.*, 2020). Moreover, a CE is especially relevant for agri-food industries, given its excessive use of resources and energy (Klein *et al.*, 2022). Besides, the agri-food industry is a crucial player in the protection and promotion of natural capital (Zuchella & Previtali, 2019). However, the agri-food industry has not yet received the same attention in the CE literature as other economic industries (Zucchella & Previtali, 2019). Therefore, this research focuses on CE within the agri-food industry.

One of the most critical sustainability issues in this industry is the reduction of food waste (Zhang *et al.*, 2022). The agri-food industry is characterized by large quantities of organic waste and by-products, which pose a major challenge to many food-related organizations (Klein *et al.*, 2022). Therefore, the valorization of food waste is applied as a CE strategy, which means processing agri-food waste streams derived from the food processing industry and farming into raw materials for another industrial process (Kabongo, 2013). In other words, discarded products are transformed into valuable products, which offers an economical as well as environmental opportunity as it reduces pollutants from linearity (take, make, waste of resources). This research focuses on agri-food waste that occurs in farming and food processing, which is referred to as 'waste streams'.

Furthermore, a need was identified to investigate REs within the CE in a specific industry in order to recognize REs to develop solutions to this in the future (Das *et al.*, 2022). Therefore, the agri-food industry is chosen as a relevant industry for this research to answer the research question: "*What mechanisms help explain micro- and meso level Rebound Effects (REs) and how is the interaction between those mechanisms in a CE?"*. The unit of analysis was the valorization of food waste as a CE strategy within organizations.

3.3 Data collection strategy

The selection of cases was purposive and sequential and followed the principles of theoretical sampling (Eisenhardt, 1989). First, organizations and industry experts in the agri-food industry were approached who deal with CE by applying agri-food waste streams into raw and valuable materials for other industries. Second, viable participants were contacted by snowball sampling

(Handcock & Gile, 2011). Snowball sampling complemented the form of sampling, as participants suggested other stakeholders to approach during initial interviews (Parker *et al.*, 2019). As a result, representative organizations were attracted to cover multiple side effects that negate the CE strategy's intended effects.

The various participants within the agri-food industry were consulted through the use of semi-structured interviews. Semi-structured interviews is a common method of data collection in qualitative research (Busetto *et al.*, 2020). The interview guideline was organized differently depending on the role and function of the interview participant in question (Gioia *et al.*, 2013), but in general consists of four thematic areas: business network of the organization (and background), achieving sustainability (through CE principles and a Circular Business Model), practices of waste valorization and challenges and opportunities when applying those CE principles (e.g., unintended consequences). Moreover, after the first interviews, topics and findings from previous interviews were included (e.g., competition in waste streams, competitive linear products, laws, and regulations). The questions were on the theme of whether, and if so, in what ways, acquiring agri-food waste streams into valuable materials has led to unintended side effects and particularly leads to REs (i.e., negating the intended effects of CE).

In total, 13 semi-structured interviews were conducted, recorded, and transcribed in a period from October 2022 to February 2023. Participants were mostly recruited through e-mail. If no e-mail address was available or after no response, the participants were contacted via telephone. After an appropriate explanation of the purpose of the research, consent was sought from the participant, and confidentiality, anonymity, and privacy were assured. In order to illustrate the data collection approach, Table 2 lists the participants with their corresponding functions and a description of their main business. Each participant brings their own perspective, as their background differs significantly.

Table 2. Interviewed participants, including function and the main business

Participant	Function	Main business
1	CEO + employee	Make green food that tastes great, is healthy for the body, and is environmentally sustainable. Green food is made out of rejected vegetables (waste streams)
2	CEO	Produces soups made from high-quality leftover vegetables
3	Farmer (founder)	Reuses leftover vegetables that don't meet the norm
4	Owner feed plant & farmer	Revolutionary pig farm: convert food waste streams to high-quality meat
5	Farmer	Achieve sustainability goals by feeding pigs with local food waste streams
6	Manager Nutrition & Regulatory Affairs	Creating a circular food chain, by producing feed with the use of animal by-products, to then also contribute to human health
7	Business Development Manager	Produce animal feed based on waste streams from bakeries and test samples in food factories etc.
8	Senior Researcher Biomass and Bioenergy	Biobased economy, agroindustrial chains, circular economy, circular food systems
9	Scientist at Research Institute of Organic Agriculture	Sustainable and healthy nutrition, sustainability assessment, food system modeling
10	Executive Vice President Innovation and Business Development	Import fresh food. Sustainability goals: e.g., better use of resources and raw materials throughout the food chain to avoid food waste.
11	Sourcing Supervisor	Collect food waste materials to convert them into high-quality raw materials for industry
12	Researcher Expert Rebound Effect	Business, Management & Organization Group, Rebound Effect
13	Postdoctoral Researcher	Circular Economy, System Dynamics Modelling, Systems Thinking, Rebound Effect

3.4 Data analysis

The data analysis approach developed by Gioia and colleagues (2013) is used to explain the REs and their interactions at both micro- and meso levels and is further augmented by taking a systems perspective to explain the complex and dynamic nature of the REs within a CE system.

3.4.1 Data structure

The data was analyzed according to a general structure adopted from Gioia and colleagues (2013) to achieve the scientific rigor needed to provide validity to such qualitative research. Using Gioia and colleagues' (2013) structure, the raw data will be transferred as transparent and rigorously as possible by structuring the data into first-order codes and second-order themes, after which aggregate dimensions will be formed (Gioia *et al.*, 2013). The first-order codes are categories that emerge from the raw data with minimal influence from pre-existing literature. It starts with seeking similarities and differences among the categories and giving those categories labels or phrasal descriptors. From these categories, code families were distinguished as second-order themes. After that, aggregate dimensions were included in a data structure that was combined with the literature to form new understandings (Gioia *et al.*, 2013). After the first-order concepts, the second-order themes, and aggregate dimensions, the basis for building the data structure is made. This data structure provides a graphic representation of how to transform the raw data into concepts and themes after the analysis is conducted. Figure 1 shows the graphic representation of the data for this research. The graphic representation can be seen as a key component of demonstrating rigor in qualitative research (Gioia *et al.*, 2013).

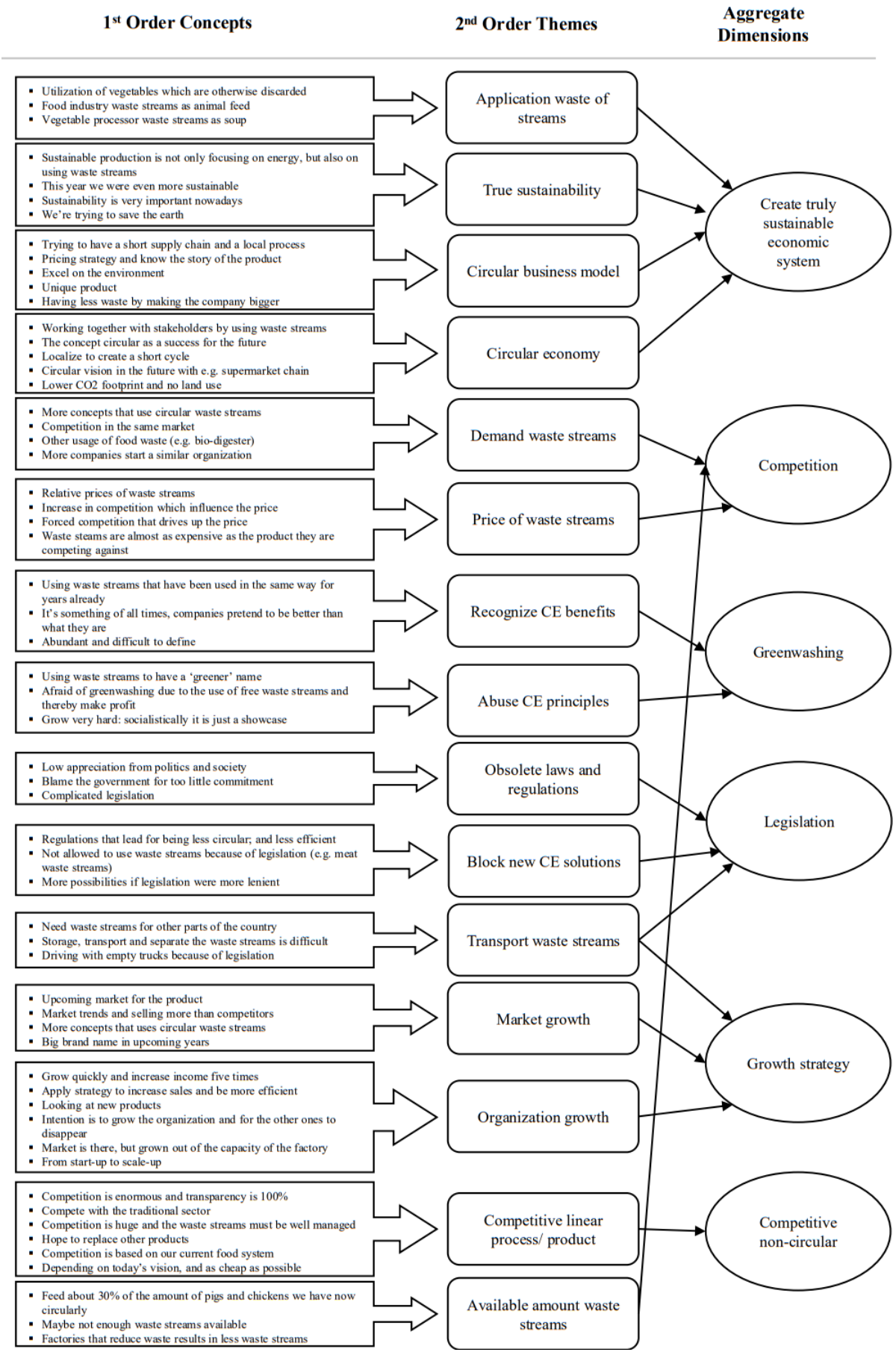

Figure 1. Data structure according to the method from Gioia and colleagues (2013)

3.4.2 Causal Loop Diagram

Figure 1 shows a static data representation; however, the data represents a dynamic interplay due to the complexity of a CE system. The research aims to identify the mechanisms of REs and their interactions. Therefore, to explain the dynamic interplay of REs, a systems perspective is used to analyze the complex, dynamic, and nonlinear nature of the CE system. This system's perspective allows for capturing the underlying components between the second-order themes and the aggregate dimensions. The dynamic interplay can be modeled by a Causal Loop Diagram (CLD) to map the sets of chains of causality (i.e., mechanisms) that exist in the system. This includes how the second-order themes are related (a positive (+) sign or negative (-) sign whether the themes move in the same or opposite direction) (Sterman, 2000). The emerging feedback loops from the causality between second-order themes occur in a balancing (B) loop or a reinforcing (R) loop type. Balancing feedback loops are goal-seeking processes (desired state) and are representative of a situation where there is an action taken to achieve that goal. A reinforcing feedback loop, conversely, is one in which an action produces a result that influences more of the same action, thus resulting in growth or decline (Sterman, 2000). After that, system archetypes can be identified on the basis of the CLD. System archetypes are generic system structures that describe the common dynamic processes that characterize the behavior of the system (Senge, 2006). It provides a simpler insight into systems structures and thereby can identify the places where an intervention should have the most influence on system behavior (Senge, 2006). Therefore, the identification of an archetype is essential to improve systems performance.

The CLD is built on interview data structured according to the method from Gioia and colleagues (2013). After identifying the second-order themes and the aggregate dimensions relevant to the CE strategy in terms of waste valorization, as part of qualitative analysis, the CLD was applied to map the mechanisms of REs and visualize their interrelations in a conceptual model.

4 Findings

In this section, the main findings from the data analysis are described. Moreover, the findings are translated to a CLD and depicted in Figure 7. The CLD is a visual representation of the mechanisms (causal relationships between the second-order themes) derived from the data analysis and is further substantiated by interview quotes. Furthermore, this CLD shows a "Fixes that Fail'' system archetype, which consists of one balancing (B) loop intended to achieve a certain result (i.e., true sustainability), influenced by reinforcing (R) loops. These two types of loops interact so that the desired result initially achieved by the balancing loop is negated by the actions of the reinforcing loops. First, the balancing loop is explained, and afterward, an explanation for each reinforcing loop is given. For clarification, each reinforcing loop is added and depicted separately to the balancing loop to eventually arrive at the final "Fixes that Fail'' CLD. Finally, the CLD in Figure 7 shows the mechanisms in the CE system, including the interactions between these mechanisms. This is followed by a perspective toward REs and their interrelationships.

4.1 "Fixes that fail" CLD

4.1.1 A truly sustainable economic system (balancing loop)

The balancing loop, as shown in Figure 2, is represented as the core of the final CLD (Figure 7) since the desired state of the CE system is to achieve **true sustainability** without creating REs. This balancing loop represents a system where a **truly sustainable economic system** can be achieved through a CE. Therefore, in the current state, a **CE** is perceived as a driver for the transition toward a truly sustainable economic system. The CE will be enhanced by **effectively processing agri-food waste streams** into raw materials for another industrial process and a valuable product. Accordingly, organizations apply a **Circular Business Model (CBM)** to promote the transition toward a resource-efficient CE. This system can be seen as the base for a truly sustainable economic system. However, in practice, side effects (i.e., unintended consequences) occur, resulting in mechanisms that negate the intended effects of a truly sustainable economic system.

In the following headers, the reinforcing loops represent the mechanisms that occur from applying CE principles in terms of waste valorization.

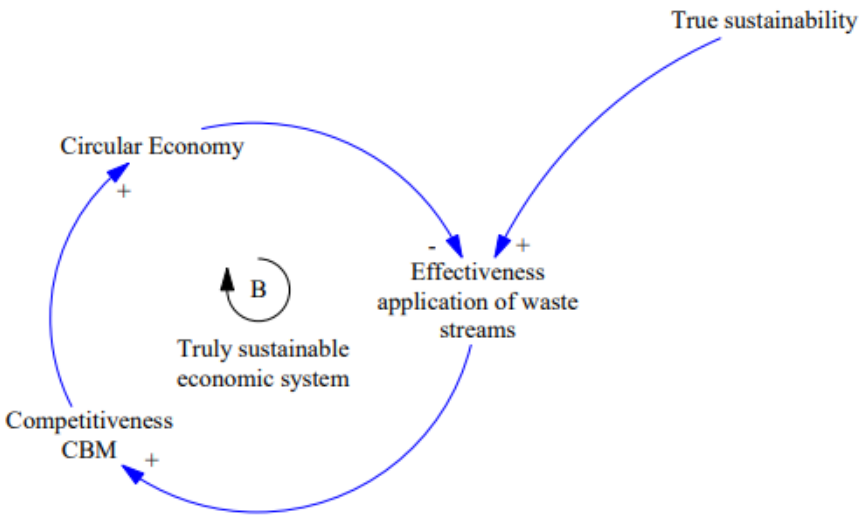

Figure 2. Balancing loop: truly sustainable economic system

4.1.2 Competition

The first reinforcing loop relates to the emergence of **competition** in the purchase of waste streams and is shown in Figure 3. Several participants mentioned an increase in **demand for waste streams** and provided various reasons for this. For instance, participant 4 mentioned the rise of more circular initiatives: *"There will be more livestock concepts that will use circular streams."*. Moreover, there are other growing industries that use the waste streams for another purpose: *"I know that like, for other use of our food waste. I know that there's some upcoming bioproduction, for example, so there's probably possibilities to get more payment." (participant 1).*

Furthermore, the **available amount of waste streams** (waste from linear producers, e.g., farmers/ food factories) should be sufficient to meet demand. However, some participants are not sure if there would be enough waste streams available to operate fully circularly in the future. Participant 1 mentioned that the available amount of waste streams depends on the competitors: *"It's of course depending on the competitors. Several guys started up this and maybe it's [waste streams] not enough of it."*. Participant 4, who talks about using the waste streams as feed, says: *"You could feed about 30% of the amount of pigs and chickens we have now circularly."*. This means that if the organizations want to feed fully circularly, more waste streams must be available. Moreover, there is an adaption of production lines in the food factories to better match on financial matters, which results in a reduced amount of waste streams; *"Surely now you can see that the factories have also just started to fine-tune a bit more to keep costs even further in check, so the number of waste streams say in the short term will make it more difficult for some by-products." (participant 5).*

The demand for the waste streams and the amount of available waste streams set a relative **price for the waste streams**. Due to the increasing demand and perhaps decreasing available amount of waste streams, the waste streams will become more scarce, which will drive the price up. This contributes to the emergence of competition in the purchase of waste streams, as mentioned by participant 11 *"Competition arises primarily because of the price of waste streams."*. Here, participants see challenges all related to paying a high price for waste streams: *"When it comes to meat, it can only be done with circular feed so the competition on the waste and return streams is going to increase in the upcoming years and that will also start to have an effect on price so there is definitely a challenge there." (participant 4)*. Also, it is hard to compete with other organizations when they can pay more for the same waste streams: *"We are really bothered by digesters, they can pay so much for this kind of waste stream now with the more current energy flows." (participant 7)*. Moreover, the waste streams are sometimes as expensive as the product it competes against: *"The waste streams are often priced so that it does pay a little bit to feed waste streams, but at some times of the year the waste streams are actually almost as expensive as the product they are competing against." (participant 5)*. When organizations have to pay a higher price for the waste streams, it will affect their **CBM** at the revenue level.

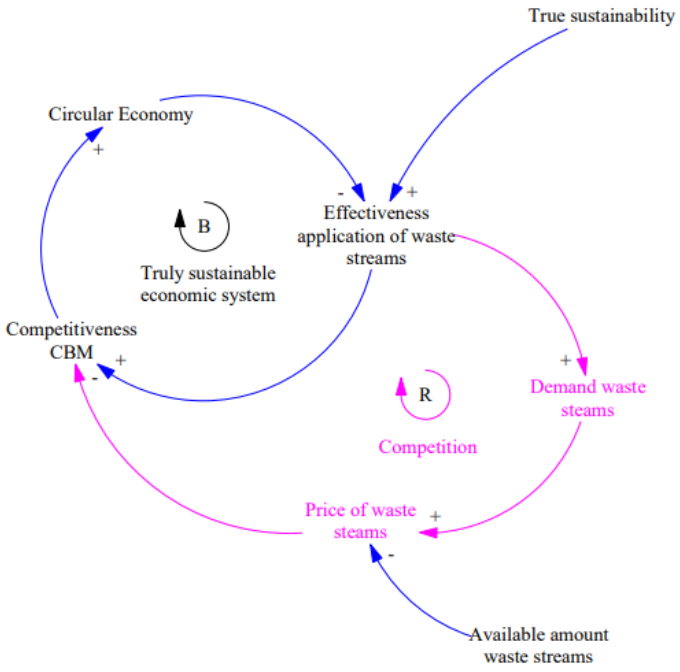

Figure 3. Reinforcing loop: competition

4.1.3 Competitive linear products

A second reinforcing loop exists through **non-circular competitors** which is depicted in Figure 4. The application of waste streams affects a **competitive linear process and product** by bringing a new circular product to the market. Therefore, the addition of circular products can be seen as a threat to their linear products. However, participants (who apply CE principles) indicated that they also feel threatened by linear processes and products. As participant 7 said, *"We have to compete with the traditional sector with our partially circular feed and no one is paying for those benefits that circular feeds bring in."*. Here, linear-producing organizations (without applying CE principles) have more flexibility in their revenue model, as they can use the cheapest resources and set a lower price for their products. Therefore, *"There is a pressure on the economy to be competitive on price, because if you end up above a threshold level for consumer purposes, then you are no longer relevant." (participant 10).* On top of that, waste streams are often of lower quality than linear resources, which therefore affects the quality of the end product: *"Always the same quality that can never be achieved with waste streams." (participant 2)* and *"There could be another reason for hindrance, taking up the alternative stream really harms the quality of the end product." (participant 9)*.

This leads back to the **CBM**, which is threatened by the flexibility (including price and quality) of the competitive linear process/product. Consumers might start preferring linear products over circular products.

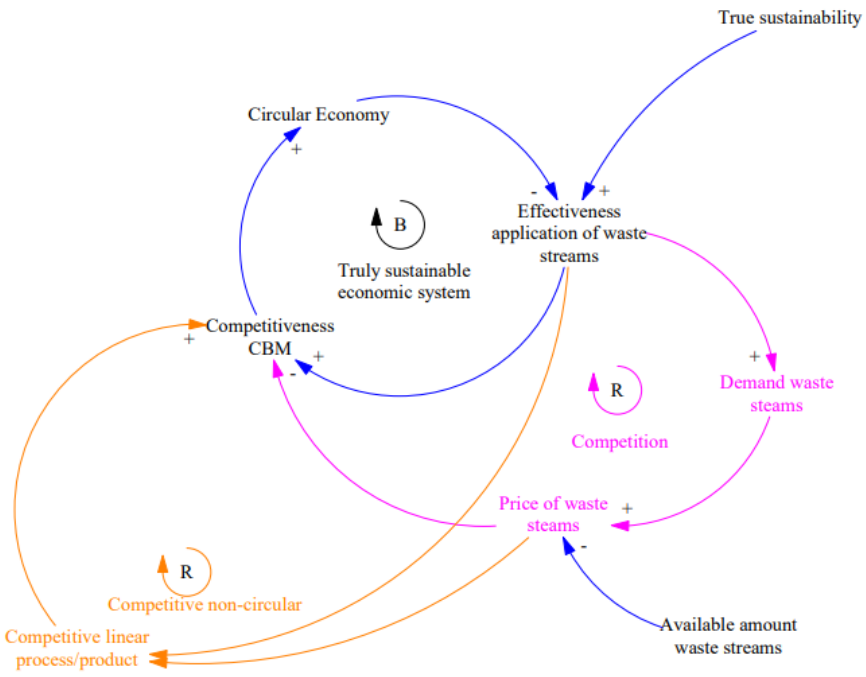

Figure 4. Reinforcing loop: competitive non-circular

4.1.4 Greenwashing

Greenwashing is also represented in the CLD as a reinforcing loop in Figure 5. Other organizations are beginning to **recognize** that the market is growing for circular products; therefore, they **abuse CE principles** to gain economic benefits from this. For instance: *"Some farmers are also smart who do that because they understand how it works, they call their pigs circular. That's because they call those raw materials circular. For example, think of potatoes from the potato fries industry and we have been feeding them to pigs for years, almost forever and yes is that circular? It is a circular raw material but it is not circular in that sense." (participant 7)*. Therefore, those organizations give themselves a "greener" name while the innovations related to circularity are already further developed. In addition, greenwashing is very present but also hard to recognize: *"I notice it is abundant of course. It is also sometimes difficult to define when they are really green washing and when there are still the good intentions." (participant 5)*.

The organizations that greenwash their products are misleading towards consumers and could pose a threat to organizations that offer "truly sustainable" circular products. Therefore, it might affect the value proposition of the **CBM** by damaging the circular image and thereby making it less competitive.

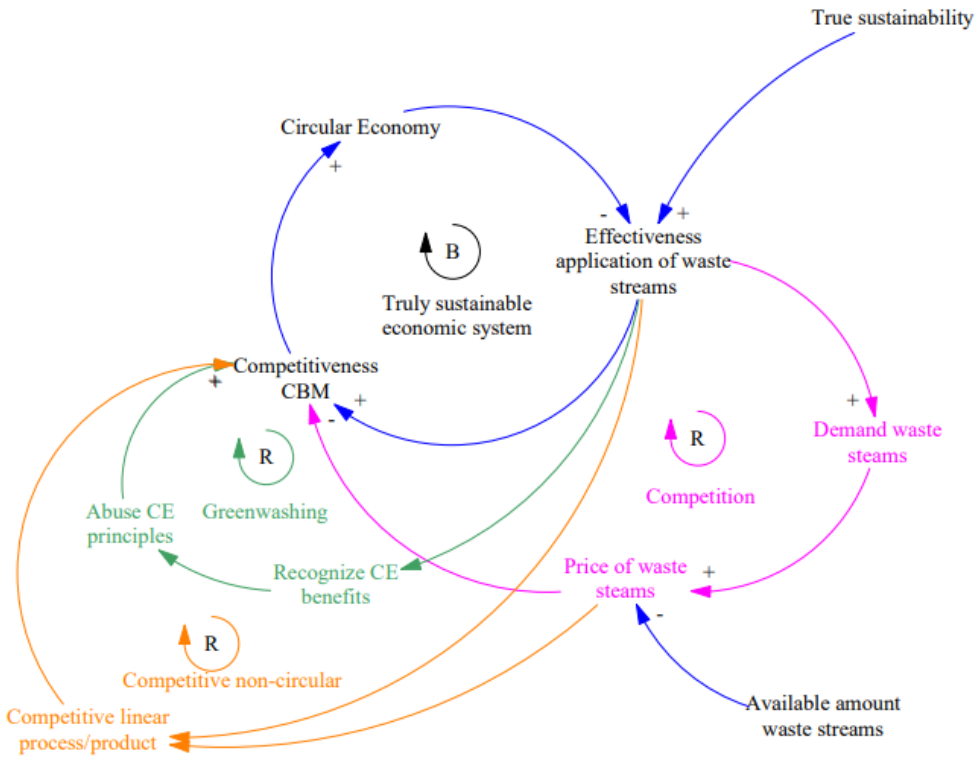

Figure 5. Reinforcing loop: greenwashing

4.1.5 Growth strategy

The CBM's value proposition creates a positive perception through sustainability goals such as reducing food waste by using waste streams in a new product. This is meaningful since the supply of circular products is increasing and even so is the demand for these products. The **market is growing** along with this increasing supply and demand of circular products. Nowadays, consumers focus on sustainable food more and more: *"Consumers want healthier foods, there is a health focus and climate footprint now in the market with more and more customers." (participant 3)*. In addition, the young generation is interested in sustainable products, which means the market will continue to grow in the coming years. *"It's a trend where you want to eat more both healthfully and environmentally soundly, especially driving by the younger generation." (participant 10)*. Another aspect of the market growth is the current trend in the use of local resources: *"We also see trends in increased interest in local food." (participant 10)*.

As the market for circular products grows, **organizations grow** along with the market to meet demand. Moreover, several participants mentioned that future growth is part of their **strategy**. This reinforcing loop is represented in Figure 6. Participant 2 focuses on lots of sales and a fast-growing organization: *"The mission is simply to start selling incredible"* and *"I expect us to grow very quickly and very strongly." (participant 2)*. Furthermore, another participant also focuses on expanding the organization and on the revenue model: *"You can say now we are going to build it a lot bigger and we are talking about increasing the total incomes five times ... So we are looking into a new factory." (participant 1)*. Despite all, participant 3 mentioned that their organization could not meet market demand because they had grown out of their plant and no longer had sufficient capacity: *"We think we could have sold 20 percent more both last year and this year if we had enough capacity then. We could have sold more, because the market is there, products got sold out." (participant 3)*.

Moreover, organization growth increases **transportation** in terms of transporting waste streams and finished products. This affects the **CBM** when it affects sustainability, such as driving longer distances which puts more pressure on the environment. For example, when there are no longer enough local waste streams, it will have to be transported from other parts of the country: *"I think we will anyway, we will have vegetables based from another part of Norway more because if we expand we will need more of some of the types." (participant 1)*. Furthermore, the growth of the organization leads to a need for more waste streams, which affects the **demand of waste streams**.

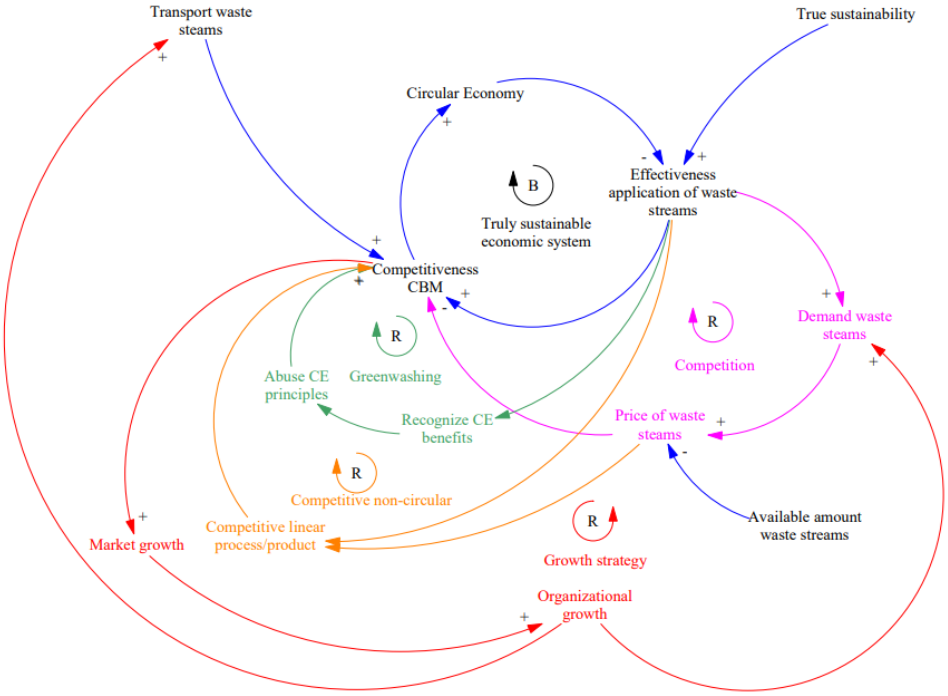

Figure 6. Reinforcing loop: growth strategy

4.1.6 Legislation

A frequently mentioned aspect by participants is **legislation**, which represents another reinforcing loop due to reducing the effectiveness of applying waste streams. There is much delay between the **application of waste streams** and a visible change in **laws and regulations**, which is also indicated by a delay sign in the CLD in Figure 7. First, laws and regulations are seen as a hindrance because they are unclear: *"One big issue is also the regulatory aspect. So what is actually allowed to reuse and what not?" (participant 9)*, *"That is a stream we would like to unlock, but are not allowed to because of legislation." (participant 7)* and "*There are no decisions in terms of legislation around the fact that what can or cannot be reused as a raw material and that it is no longer seen as a waste." (participant 11)*. Furthermore, there is a low appreciation: *"Right now, the appreciation from society from politics is so low, say so minimal." (participant 5)*. However, politics has a great influence on the implementation of CE principles: *"We are still quite heavily influenced by European legislation, so that determines enormously what we can do." (participant 6)*. All in all, this shows that the legislation is unclear and that there is a low appreciation from politicians towards CE principles, although politics has a great influence on the implementation of CE principles. Therefore, the laws and regulations affect the **CE** by **blocking new CE solutions** and thereby allowing it to be less circular than potentially achievable. Participant 8 mentioned a specific example: *"Meat waste was used for the animal, that application was heartily circular, but it was also dangerous. And then the*

government banned it all and and they started burning that stuff, instead of using it as animal feed, and in almost all cases that's much more circular than burning it."

Moreover, the laws and regulations affect the **transport** of waste streams as well. Because the laws and regulations are very strict: *"We basically never drive empty, that's the idea, but because of this legislation you will have to because if you want to change species, you have to be sure it's cleaned and that's very difficult. Especially right now with the current control technology (at the DNA level)." (participant 6)* and *"We could drive much more effectively in terms of transportation." (participant 11)*. This results in empty truck driving, which is not efficient and, on top of that, not environmentally conscious.

Finally, the balancing loop influenced by the reinforcing loops results in the final CLD, as illustrated in Figure 7. This CLD shows the influence of mechanisms on the truly sustainable economic system.

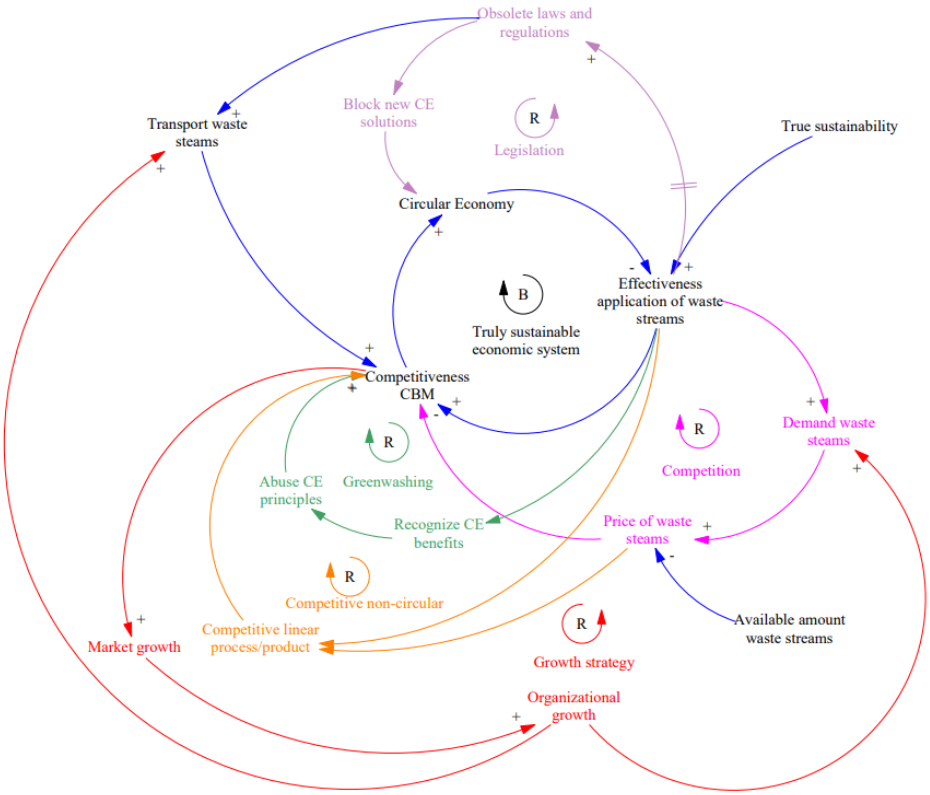

Figure 7. The "Fixes that Fail" Systems Archetype's CLD. A CLD of this archetype shows how a solution to address a symptom of a problem frequently creates side effects that, over time, exacerbate the fundamental problem linked to the perceived symptom. The variables in the CLD are linked with arrows that illustrate time-dependent relationships. A positive association, denoted by (+) for each connected pair of variables in the picture, indicates that the antecedent variable influences or causes the target variable to change in the same direction. As a result, as the antecedent variable increases, so does the target, and vice versa. When a change in the antecedent variable causes the target variable to move in the opposite direction, there is a negative relationship, shown by the symbol (-). Delays, represented as two hash marks (II), suggest that a change would take place gradually over a long period of time. The variables are connected to create a feedback loop that is balancing (B) and/or reinforcing (R). Creating goal-seeking patterns of change throughout time, balancing loops stabilize the dynamics of a situation (that often serve to maintain an undesired status quo). Reinforcing loops cause patterns of growth (or decay) over time because they feed on one another to create exponential growth (or decay).

4.2 The interconnected mechanisms towards REs

The mechanisms (reinforcing loops) within the "Fixes that Fail" Systems Archetype's CLD interfere with the balancing loop and therefore disrupt the truly sustainable economic system, which means that implementing CE principles in terms of waste valorization is less sustainable than expected and where potential REs occur.

First, as organizations grow through a growing market for circular products, their profits increase with them. The profits can be used to re-invest, as mentioned by participant 12: *"That reinvestment within organizations of the profits they've made is reinvested in more products and more sales and so you're actually monetizing those environmental gains."*, which means that potential REs on micro-, as well as meso level, occur. A RE on micro level occurs when the organizations increase their profit due to cost savings as waste streams are a cheaper input resource compared to linear produced resources, which is then used to further the production and, therefore, more resource consumption. This effect is called an Output RE (Metic & Pigosso, 2022). For instance, when the profit is used to increase sales: *"Our strategy was just go after the 50,000 to 100,000 L per month sales first." (participant 2)*. Meaning that more production leads to more resource consumption and more need for waste streams.

Moreover, *"There is another one [RE] on the organization, called the Re-investing effect. This includes pure market growth like your company is doing good, more money in the economy, more consumption of resources and more generation of waste." (participant 13)*. Here, the increased profit can also result to re-invest in other production factors, such as expanding the product range. This effect is labeled as Re-investing RE and occurs on meso level (Metic & Pigosso, 2022). For example, participant 1 mentioned to invest in a new type of product: "*We want to expand the market and sell it to another big source then we probably need to make a new brand that will be another kind of product." (participant 1)*. This finally may lead to more resource consumption as more resources are needed for another type of product and more waste streams are needed, which is also mentioned by participant 13: *"The market, like economic growth, will probably go from economic growth to more resource consumption and then also more waste."*. Both REs on micro- and meso level show that the growth of an organization can be seen as a mechanism towards RE(s).

Second, competitive linear organizations have more advantages regarding the quality of the product since waste streams are often of lower quality than linear resources. Therefore, circular products do not avoid the demand and production of linear products on a 1:1 basis. Meaning

that the production of linear products is only partially displaced by circular products, and thus the overall production increases. This is an indirect effect on meso level called Imperfect Substitution RE (Metic & Pigosso, 2022). The waste streams are insufficient substitutes for linear produced resources as they are of inferior quality. A new market is created for circular products, which leads to an overall increase in resource consumption. As a result, it can be concluded that the CBM is a mechanism towards a RE since a new market is created. Ultimately, this will burden the environment with increased production and thereby, more resource consumption.

Third, as CE needs facilities to process waste streams, more factories and associated routes for transportation and recycling will be built. Therefore, a direct cause of the adoption of CE principles is the need for transportation between organizations that now benefit from waste streams. Moreover, as organizations grow, transportation increases in terms of the greater need for assembly by the CE system and greater distances. Therefore, additional transportation associated with resale, i.e., buying waste streams, involves more GHG emissions and is therefore harmful to the environment. This Environmental RE occurs directly on micro level and is initiated by the growth of an organization mechanism due to the increasing distances. Furthermore, obsolete laws and regulations additionally increase transportation by strict legislation that results in empty truck driving. Therefore, the legislation is another mechanism towards the Environmental RE.

In sum, the following REs might occur within the CLD; Output RE, Re-investing RE, Substitution RE, Imperfect Substitution RE, and Environmental RE with the accompanying mechanisms; the growth of the organization, competition, the CBM, and legislation.

5 Discussion and conclusion

Research to date have begun to consider REs within a CE context, mostly based on review rather than research. Furthermore, the majority of studies are explored on the micro level and usually focus on a limited number of REs. In addition, there is a limited understanding of what causes REs, i.e., the causal mechanisms behind REs. By answering the research question: "*What mechanisms help explain micro- and meso level Rebound Effects (REs) and how is the interaction between those mechanisms in a CE?"* this research filled the gaps of the limitations of previous literature. The empirical research of the mechanisms of REs was designed as exploratory research and organized as a multiple-case study within the agri-food industry. As such, mechanisms are identified at micro- and meso level within the CE system. Moreover, a CLD was applied to map the mechanisms of REs and capture their interrelations in a conceptual model. The findings should be of interest to organizations, governments, researchers, and other stakeholders dealing with the transition toward a CE.

The results showed that several mechanisms at different levels help to explain REs. Moreover, those mechanisms interact with each other in a CE context. First, the effect of a growing organization can trigger different types of REs. Since the growth of an organization positively affects profits within organizations, profits can be reinvested in different ways. This can lead to two types of REs depending on the method of reinvestment, namely Output RE and Re-investing RE. Therefore, the growth of an organization can be seen as a mechanism toward REs. The mechanism "growth of the organization" will affect competition in the procurement of waste streams as there will be more demand which will increase the price of waste streams. Therefore, linear processes/products are more likely to succeed within the same market as circular products. This brings up the Substitution RE and shows that the growth of an organization and competition mechanisms interact as competition is affected by the growth of an organization. There is also an interaction between the growth of an organization and transportation. Transportation increases to enable the resale of resources, e.g., waste streams, thereby increasing GHG emissions. This triggers the Environment RE. Moreover, circular products do not completely replace linear products, so demand and production of linear products are not avoided. This means that a new market is created for circular products, which increases resource consumption. Therefore, the CBM can be considered as a mechanism since a new market is created, which triggers the Imperfect Substitution RE. Finally, legislation triggers the Environmental RE through outdated laws and regulations that increase transportation through strict legislation and thus GHG emissions.

5.1 Interrelationship between REs

The findings reveal that a mechanism that triggers a RE may subsequently trigger another mechanism and thereby cause another type of RE. This is due to the interaction between several mechanisms of REs, which means that different types of REs are also connected to each other. Although current theory provides for different types of REs, it is essential to establish the interrelationships between them in order to mitigate REs. This implies that REs have causal relationships and should be considered as a whole (Chen, 2021). In addition, this research shows that REs interact with each other at different levels. Therefore, a meso level RE may not have occurred if the micro level RE had been prevented, or vice versa (Lange *et al.*, 2021). For instance, in this research, the growth of an organization affects the competition in the procurement of waste streams, which means that the Output RE and the Substitution RE are interrelated since their mechanisms are linked. Hence, it is essential to study the interaction of REs between the different levels to avoid consequential REs in advance. This research focuses on the micro- and meso level, but that does not necessarily mean that this effect does not occur between the macro level and the meso- or micro level. Therefore, since this research has shown that REs are interrelated at different levels, the macro level, in addition to the micro- and meso levels, should also be considered when developing new strategies to mitigate REs. Quantifying REs is another challenge due to the interaction of multiple processes and variables, especially with pre-assessments (Paul *et al.*, 2019). Hence, due to the interplay between the different REs, REs should be calculated together as a whole and not individually. Those points need to be considered in efforts to mitigate REs, especially with regard to the interrelationship between REs, where RE should be considered as a totality.

5.2 Interdisciplinary research

The identification of mechanisms of REs within a CE system highlighted the importance of a need for interdisciplinary research to develop CE initiatives and associated CBMs that contribute to a truly sustainable economic system. As can be seen in the CLD in Figure 7, many different stakeholders are involved in REs, such as managers and policymakers, which shows the complexity of a CE system. Therefore, REs cannot be adequately understood from a single scientific field, and multiple scientific fields need to be involved in the development of efficient solutions to apply CE principles in order to mitigate REs and achieve a truly sustainable economic system. Meaning that connecting multiple scientific fields, e.g., economic/management and engineering/natural science, is essential for reducing unexpected REs and truly bringing CE to sustainability (Chen, 2021). For example, engineering/natural

scientific fields have the capability to provide efficient technical solutions to apply CE principles (Nikolaou *et al.*, 2021), such as the development of adapted CBMs that prevent the creation of new markets in order to overcome the Substitution RE. Furthermore, this research encourages for the multiple scientific fields the combination of system thinking (e.g., CLD) and REs in the development and assessment of CE principles and CBMs towards a truly sustainable economic system implemented by organizations, civil society, and authorities. This interdisciplinary approach provides optimal and applicable solutions for environmental protection, economic viability, and social cohesion (Nikolaou *et al.*, 2021).

5.3 Practical implications

Practical recommendations are presented from different perspectives as, for example, organizations and governments have different roles to play in promoting the CE transition. Also, some recommendations imply mitigating strategies of REs whilst others relate more to larger systemic changes. Applying CE principles, i.e., using waste streams into new products, requires an integrated approach to managing the supply chain, which underscores the need for close collaboration between various stakeholders (Hamam *et al.*, 2021). Since a shift from a linear economy to a CE is significant, it is crucial to understand the barriers and drivers to facilitate that transition, as well as the role of industry, practitioners, and researchers in achieving the full potential of CE (Dora *et al.*, 2021). Therefore, raising awareness and dissemination of knowledge about REs and their mechanisms is essential. Furthermore, the dissemination of good practices for the application of CE can help researchers and organizations gain knowledge on CBMs for a CE, thus helping organizations to achieve a truly sustainable economic system. The implementation of CE principles by organizations to improve the circularity of the supply chain also requires collaborations with other organizations to achieve the most effective CBM possible. In the agri-food industry, implementing a CE has a different understanding since food products have short life cycles in the economy and encounter biophysical limits and resource quality degradation (Klein *et al.*, 2022). Therefore, the implementation of CE principles is not easy to undertake, which further emphasizes the importance of multi-stakeholder cooperation. From a political point of view, the lack of government support is one of the main obstacles that organizations must overcome to adopt CE principles (Kirchher *et al.*, 2021). The laws and regulations governing CE are currently outdated and, as a result, are a barrier for organizations to apply CE principles. As also mentioned by Chen (2021), new laws and regulations for circular systems are needed to move to a CE. Therefore, policymakers should update their legislation to help organizations move

toward a CE without creating REs. Finally, given the sustainable economic, environmental, and social dimensions of CE, circularity within the agri-food industry should become a pillar of the economy (Hamam *et al.*, 2021) rather than a competitor of linear processes/products. This implies that systemic changes will guarantee economic sustainability, sufficient attention to pollution (e.g., conservation of biodiversity), environmental impacts from resource consumption and waste disposal, and in general, contributing to food security, as well as improving social sustainability.

6 Future research and limitations

Suggestions for further research are provided, including a research agenda. Thereafter, the limitations of the research are recognized and described.

6.1 Research agenda

Although the number of studies on the interface between RE and CE has increased in recent years, there remain questions to answer in terms of recommendations for future research and academic investigations. This section discusses the main thematic areas derived from this research that needs more research—Table 3 lists research topics with possible questions to be addressed.

This research shows the interplay between various REs and their mechanisms in the agri-food industry. However, several REs may occur outside the presented CLD in Figure 7. Various stakeholders, including research institutions, value chain actors, and consumers, support the transition to a CE (Scarpellini, 2022). Therefore, a wider range of stakeholders within and across the agri-food industry will need to be engaged to mitigate REs. This considers REs in a CE context from a broader perspective, which may trigger macro level REs in addition to micro- and meso level REs (Metic & Pigosso, 2022), which means that REs and mechanisms should be considered within and across micro-, meso- and macro levels. Moreover, including consumers would also allow REs to be found on the consumer-side rather than only on the producer-side. For example, a Re-spending RE may occur when consumers can buy more of the product with the same amount of money when CE products become cheaper by utilizing recycled materials. In addition, when a significant proportion of consumers increase their consumption from the previous level, a RE may occur. Meaning that the RE at macro level consists of individual consumption actions at micro level. This again reveals that the different levels are interrelated. In short, further research on REs and mechanisms is needed within and across industries, between different levels, and including the consumer-side REs.

Due to the interaction between mechanisms and REs, new tools need to be developed to measure REs as a whole. Quantified REs can provide novel insights into the performance of CE towards a truly sustainable economic system. In addition, appropriate business models must be developed to avoid REs that emerge from the current CBM. The CLD presented in Figure 7 can be expanded by including more side effects, i.e., more mechanisms. This will bring a more fulfilled insight into what mechanisms and, thereby, REs occur within the system. However, be aware of an overly complex CLD where it is hard to see the loops, understand which are important, and determine how they generate certain behaviors. Lastly, the CLD should be simulated to resolve the REs about how the mechanisms play out. Doing this makes it possible to determine which mechanisms are more influential. However, in the first place, quantification of REs and their mechanisms are needed to simulate the CLD.

Table 3. Research agenda topics and questions

Topic	**Research questions**
More industries and across industries	What other REs may occur in the agri-food industry? Which industries play a significant role in the occurrence of REs? How do REs compare across industries?
Macro-, meso- and micro level REs	Which mechanisms of REs are linked to each other through the different levels? Which REs are connected to each other, and at what level do they occur? How can an RE that occurs at one level be prevented at another level?
Consumer-side REs	Which REs may occur on the consumer-side? How are producer-side REs and consumer-side REs related?
Quantify REs	How can REs be measured as a whole? Which tools are appropriate to measure REs?
CBM	Which REs can be prevented through a CBM? What needs to be modified in the current CBM to prevent REs? How should the CBM be modified to prevent REs?
CLD	Which mechanisms are missing from the current CLD, and what REs are missing as a result? How can the current CLD be simulated?

6.2 Limitations

There are several limitations to this research. First, a limitation of this study concerns the relatively small number of participants that comprised the data collection. Thirty-seven stakeholders have been approached, although a majority of them did not respond. Moreover, due to the scale and time constraints of this research, it was not feasible to include a much larger number of participants. However, the exploratory nature of the research, the diversity of backgrounds, and the function of the participants allowed valuable insights to be drawn. Moreover, the relatively small number of academic articles demonstrates the need for further research on specific issues facing CE in the agri-food industry.

The methodology developed as part of identifying REs within the agri-food industry case studies provides a response to research gaps previously found in the literature: the explanation of the mechanisms of REs and their interaction. The exploratory nature of the case studies limits the external validity of the findings. Although the identified mechanisms and REs are rather general and not necessarily tied to the agri-food industry only, the generalizability of the findings needs to be improved. Extending the research to other industries would not only enhance and enrich the mechanisms and REs found, but it would also identify further patterns to address the CE failures caused by the interrelations between REs. Moreover, research findings cannot be generalized to other settings by extrapolating the context due to qualitative research. Therefore, to achieve maturity and reliability, this research requires a mixed method approach where qualitative methods are complemented by quantitative approaches that add generalization capability to the findings.

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