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The Sustainable Configuration of a Circular Economy in the Agri-food Supply Chain: A Case Study of the Sugar Cane Supply Chain

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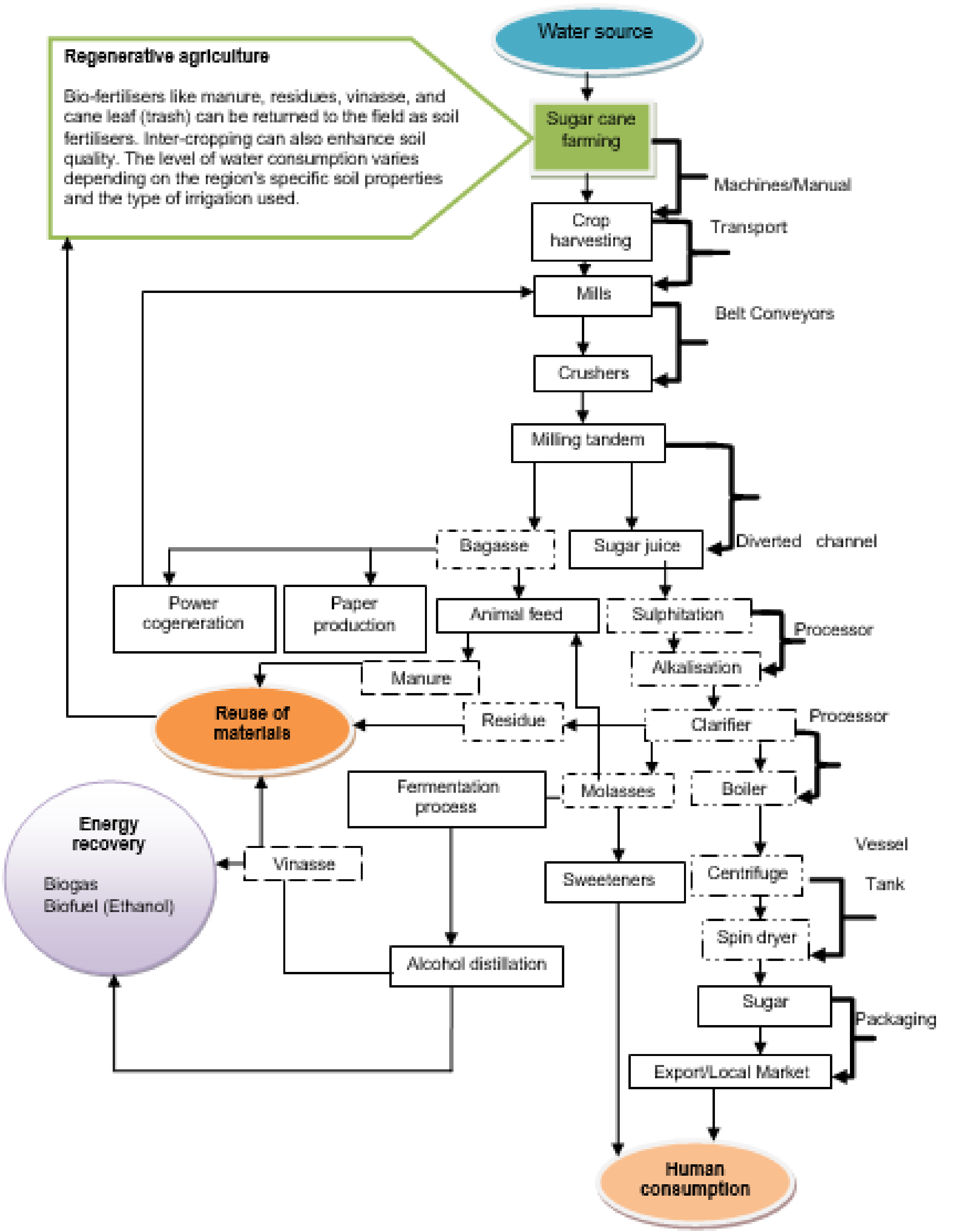
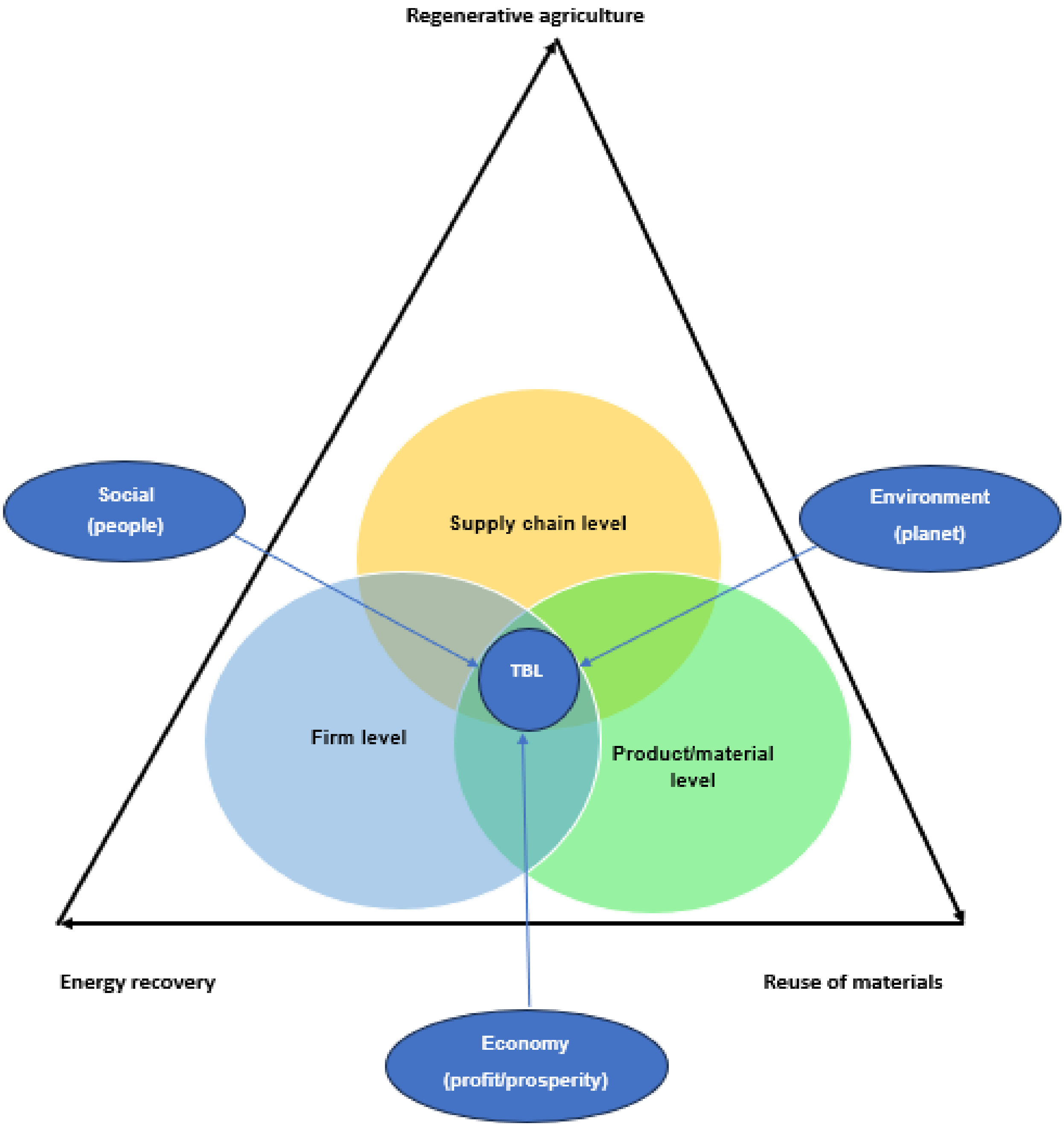

Water source
Regenerative agriculture
Bio-fertilisers like manure, residues, vinasse, and cane leaf (trash) can be returned to the field as soil fertilisers. Inter-cropping can also enhance soil quality. The level of water consumption varies depending on the region's specific soil properties and the type of irrigation used.
Sugar cane farming
Machines/Manual
Crop harvesting
Transport
Mills
Belt Conveyors
Crushers
Milling tandem
Bagasse
Sugar juice
Diverted channel
Power cogeneration
Paper production
Animal feed
Sulphitation
Processor
Alkalisation
Manure
Reuse of materials
Residue
Clarifier
Processor
Energy recovery
Biogas
Biofuel (Ethanol)
Fermentation process
Molasses
Boiler
Vinasse
Sweeteners
Centrifuge
Vessel
Tank
Spin dryer
Alcohol distillation
Sugar
Packaging
Export/Local Market
Human consumption


Regenerative agriculture
Social
(people)
Supply chain level
Environment
(planet)
TBL
Firm level
Product/material
level
Energy recovery
Reuse of materials
Economy
(profit/prosperity)

The Sustainable Configuration of a Circular Economy in the Agri-food Supply Chain: A Case Study of the Sugar Cane Supply Chain

Abstract

Purpose — This paper explores the connection between agri-food supply chains (AFSCs) and levels of circular economy (CE): supply chain (SCs), firm, and product/materials. We aim to answer the following crucial research questions: (1) What are the specific characteristics of the AFSC that affect the implementation of CE? (2) How can the interplay of AFSC characteristics and CE levels be understood and utilised to close the current knowledge gap in CE implementation? (3) How do the CE levels established (in question 2) correspond to the notion of cascade chains? (4) Can the Triple-Bottom Line (TBL) principles be used to report CE impacts in the agri-food industry? (5) What future research directions need to be explored for sustainable CE configuration in AFSCs? Answering these questions expands the knowledge of the implementation of CE in AFSCs, which is crucial for sustainable configuration based on the TBL principles.

Approach/method — We conducted a comprehensive narrative overview (a type of narrative literature review) followed by a case study guided by the cascade chain theory. The sugar cane industry, a significant source of bioenergy that can contribute to sustainable development, was selected for the case study. To validate our findings from the narrative overview, we interviewed five directors from international sugar companies.

Findings — Our research has shown that CE can significantly benefit the sugar cane industry. Based on TBL principles, we have developed a framework to achieve sustainable configurations in AFSCs. The framework starts with regenerative agriculture, material reuse, and energy recovery, where different CE levels intersect. This intersection can guide firms to improve decision-making, promote sustainable practices, and inform policymaking across the sugar cane value chain.

Limitations/implications — Narrative overview has limitations such as potential subjectivity and bias and may not be suitable for generalisation. To mitigate this limitation, we have included a case study to produce a rounded analysis. We have also gathered information from secondary sources, such as reports and company news articles, to prevent biased results.

Originality—Analysing the connectedness between CE levels and AFSC characteristics is crucial to fully understanding the CE sustainable configuration. Unlike other frameworks that only describe the CE concept, the framework presented in this paper clearly explains the implementation of CE in AFSCs. It helps industrial practitioners and policymakers validate current practices and future policies. The paper also highlights future research directions and provides valuable insights.

Keywords: circular economy, supply chain, bioeconomy, cascade chain, sustainability, agri-food.

1. Introduction

CE is an approach to tackling vast socio-economic and environmental challenges, such as climate change, resource depletion, and over-consumption (Geissdoerfer et al., 2017). CE is a generative system in which resource input and waste, emissions, and energy leakage are minimised by slowing, closing, and narrowing material and energy loops (Geissdoerfer et al., 2017). Despite varied approaches, methods, and tools to evaluate CE, scholars agree that ambiguity remains when defining the meaning of CE performance, its levels, its spatial and temporal scales, and its measurable dimensions (Stillitano et al., 2021). The importance of introducing CE strategies into the agri-

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food sector is primarily based on the circumstance — that among the main contributors to pollution worldwide are livestock and crops, in addition to the waste production caused by downstream links in the food sector (Stillitano et al., 2021). CE has been extensively studied in industrial SC settings, primarily in manufacturing companies. For instance, opportunities and barriers to implementing CE (Kumar et al., 2019), CE adoption in the manufacturing sector (Acerbi and Taisch, 2020), developing circular strategies for supporting CE-orientated innovation (Blomsma et al., 2019), CE practices in industrial SCs (Elia et al., 2020), and CE implementation in the manufacturing industry (Lieder and Rashid, 2016). Schroeder et al. (2018) state that a CE is critical to achieving the 2030 agenda for sustainable development.

The food industry faces SC issues, price fluctuations, and food crises. Due to a lack of data, Zhong and Xu (2017) state that complex food SCs increase management difficulties. Dani (2016) states that the agri-food sector faces significant challenges in production and consumption arising from the availability of finance, governance systems, natural resources, energy prices, technologies, fluctuating consumer demand, and transparent government policies. Implementing CE in AFSCs is crucial in addressing global issues such as income inequality, financial development, and global policies. Pal (2022) states that financial development promotes economic globalisation, which leads to economic growth. Lau et al. (2022) acknowledge that economic globalisation is beneficial in driving policies between developing economies. Globalisation reduces the ecological footprint in the long run (Villanthenkodath and Pal, 2023). Addressing these issues promotes the implementation of the CE in the agri-food sectors, enhancing sustainability indicators, promoting a circular bioeconomy, and enabling the achievement of Sustainable Development Goals (SDGs).

Sustainability in AFSCs has been limited to reducing food waste and recycling. Reducing food loss and waste can generate new economic opportunities, create local businesses and jobs, and lead to new economic avenues (Esposito et al., 2020). Montag (2022) embraces the broad and deep focus of the circular SCs concept. Although some scholars have focused on developing circular business models (CBMs) based on the 10 Rs of Reike (2018), remanufacturing, recycling, repurposing, reusing, refusing, reselling, repairing, refurbishing, and recovering, such models primarily deal with technical products, unlike agricultural products that have a biological structure. Supply chain management (SCM) is critical in implementing CE principles. Hazen et al. (2020) argue that the connection between SCM and CE in the context of agri-food is still unexplored. Implementing CE in AFSCs is vital for sustainable operations, considering social, economic, and environmental dimensions. Poponi et al. (2022) proposed agri-food indicators for CE based on air, water, soil, energy, waste, cost, equality, knowledge, and innovation. However, more studies are needed to address the sustainable configuration of CE in AFSCs. This paper seeks to uncover the knowledge gap by answering the following critical questions:

RQ1. What are the specific characteristics of the AFSC that affect the implementation of CE?
RQ2. How can the interplay of AFSC characteristics and CE levels be understood and utilised to close the current knowledge gap in CE implementation?
RQ3. How do the levels established (in question 2) correspond to the notion of cascade chains?
RQ4. Can the triple bottom line (TBL) principles be used to report CE impacts on AFSCs?
RQ5. What future research directions need to be explored in sustainable CE configuration in AFSCs?

To address the research questions, a thorough analysis of existing literature was conducted through a narrative overview approach, which is then supported by a case study guided by the cascade chain theory. This study investigates the sustainable configuration of CE in AFSCs using the sugar cane industry as a case study to address the research questions. Sugar cane is an essential source of ethanol production, which can replace fossil fuels. Ferraz and Pyka (2023), the circular bioeconomy can help achieve the 17 SDGs. Barros et al. (2020) state that producing biomass energy from agricultural waste advances the area of CE. This paper establishes a conceptual framework that helps practitioners understand the relationship between CE levels and AFSCs. The study highlights the role of LCA in developing circular measures and indicators targeting the TBL dimensions of people, planet, and profit, which Elkington introduced in 1998. The research acknowledges its limitations and proposes recommendations for future research efforts.

The paper is organised in six sections. Section 2 presents our research methodology, followed by section 3, which provides a narrative of a literature review discussing the emergence of CE, CE, SCs theories, AFSCs, and cascade chain theory. Section 4 presents a case study of sugar cane industry, outlining the CE adaptation across various levels (SCs, firm, product/materials). Section 5 discusses the results and findings, including CE, sustainable agri-foods, and the TBL concept. Section 6 acknowledges the study's limitations, and the conclusions and recommendations for future research are presented.

2. Method

Green (2006) classified narrative review types as editorials, commentaries, and narrative overviews. For our study, we chose a narrative overview (unsystematic review) instead of a systematic review of CE. We chose a narrative overview instead of a systematic review due to the vast and complex nature of the topics we were dealing with. CE implementation in agri-foods covers many aspects, including farming, transportation, processing, distribution, retail, and waste recycling. Sustainability is a growing concern covering various aspects of agri-food products and materials at different life cycle stages. As a result, conducting a systematic review of CE and AFSCs is not feasible, and the findings will be overly rigid. Our research involves a narrative overview of varied concepts, approaches, and theories from different sources. We prioritise relevance, objectivity, and coverage of existing literature to focus on the most pertinent articles.

We ensured the validity of our narrative overviews by identifying similarities and differences between selected topics, drawing meaningful conclusions for each paper studied in our investigation, and avoiding an opinion-oriented argument. We determined each paper's accuracy, reliability, and reputability and focused on articles published between 2011 and 2024. We carefully selected this timeframe based on the rising importance of CE thinking. The progress made in CE during this period also bolstered our criteria. Furthermore, we have incorporated cascade chain theory and the TBL concept into the broader context of the paper.

Our overview covers various topics, including SCs and sustainability, CE and AFSCs, food waste and loss, CBMs, LCA application in agri-food, and CE-bioeconomy. Other topics include regenerative agriculture, sustainability and the TBL, CE and sustainable development. We conducted a literature search using the Google Scholar database to cover relevant literature, including peer-reviewed articles, textbooks, book chapters, conference proceedings, university repositories, and company reports.

3. A narrative literature overview

Implementing CE in AFSCs requires a clear understanding. This paper extends existing knowledge by connecting theory and practice, emphasising the relationship between CE levels and AFSCs' characteristics using cascade chain theory to guide and facilitate sustainability reporting based on TBL. Therefore, the following sections critically examine available literature on CE and its implementation in AFSCs to stimulate discussion.

3.1 Emergence of the circular economy concept

According to Murray (2015), CE thinking began in the 19th century with the concept of industrial metabolism and was formally used in an economic model by Pearce and Turner in 1990; it seeks to restore natural fluxes and

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reduce excessive removal and excessive release of materials into a cycle. CE offers a new perspective on waste and resource management and provides a new cognitive unit and discursive space for debate (Blomsma and Brennan, 2017). Blomsma and Brennan (2017) state that ample ground exists to conceptualise CE as an umbrella encompassing diverse phenomena. EMF (2013) defines CE as an industrial economy restorative or regenerative by intention and design.

Kirchherr et al. (2017) describe CE as an economic system that replaces the 'end-of-life' concept with reducing, reusing, recycling, and recovering materials. It operates at micro, meso, and macro levels to achieve sustainable development. Murray et al. (2015) in China CE viewed as reducing, reusing, and recycling activities. Mhatre et al. (2021) state that the EU has implemented regulations to encourage cleaner production, pollution prevention, and waste control to facilitate circular practices. Webster (2021) CE concept emphasises value sharing among economic system participants. However, it is essential to note that Webster's perspective portrays CE primarily as an economic engine driving growth, potentially overlooking its social and environmental impacts. Integrating life cycle and circularity assessments is critical to achieving a sustainable CE. This approach allows for evaluating the environmental, social, and economic impact, leading to the development of circular metrics.

3.2 Circular economy and the supply chain: Theoretical approaches

Gonzalez and Leung (2019) CE connect various concepts and approaches like sustainability, industrial ecology, and circular business models. Specific value chains, material flows, and products need to be assessed to show the value of applying the CE concept (Winans et al., 2017). Hazen et al. (2020) state that central to CE initiatives is reconfiguring core SC processes that underlie production and consumption patterns. Fritz (2019) sustainable SCM requires integrating sustainability at various strategic levels, including governance mechanisms, top management, operational level, product/service level, and SC partners. Masi et al. (2017) state that financial, technological, societal, informational, and institutional factors can be CE adoption enablers or inhibitors. The CE's implementation is primarily associated with supply chains connecting various sectors. A cross-sector strategy recognising resource flow could speed up the transition to a circular economy (Marshall et al., 2018).

The SCM concept helps us understand the CE but does not provide the complete picture. Batista et al. (2018) conducted a study exploring how SC sustainability research contributes to CE. They identified four narratives that form CSCs: 'reverse logistics,' green SCM, sustainable SCM, and closed-loop SCM. Sustainable SCM literature has mainly focused on minimising the environmental footprint of SC activities (Malik et al., 2019). Difrancesco and Huchzermeier (2016) explain that closed-loop SCM deals with a reverse of material flow. Hazen et al. (2020) show that GSCM focuses on making SCM "green" by embracing green manufacturing and logistics. In contrast, SSCM explicitly considers supply chains' social, environmental, and economic aspects to achieve the TBL and focuses on forward and reverse supply chains (Roy et al., 2018). Hazen et al. (2020) link SCM theory and CE through circular SCM loops (closing, slowing, intensifying, narrowing, and dematerialising). Farooque et al. (2019) define circular SCM as integrating circular thinking into managing the SCs and their surrounding industrial and natural ecosystems. Hence, SCM practices are primarily associated with CE; they do not accurately capture the whole meaning of the sustainable configuration of AFSCs.

3.3 Agri-food supply chain (AFSC) focus

Tsolakis et al. (2014), the AFSCs involve various activities from farming to consumption, including cultivation, production, processing, packaging, transportation, distribution, and marketing. Hamam et al. (2021) CE models aim to reduce food waste and losses. Mehmood et al. (2021) identified different CBMs and factors that drive or hinder implementation in AFSCs. De Bernardi et al. (2022) outline critical issues for transitioning to circular food systems, including consumer behaviour, stakeholder coordination, business models, digital technologies, barriers, transition processes, and performance and measurement systems.

AFSCs are responsible for high greenhouse gas (GHG) emissions and creating a single CE model is complex as it requires the whole system to be considered. According to Esposito et al. (2020), future research should focus on integrating different SC stages to create a closed-loop system. Despite the significant work done, the relationship between the CE and SCs needs further assessment (Geissdoerfer et al., 2018). Boenzi et al. (2022) indicate that CE primarily targets waste reduction and promotes circularity across value chain members. Morseletto (2020) notes that CE aims to decrease waste, increase efficiency, close production loops, and maximise the retention of the economic value of materials and products.

By effectively implementing CE in AFSCs, we can increase value output and economic growth. However, given the constantly changing production and consumption patterns, engaging more stakeholders and implementing effective policies is imperative. When implementing CE practices in agriculture, it is vital to consider the unique biological nature of agricultural materials. Biological cycles are mainly connected to the farming sector (Rocchi et al., 2021). AFSC's characteristics include managing the linear flow of natural resources like land and water, reusing materials, and recovering energy through biomass production. By examining these three characteristics, we can better understand the relationship between different levels of CE and AFSC characteristics. To explore the levels of CE, we use the cascade chain theory introduced by Sirkin and ten Houten in 1994 as a guide.

3.4 Cascade chain theory

The cascade chain is a theoretical notion that integrates concepts of resource economy and sustainability into an operational framework for determining the efficiency and appropriateness of a given resource exploitation in a given context (Sirkin and ten Houten, 1994). According to the authors, a cascade chain comprises two interrelated theoretical entities. First, it contains four-dimensional resource economy models: resource quality, utilisation time, consumption rate, and salvageability. Second, it outlines four principles: appropriate fit, augmenting, consecutive re-linking, and balancing resource metabolism. According to the authors, cascading optimises resource utilisation by sequentially re-using the remaining resource quality from previously used commodities and substances. Odegard et al. (2012) and Jarre et al. (2020) studied the use of cascade chains in the biomass sector, considering several biomass wastes and residues of the wood industry. Odegard et al. (2012) further explain that cascading in the biomass sector comprises time, value, and function.

Researchers have linked cascade chain theory with sustainable policies, but hidden themes still hinder a complete understanding of the cascading concept. Olsson et al. (2018) state that the cascade chain is a tool that sets industry-guided policies related to sustainability targets. Its central objective is to mitigate climate change, not to increase chain or bioenergy use. Resource quality is a central element but lacks a concise definition of what it entails. Sirkin and ten Houten (1994) argue that the quality of a resource can be defined as its potential utility in a specific process, task, or set of tasks. In addition, the authors explain that the suitability of a specific resource, material, substance, or product is evaluated based on how well it matches a particular context. Despite the cascade chain supporting sustainable agendas, economic implications are emphasised more than environmental impacts. Olsson et al. (2018) suggest that scholars remain unclear on how cascading can reduce environmental impacts.

Mair and Stern (2017) state that cascade utilisation is a concept that promotes the efficient use of resources and value retention of materials' life cycle, connecting the circular economy to the bioeconomy. However, it lacks empirical studies and does not explain how circularity can be achieved at an operational level. Blomsma and Brennan (2017) state that cascading promotes resource efficiency through consecutive resource circulation and is often conflated with recycling or downcycling, but it refers to forward open-loop secondary materials flow that connects producers, firms, and organisations across other supply chains. cascading refers to forward open-loop secondary materials flow that connects producers, firms, and organisations across other supply chains

(Montag,2021). It is, therefore, imperative to highlight the direct relationship between value cascading and CE levels: SCs, firms, products/materials.

This paper highlights the benefits of cascade chain theory as a tool for guiding CE practices in AFSCs. Resource cascading encompasses practices that promote regenerative practices, closed-loop systems, and energy recovery. According to Sayadi-Gmada et al. (2020), resource cascading helps collect data and conduct life cycle and circularity analyses. Adopting a circular strategy considering the entire product and material life cycle is crucial. Sirkin and ten Houten's theory of resource quality, utilisation time, consumption rate, and salvageability, along with their four principles (appropriate fit, augmenting, consecutive re-linking, and balancing resource metabolism), can aid in this planning and designing CE system. Resource cascading enables companies to gather data and conduct life cycle and circularity analyses. Cascading also aids in creating a circular bioeconomy strategy that promotes material exchange and the reuse of waste and residues.

4. Case study

A case study explores the relationship between CE levels and the value cascade in the sugar cane industry. Unstructured interviews were conducted with 5 participants representing global sugar companies during the annual international seminars organised by the International Sugar Organisation (ISO) in London in 2023. Participants' personal and company information was anonymised to ensure confidentiality.

For a duration of two and a half hours, unstructured interviews were conducted with five directors of sugar cane companies to understand the extent of their knowledge about CE, as well as current practices on the sustainable production of sugar cane and its by-products. A deductive approach was utilised and assumed that all sugar cane production processes are similar across different countries, producers, and refiners. The gathered data was cross-checked with secondary sources, including existing literature and company reports. Case studies were employed to scrutinise the data at a micro level. Limitations of this exploratory case study and the method of collecting data, which was based on note-taking, are addressed in section 6.2, along with methods to alleviate them.

4.1 Circular economy adaptation in the sugar cane industry

Sugar cane occupies a commanding position as an agro-industrial crop and is commercially grown in 115 tropical and sub-tropical countries (Singh and Tiwari, 2018). Hess et al. (2016) state that the demand for bioethanol and sugar for human consumption has led to a global increase in sugar cane production. According to a study by Hess et al. (2016), sugar cane farms in Sub-Saharan Africa are usually close to the mill to facilitate rapid transportation and intensive water usage. This necessitates substantial infrastructure, including housing, roads, schools, and medical and recreational amenities. Rodrigues et al. (2024) state that sugar cane cultivation significantly impacts climate change due to land and water use, compared with ethanol production and transportation. Fertilisers, pesticides, burning crops, and chemicals used in ethanol production all threaten sustainability (Rodrigues et al.,2024).

Due to their biological nature, sugar cane materials have the potential to be a renewable source of energy, including biofuel and biogas. Biofuels — fuels produced from biomass — are considered a potential alternative to fossil fuels in the global effort to decarbonise. Most biofuel production still relies on traditional feedstock such as sugar cane and maize for ethanol and various vegetable oils for biodiesel. OECD and Food and Agriculture Organisation (FAO)'s (2021) report on the agricultural outlook for (2021-2030) reveals that 60% of ethanol production is from maize, 25% from sugar cane, and other sources like molasses, wheat, cassava, or sugar beets. According to Venkatesh (2021), renewable resources are the foundation of the bioeconomy, and the CE is driven by resource conservation. To create a sustainable CE framework for the sugar cane industry, it is essential to highlight the connection between sugar cane crop features, such as by-products and co-products, and levels of CE, including SCs, firms, and products /materials.

4.1.1 Supply chain level

Research studies indicate that proper SC configuration aids in implementing CE. Hussain and Malik (2020), Howard et al. (2019), and Batista et al. (2019) state that an organisation narrative is a critical enabler for achieving circular SCs. However, as Masi et al. (2017) stated, combining different SC configurations into a sustainable and commercially viable model can be challenging. Kumar et al. (2022) underscore the importance of transparent government policies on environmental regulations to promote sustainable practices throughout supply chains. The sugar cane SCs is a generally inclusive agri-industrial system that aims to grow, harvest, transport, and process sugar cane from the field to the mill (Kadwa and Bezuidenhout, 2015). A typical SC comprises three main echelons: upstream, midstream, and downstream (Morales Chavez et al., 2020). In the case of sugar cane, the upstream echelon includes several activities, such as growth, harvest, and transportation to mills (Morales Chavez et al., 2020).

Nicula de Castro et al. (2019) describe the downstream ethanol fermentation process. Mursidah and Fauzi (2022) highlight the complexity of sustainable SCs with multiple actors. Poor scheduling affects sugar quality and mill productivity (Lozano-Moreno and Maréchal, 2019). Reddy et al. (2015) state that an efficient SC is paramount to preserving cane quality. According to Bezuidenhout et al. (2012), the sugar industry in India lacks collaboration among growers, processors, and SC. The uncertainty of cane yield is a primary concern affecting the profitability of SCs, as stated by Kusumastuti et al. (2016). The quality of cane yield is dependent on various factors, including weather, technology, variety, and soil, as indicated by Lozano-Moreno and Maréchal (2019).

A holistic approach is necessary to ensure a sustainable CE, considering Sirkin and ten Houten's (1994) cascade chain dimensions: resource quality, utilisation time, consumption rate, and salvageability. At the upstream level, effective harvesting methods and efficient logistics are necessary for resource quality and utilisation time. Using animal waste (manure) and reusing cane leaf residues in the field contribute to soil fertility for salvageability. The efficient use of resources like water is necessary to ensure the stability of resource consumption. A critique arises on how quality can be restored and the extent to which materials can be used in another product system over time. Supplying materials to other industries for further processing, reusing them as organic materials, or recovering them as energy (biomass) is known as system expansion in LCA, as shown in Figure 3. In section 4.1.3, we will discuss system expansion in more detail.

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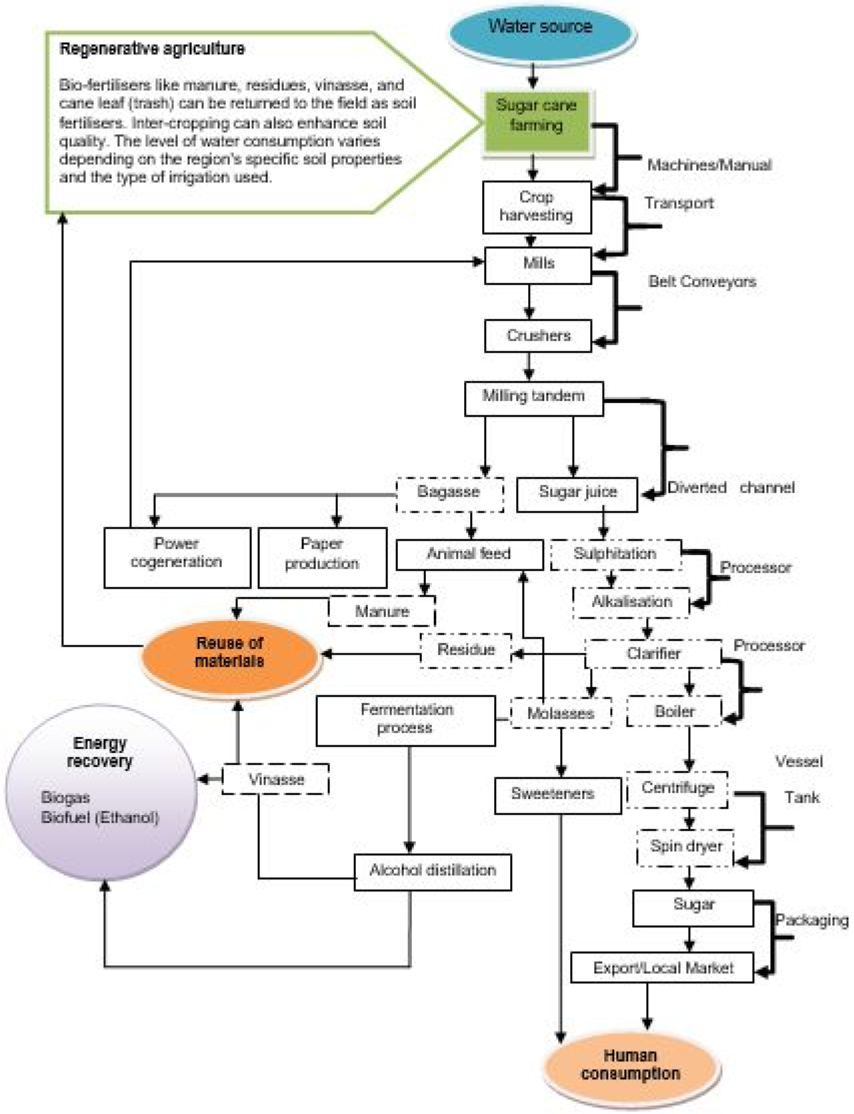

Figure 3. The SC's operational flow and processes of the sugar cane industry.

4.1.2 Firm level

CE is a model that involves sharing, renting, reusing, repairing, renovating, and recycling existing materials and products for as long as possible (European Parliament, 2015). CE represents a promising strategy for saving resources, reducing negative environmental impact, and improving economic performance (Velasco-Muñoz et al., 2021). Donner et al. (2020) identified six types of circular business models in agri-food: biogas plants, upcycling entrepreneurship, environmental biorefineries, agricultural cooperatives, agro-parks, and support structures. Implementing CE requires changes in SCs' design and commercial strategy (Bocken et al., 2016). Velenturf et al. (2019) state that companies need innovative circular business models for new resource recovery systems that enable creating, supplying, and capturing values from circular supply chains.

Montag (2022) points out that circular SC entails radical adjustment, including organisational, structural, and institutional changes. Masi et al. (2018) found that implementing CE practices at the firm level is more effective than at the SCs level. Masi et al. (2018) state that transitioning to a CE can give firms a competitive advantage. Mies and Gold (2021) state that it is essential for organisations to implement social and environmental standards for a successful transition towards sustainability and circularity, which can enhance their image and reputation while promoting job creation. Campbell-Johnston et al. (2020) proposed a steering framework for CE based on cascading that provides a systems perspective. Olsson et al. (2018) suggest that the bottom-up emergence of cascading systems should not be imposed top-down through politically determined hierarchies. Campbell-Johnston et al. (2020) examine the role of CE-cascading systems in aiding decision-making and implementation beyond resource supply and waste generation to evaluate the social and environmental processes in which they are embedded.

Efficient resource management is vital to sustainable sugar cane production. Bhatt (2020) states that to achieve positive outcomes, firms should plan to manage water consumption and soil and adopt sustainable practices such as plant breeding, soil testing, and proper management techniques. Combining various SC configurations into a sustainable and commercially viable model is a challenging task, both in theory and practice, as Masi et al. (2017) stated. Therefore, government support is crucial in promoting sustainable practices for sugar cane production, which is critical for the value chain. Encouraging firms to adopt sustainable practices and shift towards cleaner energy sources through regulations can directly impact a company's sustainability efforts.

4.1.3 Product/materials level

Products and materials are considered crucial for CE configuration in AFSCs. The intrinsic variability of food production systems requires dedicated modelling approaches, including addressing issues related to the distinction between the technosphere and the ecosphere (Notarnicola et al., 2017). LCA is mainly used to measure food's environmental impact and find ways to optimize food system management, including recovering potential waste in the supply chain (Corrado et al., 2017). LCA is a commonly used sustainability assessment tool that primarily assesses environmental impacts. It quantifies food's environmental impact and identifies the advantages and disadvantages of alternatives to optimise decision-making, including the recovery of potential waste along the SCs. LCA is an analytical tool that captures the overall environmental impact of a product, process, or human activity from raw material acquisition through production and use to waste management (Curran, 2013).

Cucurachi et al. (2019) assess the environmental impact of production systems, diets, and food as crucial in improving practices in AFSCs. Notarnicola et al. (2017) suggest that evaluating every aspect of the SC is necessary and presents challenges in identifying the appropriate functional unit, addressing multi-functionality in biological systems, and modelling emissions. In a multi-output system, two approaches for assessing by-products/co-products are allocation and system expansion, depending on data availability. Notarnicola et al. (2017) state that co-production is a common issue in food LCA, with the economic or physical allocation being the most used approach in food product studies due to the ease of data collection. A multi-output agro-system usually goes into a system expansion, even though it is more complex and demands varied data from different sources along the value chain members. On the other hand, system expansion or substitution should be used for multiple products/co-products. This approach involves expanding system boundaries to include an alternative system subtracted from the investigated system, as described by Heijungs et al. (2021). By defining system boundaries during the goals and scope phase, it is possible to assess the environmental impact of each product system independently.

In the agri-food sector, implementing CE practices requires a product-based approach to identify the most suitable models and tools for each SC (Esposito et al.,2020). In addition, Esposito et al. (2020) state it is unrealistic to expect a homogeneous adoption of CE models throughout the sector. Mehmood et al. (2021) found that product-based analysis can provide the most appropriate tools and models for implementing CE initiatives in each supply chain. Sayadi-Gmada et al. (2020) state that resource cascading is the process of closing resource loops when dealing with biological resources. Using discarded materials from the value chain as raw materials in another product cycle can replace the need for virgin materials as input (Velasco-Muñoz et al., 2021).

Bordonal et al. (2018) state that sugar cane by-products can be used for cattle feed, electricity, and second-generation ethanol production, while trash in cane leaves can improve soil fertility. Nicula de Castro et al. (2019) state that there is potential energy recovery from bagasse to produce electricity and the possibility of producing second-generation ethanol from molasses. Implementing integrated ethanol/livestock systems can also increase land use efficiency in meat and dairy production (Bordonal et al., 2018)

Campbell-Johnston et al. (2020) argue that cascading is a highly beneficial approach for managing material exchanges and transfers. Cascading is an important option that deserves attention in the quest to decide the best approach to achieving an efficient and sustainable bio-based economy (Odegard et al., 2012). The TBL helps firms measure their impact on people, the planet, and profit. By utilising the TBL concept, firms can gauge their impact on these three critical areas. With the TBL, firms can monitor their sustainable practices, measure their impact on people, planet, and profit, and report on their sustainable performance. Section 5.2 will discuss TBL in more detail.

5. Results and discussion

5.1 Regenerative agriculture and sustainability

Sustainable farming has become a topic of increasing interest among various institutions. Due to the complex and unpredictable challenges of agricultural and resource management, the FAO has recommended integrated policy approaches at both national and international levels (FAO, 2017). Sustainable farming encompasses a range of practices, including intensive agriculture, organic farming, and regenerative farming. While the definition of regenerative agriculture is somewhat nebulous, it generally involves crop rotations, cover crops, and livestock integration (Giller et al., 2021). Schreefel et al. (2020) regenerative farming use soil conservation as an entry point to regenerate and enhance the environmental, social, and economic dimensions of sustainable food production. Considering environmental, social, and economic factors, sustainable agriculture practices are financially feasible and environmentally responsible (OECD, 2019). Using bio-fertilisers made from biological waste is one way to promote CE in agriculture (Chojnacka et al., 2019). Morseletto (2020) states that circular agriculture must be regenerative to maintain the ecosystem's functionality.

In sugar cane, Bordonal et al. (2018) suggest that non-burning sugarcane harvesting can benefit the environment and improve agronomic aspects. The authors explain that improving agricultural management can increase cropping systems' efficiency, decrease synthetic fertiliser use, and close yield gaps. For example, intercropping in sugarcane farming is cost-effective and curbs weed growth. Bordonal et al. (2018) also suggest that restoring degraded pastures is crucial for sustainable bioenergy production. Moving from a linear to a CE approach in the AFSCs requires a comprehensive understanding of transforming biological materials into biomass, a renewable energy source. The adoption of CE practices has gained significant attention from companies and governmental and non-governmental organisations due to their potential to promote sustainability. However, the complexity of SCs limits the availability of quantitative data on implementing the agri-food system. Fortunately, the current development of tools to assess circularity has benefited industries in understanding environmental issues related to the impact on nature and GHG emissions.

The circular bioeconomy is a closed-loop cycle that converts end-of-life products into biomass linked to agri-food waste. In 2020, the World Economic Forum highlighted the importance of promoting a circular bioeconomy as an engine for job creation, biodiversity, and prosperity. It offers economic, social, and environmental benefits, including job creation, biodiversity, and prosperity. Using residues and recycled materials optimises resource utilisation and extends biomass availability. According to Kalverkamp et al. (2017), material cascading is linked to the biomass domain and industrial ecology. The demand for a system change is urgent, and a circular bioeconomy could provide the necessary transformation to address these problems. Sugar cane, as a significant source of biomass, can play a pivotal role in the growth of the bioeconomy.

5.2 Triple bottom line concept

In line with the paper's aim and response to RQ4, it is crucial to understand the impact of CE implementation in AFSCs on sustainability dimensions (environment, social, and economic). Wiebe et al. (2022), transitioning to a CE, aim to reduce emissions, minimise environmental impact, decrease resource use, and positively impact employment and value-adding. This aligns with the TBL dimensions of sustainable development: planet (environmental quality), people (social equity), and profit (economic benefits) (Elkington, 1998). Correia (2019) states that TBL can be understood through the nested sphere model, where the three dimensions overlap. As Allhaddi (2015) outlined, TBL and sustainability are frequently used interchangeably since they consider social, environmental, and economic factors. However, according to Slaper (2011), there are no universally recognised standards for calculating TBL, nor is there a consensus on which measures should be included in each of the three TBL categories.

Dahl (2012) adds institutional, cultural, and ethical aspects to the three dimensions environment, economic, and social. Burford et al. (2013) propose human values and worldviews when evaluating policy options. However, collecting appropriate data can be a challenge. Moreira-Dantas et al. (2022) state that open data sharing and collaborative governance involving all relevant stakeholders are essential to achieving net-zero targets. A broader approach that addresses different dimensions and stakeholders (Siebrecht, 2020). The authors suggest four areas of action: institutionalisation, assessment and system development, education and capacity building, and social and political support. Net Zero refers to reducing GHGs as close to zero as possible (Glavič et al., 2023). It requires the involvement of farmers, processors, retailers, consumers, and government/non-government bodies. Further research is needed to develop policies that engage multiple actors in agriculture and food SCs to achieve a Net Zero by 2050.

Slaper (2011) TBL emphasises the importance of ecological stewardship, education, and innovative economic models. To achieve social sustainability, it is crucial to prioritise workers' rights (Mies and Gold,2021). Slaper (2011) states that TBL can be applied to businesses, governments, and non-profit organisations. Antikainen and Valkokari (2016) state that CBMs can be adopted to reach TBL objectives. Vermeulen (2018) suggests the replacement of 'profit' with 'prosperity' in sustainable development is a debated topic. However, it should be noted that adopting CE practices benefits the environment, human health, and overall welfare and leads to economic prosperity. The sustainable configuration of CE should consider both LCA and TBL, and Figure 4 provides a conceptual framework that integrates CE levels and AFSC characteristics with TBL. To accomplish the objectives of this paper and answer the questions raised, the sustainable configuration of CE in AFSCs is compatible with the definition of CE implementation in agriculture as outlined in Velasco-Muñoz et al. (2021):

"*The set of activities designed to not only ensure economic, environmental and social sustainability in agriculture through practices that pursue the efficient, effective use of resources in all phases of the value chain but also guarantee the regeneration of and biodiversity in agro-ecosystems and the surrounding ecosystems.*"

CE's sustainable configuration involves reducing waste in landfills, air emissions, and energy waste in sugar cane production. To achieve this, bioenergy and renewable sources for electricity generation are recommended. Research explores using ethanol-fuelled vehicles, electric and hybrid technologies, and producing biochemical products like bioplastics. Legislative changes, such as taxation and incentives for clean production, are being implemented. Similar to that of Kim et al. (2023) in their study of the Brazilian sugar cane industry, our study revealed that the main obstacles to implementing a CE, which is the ethanol sector, centre around economic and financial factors and a lack of relevant legislation. To achieve a sustainable CE, a cascading approach as a policy tool should guide practices at the CE levels: supply chains, firms, and products/materials, informed by legislation. Policy, practices, and legislation should align with the 3Ps of the TBL as follows:

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- Planet

Adopting CE practices in the sugar cane industry can protect the environment. These include responsible fertilisation, mechanical harvesting, efficient water management, renewable energy use, and material circularity. Firms in the industry can contribute to protecting the planet by adopting these measures.

- People

Broadening social indicators and involving farmers and processors is crucial to tackling global food insecurity. Initiatives like incentivising farmers with support for healthcare, education, and fair pay and promoting responsible retailer programmes can help reduce food waste. Raising consumer awareness about food, diet, and nutrient intake can also improve overall well-being.

- Profit/Prosperity

Sugar companies can diversify their business strategies with compelling business models and CE strategies for by-products to increase profits, create jobs, foster innovation, and promote green prosperity. This will promote economic prosperity by driving bioeconomy growth and achieving SDGs and Net Zero ambition.

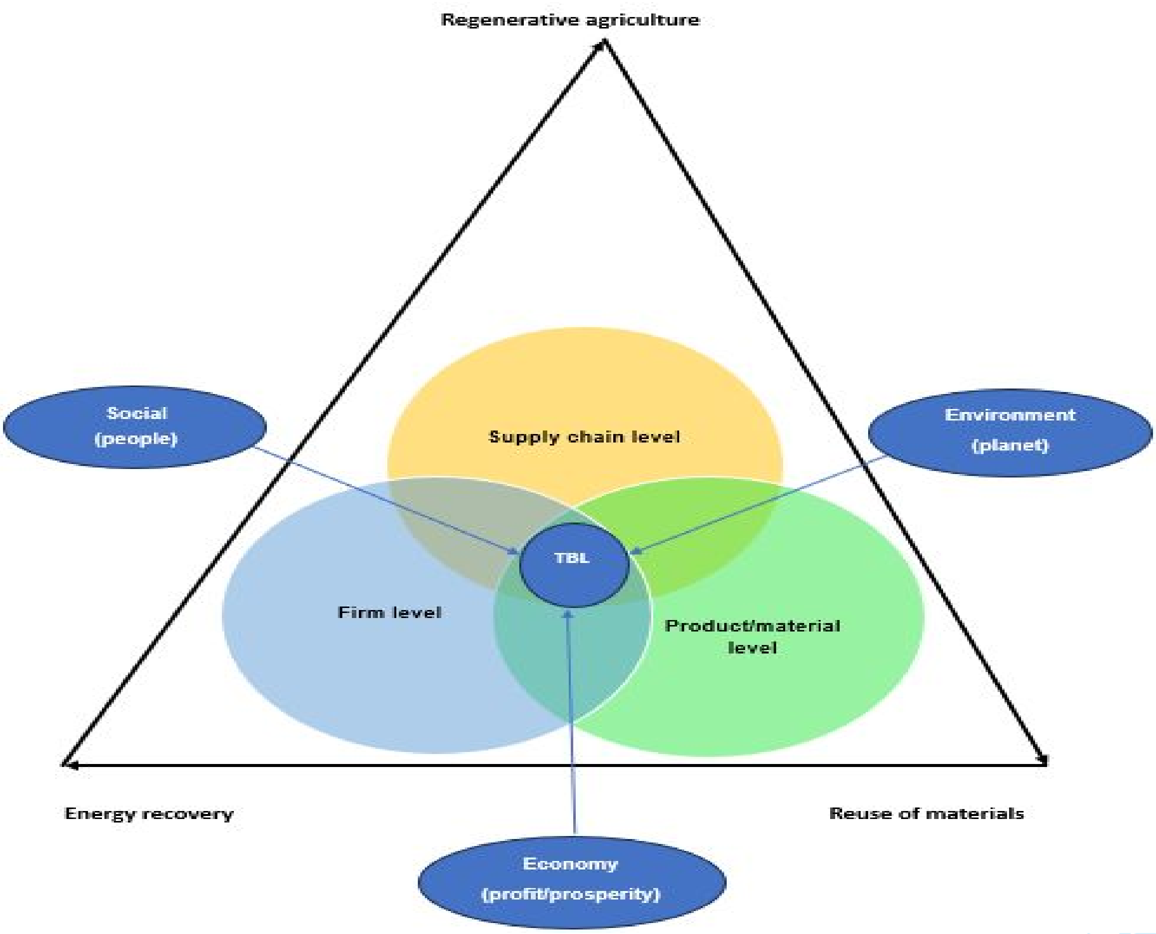

Figure 4. An integrated conceptual framework for sustainable CE configuration in AFSCs.

6. Conclusions, limitations, and future research direction

To achieve sustainable outcomes through circular economy practices, companies can follow a six-step process that includes planning, designing a system, implementing closed-loop at different levels, assessing the impact through LCA, interpreting results, and reporting using the TBL approach. In AFSCs, the cascade chain theory guides the planning and design of CE systems. It guides CE practices and serves as a policy tool, promoting regenerative agriculture, material reuse, and energy recovery.

CE sustainable configuration involves synthesising the three levels: SCs, firm, product and materials, and AFSC characteristics. LCA offers insights into the environmental impacts of SCs, while circularity assessment tools measure the economic, social, and ecological implications of reusing and converting materials. This information can better inform firm business models and CE strategies. A comprehensive approach is necessary to implement CE strategies in AFSCs effectively. Aligning LCA-CE outcomes and TBL reporting is crucial for informed decision-making on CE strategies. The results achieved could expand the concept of CE, positively contributing to the current state of knowledge and theory. Accelerating bioeconomy development while tackling the sustainability challenges of AFSCs is also essential. This research provides valuable insights to assist companies in aligning their practices with CE levels, leading to sustainable outcomes in AFSCs. The study emphasises the importance of integrating CE levels and AFSC characteristics for policymakers to validate and develop new policies. Through our in-depth analysis of sugar cane SCs, we demonstrate that the various CE levels are interdependent and work in tandem with the unique characteristics of sugar cane, resulting in a sustainable configuration.

The narrative overview and the case study play an essential role in understanding the relationship between AFSC characteristics and CE levels, which helps to bridge the knowledge gap in CE implementation from an operational perspective. Studying the implementation of CE in the agri-food industry can be difficult to generalise beyond the specific situation studied. Verifying the validity and trustworthiness of data is also challenging. Reviewing a broad concept like CE requires more clarity in the search for evidence. This study combines cascade chain theory and the TBL concept to mitigate these challenges and improve our understanding of CE sustainable configuration. While systematic reviews use objective criteria to select relevant publications, the concept of CE is still evolving. Due to the broadness of the study focus, varying interpretations restrict the use of a systematic literature review in this paper. We aim to drive an impartial conclusion from existing literature, reach findings, and draw objective conclusions. We conducted an exploratory case study with five directors from sugar companies who attended the annual ISO international seminars in London in 2023. To collect participants' responses, we used a note-taking technique and combined them with secondary sources. To ensure a thorough and well-rounded study, we incorporated the concepts of TBL, sustainable agriculture, and sustainability performance into our results and discussions. We also cross-checked our sources of data with reputable think-tank organisations such as ISO. The unstructured interviews did not follow a standardised form, which sometimes caused delays in the record and prioritised responses. As a result, it was not feasible to record all the responses during the interview. However, to mitigate this, the responses were reviewed afterwards and verified using secondary sources, e.g. company news. During note-taking, some issues arose where specific responses could not be written down due to their sensitivity. Instead, these responses were recorded more generically.

We recommend conducting an empirical investigation based on sector and country-specific data. Future research should conduct quantitative-based studies to configure CE more effectively in AFSCs. These studies should focus on how CE practices improve agronomic factors such as food inequality and labour relations. In addition, developing circular indicators of societal implications such as income inequality, financial development, and human capital development is imperative to enhance CE measures pertaining to AFSCs.

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