

Perspective

Systems and Ecosystems in the Circular Economy: What's the Difference?

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Abstract

'Systems' and 'ecosystems' are buzz concepts in the circular economy literature. However, the differences between these concepts remain ambiguous. Systems and ecosystems are often used interchangeably and at times confusingly. While conceptual ambiguity offers possibilities for broad interpretations and engagement, it can undermine the relevance of these concepts as analytical lenses to disrupt the linear economy. In this perspective article, I examine whether systems and ecosystems are distinct concepts and how they complement each other. To do so, I analysed these concepts and applied them to a case of biomethane for transportation using scientific literature. Systems and ecosystems are not mutually exclusive; rather, they offer nuanced perspectives to describe, analyse, and facilitate complex interactions among entities and their external environment. They signify the complexity, interdependency, and co-evolutionary nature of the circular economy. Ecosystems are a subcategory of systems. Differences between the concepts of systems and ecosystems partially arise from their origins, evolution, and the research communities using them. The article shows how systems and ecosystems perspectives can enrich each other and calls for better integration between the two concepts in the circular economy discourse.

Keywords: Systems, Ecosystems, Circular Economy, Co-evolution, Orchestration

1. INTRODUCTION

The circular economy (CE) is an economy that is restorative and regenerative by design. The concept builds on the principles of minimizing waste and pollution, circulating products and materials, and the regeneration of nature. Thus, the circular economy has received widespread attention as an approach to sustainability (Geissdoerfer et al., 2017). In this regard, the concepts of 'systems' and 'ecosystems' are increasingly used interchangeably to highlight the complex, interdependent, co-evolutionary and feedback loop-driven nature of the circular economy. The concepts are used to characterise different exchanges between entities including the flows of economic value, energy and material resources, and knowledge (Aarikka-Stenroos et al., 2021). Consequently, variations of the concepts have emerged encompassing different domains and perspectives. Furthermore, the concepts of systems and ecosystems are used as though they are at the same analytical level and at times confusingly. Thus, the differences between the concepts of systems and ecosystems in the circular economy discourse remain unclear. While conceptual indistinctness offers a broad basis for agreement and inspiration, it can also undermine the relevance of the concepts as analytical lenses to challenge the dominant linear economy. Thus, the aim of this perspective article is to examine the application and interpretation of the concepts of systems and ecosystems in the circular economy discourse, discerning if they are distinct concepts and offer complementary insights to understand, discuss and support the transition towards a circular economy. To do so, I analysed these concepts and applied them to a case of biomethane for transportation using scientific literature. Thus, this perspective article does not include typical sections of a scientific article such as empirical data collection and analysis. Furthermore, my overall ambition is not to present a

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complete conceptual model or empirical analysis but rather to raise awareness in the CE research community about this conceptual ambiguity and facilitate careful future research reflexivity to address this challenge.

2. THE CONCEPT OF SYSTEMS

The concept of systems has a long history and spans across several disciplines. The modern development of systems thinking is often attributed to the mid-20th century development of General Systems Theory (GST) by Ludwig von Bertalanffy and colleagues (see Von Bertalanffy, 1968). A system is composed of several distinct entities called elements, with some kind of relation existing among these elements. As a result of this relationship, a new distinct entity emerges, operating at a higher level of analysis. General Systems Theory seeks to understand the common principles that underlie all systems, regardless of their size or complexity. GST is based on the thinking that all systems are composed of interconnected parts that interact with each other giving rise to the properties of the system. Systems exhibit several different characteristics. First, they are hierarchical and thus nested within larger systems. Second, they incorporate feedback loops, constantly interacting with their environment to maintain dynamic equilibrium. Furthermore, systems can either be open or closed, depending on the extent of their interaction with the surrounding environment. Scholars hold different perspectives on the nature of systems. Some posit the existence of systems outside the human mind, defined as a set of objects interconnected by relationships. Others adopt anti-realist views, and instead, define systems as conceptual constructs shaped by human perceptions and assumptions, viewing them as cognitively constructed entities or analytical lenses of reality.

According to Kirchherr et al., (2017), circular economy can be operationalized on three analytical system levels. Macro-level (e.g., city, region, nation and beyond), meso-level (e.g., eco-industrial parks) and micro-level (e.g., products, companies, consumers). A macro-level system perspectives in the CE discourse can be the *socio-technical systems* approach (Jackson et al., 2014). This approach acknowledges that social and technological factors are deeply intertwined and should be considered together when analysing radical or incremental changes to new kinds of socio-technical systems. It also emphasizes the supply side (innovations) and the demand side (user environment) in the definitions of systems. Socio-technical systems are characterised by multiple and co-evolving elements (e.g., technologies, markets, user practices, cultural meanings, policies); multi-actor processes (e.g., learning, conflicts, power struggles); an interplay between stability and change; long-term, open ended, contested, and uncertain processes.

The socio-technical systems perspective highlights interactions between new entrants and incumbents in the circular economy. In principle, both new entrants and incumbents can pioneer circular innovations. However, new entrants often strive to commercialise circular innovations (e.g., business models, products, and services) while incumbents may (but not always) seek to defend the status-quo. New entrants have the tendency to develop radical circular innovations due to their agility and market responsiveness while incumbents can be constrained by previous investments, existing supply chains and business models (Henry et al., 2020). In practise, the relation between new entrants and incumbents in CE is complicated and characterised by both collaboration (e.g., to scale up circular business models) and competition (e.g., for market share). Due to deeply entrenched linear socio-technical systems for production and consumption (e.g., food, energy, textiles), CE transition is characterised by path dependence, lock-in, and incremental change highlighting the need for policies mixes that both support the scaling-up of circular innovations but also deliberately seek to destabilise the institutional structures of the linear economy across sectors, time, and scale (Iacovidou et al., 2021).

System perspectives on the meso-level include industrial and urban systems. Industrial systems encompass the processes, activities, and infrastructure of production and manufacturing. Within the circular economy, industrial systems are analysed for resource efficiency, waste reduction, and the integration of circular principles into production and manufacturing processes. This involves implementing closed-loop production systems that aim to minimize virgin resource consumption, waste generation, and maximize material and energy reuse (Gómez et al., 2018). An industrial systems approach based on circular economy principles can be applied to eco-industrial parks (industrial zones that promote collaborations between firms and the local community potentially generating sustainability benefits), where nature inspire symbiotic relationships between industries to utilize waste generated

from one industrial process as raw material input for another industrial process. Similarly, urban systems focus on the material and energy flow dynamics in cities and urban environments. In the context of the circular economy, urban systems are explored to identify opportunities for circular practices in areas such as waste management, energy use, transportation, and urban planning. This entails adopting strategies that optimize resource flows, promote recycling and reuse, and enhance the overall circularity of urban systems. By studying and integrating industrial and urban systems within circular economy, an understanding of the interconnectedness between production, consumption, and urban development can be achieved with a particular focus on the analysing the flow of material and energy resources for circularity. Thus, an integral approach of circularity in industrial and urban systems is the design framework of cradle-to-cradle approach characterised by reusing materials and energy resources as technical and biological nutrients, utilizing clean and renewable energy, and adapting circularity to the diversity of different places. To facilitate circularity of resources in industrial and urban systems, it is necessary to develop and manage relationships among diverse organizations often located in proximity to enable physical exchanges of materials, energy, waste, and by-products (Gómez et al., 2018).

Micro-level systems perspective on circularity focusses on products, services, customers, and companies. For example, Product-Service Systems (PSS) (Sakao & Lindahl, 2009) challenges the traditional model of selling products as standalone offerings and instead adopts a lifecycle approach to delivering value through integrated bundles of products and services. It shifts the emphasis from product ownership to product use and access, promoting resource efficiency. PSS seeks to provide customers with the desired benefits and functionality of products while potentially reducing the associated environmental impacts. Key actors in a product-service system are the providers of integrated bundles of products and services, and their customers. Customers engage with PSS providers by subscribing to a service, sharing a product with other users, or accessing products on a pay-per-use basis. This gives providers the incentive to make longer lasting products and refurbish them. Digital platforms, data analytics, Internet of Things (IoT) devices enable the integration of products and services, communication between actors, and efficient product management and operations. PSS considers the interdependencies and relationships between different actors and entities within a specific industry or sector encompassing the development of new business models, partnerships, and networks to facilitate the delivery of integrated offerings. Realizing sustainability benefits in PSS cannot be taken as a given. It relies on adopting the appropriate business model and strategy throughout the lifecycle from design to provision, and end-of-life management through re-use, remanufacturing, and recycling (Matschewsky, 2019).

3. THE CONCEPT OF ECOSYSTEMS

The concept of ecosystems is often attributed to Sir Arthur Tansley, who introduced it in the field of ecology in 1935. Tansley (1935) argued that in a fundamental sense, organisms, cannot be separated from ‘the environment of the biome – the habitat factors in the widest sense ... with which they form one physical system’ (p. 299). Thus, he regarded ecosystems as the ‘basic units of nature’ and to be of ‘various kinds and sizes.’ He further considered that, although the organisms are thought of as the most important parts of these systems, the inorganic factors are also parts and there is constant interchange of various kinds within each system not only between the organisms but also between the organisms and their physical environment. By extension, in the management and business strategy literature, the prefix *eco* in ecosystems emphasizes ecological aspects of systems as introduced by Moore (1993). Moore, (1993) drawing inspiration from anthropology and biology on the co-evolution process in which interdependent species evolve in an endless reciprocal cycle and how natural ecosystems collapse when environmental conditions change too radically suggested companies should be analysed not as members of a single industry but as part of a *business ecosystem* that cuts across several industries. In his analogy, a business ecosystem moves gradually like their biological counterparts from a random collection of elements to a more structured community going through four distinct development phases of: birth, expansion, leadership, and self-renewal, or death.

The concept of ecosystems adapted into the management literature focuses on communities or aggregations of economic actors whose activities need to be coordinated to create value. The concept is also often used in practise to describe firms that build multiple products or experiences that consist of bundles of connected goods and services (e.g., cloud storage, smartphone, and computers) (Jacobides et

al., 2024). *Circular business ecosystems* emphasize coordination among diverse actors, including producers, suppliers, service providers, end users, regulators, and civil society organizations to create value for customers (Kanda et al., 2021). Altogether, these economic actors work towards achieving collective outcomes by leveraging their expertise and resources. This concept underscores the collaborative nature of business in driving circularity. It highlights the need for a broader perspective encompassing multiple sectors and stakeholders beyond a focal firm when analysing value proposition in the circular economy. A related concept of *circular innovation ecosystems* focuses on diverse actors, such as firms, universities, research institutions, and government agencies, working together to maximize resource efficiency and reduce environmental impact. Key elements include the development of circular offerings, resource infrastructure, and effective coordination among stakeholders based on collaboration, experimentation, and facilitating platforms. By fostering collaboration and value co-creation, circular innovation ecosystems facilitate the exchange of economic value, innovative ideas and technologies through the innovation chain creating conditions for a transition towards a circular economy. Compared to business ecosystems generally characterised by collaboration and competition, collaboration is particularly necessary for developing circular business models due to the dependency on specific actors and sources for re-circulation of technical products and biological materials across different sectors. *Digital and platform ecosystems* have emerged as technological and online platforms developed by organizations to enable many other organizations build complementary products and services, increasing value and attracting users. Collaboration and innovation within the digital landscape are central to these ecosystems, shaping the way digital technologies contribute to the circular economy. *Service ecosystems* focus on the integration of resources and the co-creation of value among interconnected actors. The concept focuses on the multi-actor and dynamic nature of service exchange and value creation. Through shared institutional logics, various value proposing actors collaborate to deliver value and meet customer needs. Service ecosystems highlight the interdependence and collective efforts of actors in providing value within circular economy.

From the field of industrial ecology, the concept of *industrial ecosystems* draws inspiration from natural ecosystems, aiming to optimize the use of materials and energy while minimizing waste in industrial processes (Parida et al., 2019). By channelling waste as inputs into other processes, these ecosystems foster closed-loop production that promotes resource efficiency and effectiveness. Circular resource flows and the valorisation of waste are central to industrial ecosystem approaches. The optimization of material and energy resource flows can occur within one factory, an industrial park with a different industry, or within a geographic area. A related ecosystem concept focused on material and energy flows in cities and urban areas is *urban ecosystems*. In this approach, cities and urban areas are analysed as complex milieus that provide habitats for citizens and institutions while offering valuable ecosystem services. Urban ecosystems are hosts to multiple actors, groups, sectors, industries and governance structures, with diverse and sometimes conflicting interests who share a common locality. By sharing a common territory, these diverse actors often strive for collaboration and alignments of interests for common interests. The concept of urban ecosystems recognizes the materials and energy metabolism within cities and urban areas, emphasizing sustainable urban development, resource management, and the well-being of both human and natural ecosystems.

In addition to ecosystems concepts focused on the exchanges of economic value, and material and energy resources, knowledge exchange is central in *entrepreneurial and knowledge ecosystems* (Konietzko, 2020). An entrepreneurial ecosystem consists of a set of interdependent actors and factors that enable productive entrepreneurship within a particular territory. Entrepreneurial ecosystems foster the establishment of new ventures by interdependent actors. Entrepreneurial ecosystems consider contextual elements including actors, networks, institutions, culture and infrastructure, and their dynamic interactions, supporting successful entrepreneurship often within specific regions. *Circular entrepreneurial ecosystems* encompass interdependent set of actors (and factors) in a territory that seek to explore entrepreneurial opportunities using circular economy principles. These actors include accelerators, incubators, maker spaces, universities, and intermediaries facilitating circular business model experimentation and venturing. *Knowledge ecosystems* include users and producers of knowledge organized around a collective search for knowledge. Knowledge ecosystems focus on the early stages of new knowledge production in pre-commercial settings often led by universities, research and competence centres. Knowledge ecosystems can be connected to specific industries such as biogas, textiles under a broad circular economy umbrella.

4. CONCLUDING DISCUSSION

The concepts of ‘systems’ and ‘ecosystems’ are useful for analysing the complex, co-evolutionary, and interdependent nature of the transition towards a circular economy. However, the distinction between these concepts remains ambiguous, leading to conceptual confusion and inconsistency. Therefore, there is a need for conceptual clarity and examination of their similarities and differences. Essentially, systems and ecosystem approaches share an emphasis on interlinkages between entities and their external environment and thus considers the circular economy as a co-evolutionary process. However, there are some differences between the concepts with regards to the analytical emphasis when adopting either of them (see Table 1 and Table 2).

Table 1. Comparing Systems and Ecosystems Approaches in the Circular Economy

Dimension	Systems	Ecosystems
Basic definition	Interactions and interdependencies between interrelated entities working towards a goal.	Interactions and interdependencies between interconnected entities and their external environment.
Focus and contextualization in CE	Describes relationships, interdependencies and co-evolutionary interactions between entities exchanging (i) material and energy resources, (ii) economic value, or (iii) knowledge in a particular context.	
Scale	Varies from micro, meso, to macro scales (e.g., individuals, products, companies, industrial parks, sectors, regions, nations).	Typically studied at larger scales, encompassing broader scopes (e.g., businesses, industries, cities, regions).
Analytical boundaries	Conceptualised as open or closed systems depending on the degree of interaction with the context.	Often conceptualised as open interacting with their external environment.
Examples	<ul style="list-style-type: none"> • Socio-technical systems • Innovation systems • Industrial and Urban Systems • Product-Service Systems 	<ul style="list-style-type: none"> • Industrial ecosystems • Urban ecosystems • Knowledge ecosystems • Entrepreneurial ecosystems • Innovation ecosystems • Business ecosystems

To illustrate the differences between the concepts of systems and ecosystems in the circular economy, I concisely apply them (see Table 2) to a case of biomethane for transportation (see Figure 1). Biomethane production is prominent in biological cycles of CE providing benefits such as nutrient recycling, waste management, and substituting fossil fuels. Biomethane production is highly localised and customised. Raw biogas is produced from the degradation of organic matter under anaerobic conditions. The raw biogas produced can be used for heating and electricity generation. For public and private transportation purposes, the raw gas is purified to above 95% methane content while carbon dioxide and contaminants are removed. Biomethane producers can include municipality owned companies, privately owned energy companies, and farmers with access to organic material and anaerobic digestion technology. The business development encompasses the identification of potential feedstock including its amounts, quality, location, and projected future generation and demand for the biomethane, biofertilizer and carbon dioxide. The resulting digestate can be applied as a biofertilizer in agriculture, while the carbon dioxide can be captured and used in industrial applications such as for carbonating beverage. Several stakeholders, e.g., municipal authorities have significant influence on the development of biogas production through regulatory and permitting processes. There are also contractual agreements between different actors related to material, energy and technology transactions occurring on markets with different logics.

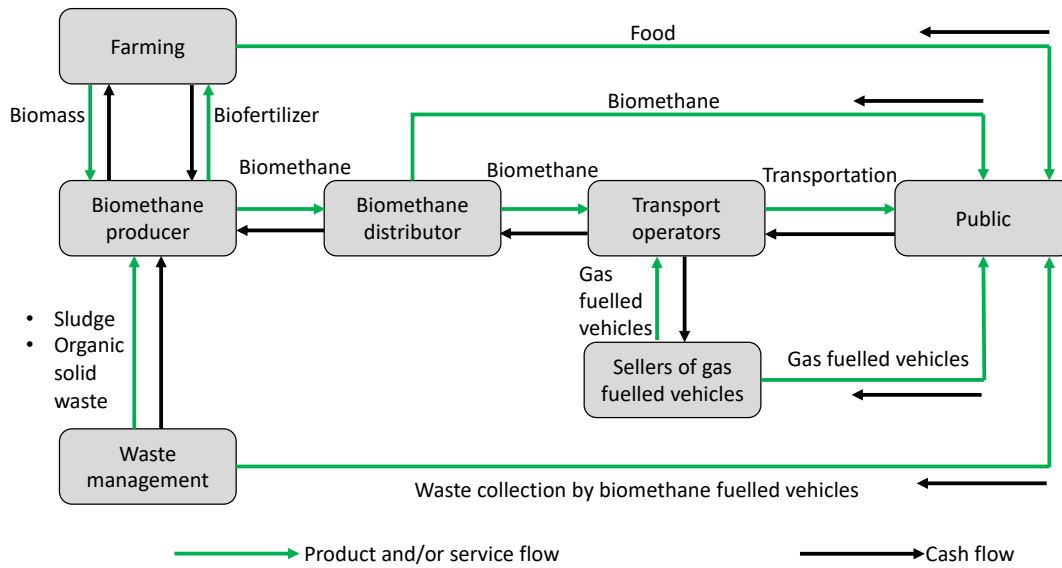


Figure 1. Biomethane for Transportation, Adapted From (Kanda et al., 2021; Tsvetkova & Gustafsson, 2012)

Table 2. Exemplary Application of the Concepts of Systems and Ecosystems to Biomethane for Transportation

Systems	Ecosystems
<p>Socio-technical systems</p> <ul style="list-style-type: none"> <p>Analytical focus: the interplay between the social (i.e., actors, networks, and institutions) and technological components for biomethane production, distribution, and use. Starting unit of analysis is socio-technical systems for providing a societal function i.e., biomethane for transport.</p> <p>Key concepts:</p> <ul style="list-style-type: none"> <p>(i) Co-evolutionary processes – the interdependencies and influence between actors and networks, for biomethane production, distribution and use for transportation and their related technologies, markets, user practices, cultural meanings, infrastructure, and institutions.</p> <p>(ii) Multi-actor processes – cooperation and competition between several stakeholders both new entrants and incumbent actors for biomethane production, distribution, and use for transportation.</p> <p>(iii) Long term processes – the emergence and diffusion of technologies for biomethane production, distribution and use and its alignment (or misalignment) with the adoption context takes time decades due to the need for both emergence and scale up of new technologies but also the destabilization of existing technologies.</p> 	<p>Innovation and business ecosystems</p> <ul style="list-style-type: none"> <p>Analytical focus: interactions between independent, yet interdependent set of actors who collectively deliver economic value based on the valorisation of waste. Starting unit of analysis is often a business e.g., biomethane producer.</p> <p>Key concepts:</p> <ul style="list-style-type: none"> <p>(i) A Focal firm (keystone actor, orchestrator) that together with a set of coordinated actors upstream and downstream actors seek to deliver economic value through waste valorisation.</p> <p>(ii) Dependence on specific actors for organic waste resource as raw materials for biomethane production distribution and use.</p> <p>(iii) Multi-stakeholder avenues for value proposition based on waste valorisation for biomethane for transport.</p> <p>Key actors: Focal firm, upstream and downstream actors</p> <p>Exemplary research field: Business strategy</p>

<ul style="list-style-type: none"> • Key actors: New entrants, incumbents, and governments • Exemplary research field: Science and Technology Studies 	
<p>Industrial and Urban Systems</p> <ul style="list-style-type: none"> • Analytical focus: using natural ecological systems as inspiration to develop the circular flow of material and energy resources in industrial processes and urban contexts (e.g., cities) for the production, distribution, and use of biomethane for transportation. Starting unit of analysis is often an industry and or city-level. • Key concepts: <ul style="list-style-type: none"> (i) <i>Organic waste from one production is a resource</i> which can be valorised in another industrial production system. (ii) <i>Biogas is a renewable energy carrier</i> which can be used for heat, electricity or upgraded into biomethane for transportation. (iii) <i>Biogas production is multi-functional</i>, cutting across several sectors, involving several actors, and institutions and thus has different configurations in different geographical contexts. • Key actors: Organic material producers, biomethane producers, biomethane distributors, biomethane users • Exemplary research field: Industrial ecology 	<p>Industrial and Urban ecosystems</p> <ul style="list-style-type: none"> • Analytical focus: using natural ecological systems as inspiration to develop the circular flow of material and energy resources in industrial processes and urban contexts (e.g., cities) for the production, distribution, and use of biomethane for transportation. Starting unit of analysis is often an industry and or city-level. • Key concepts: <ul style="list-style-type: none"> (i) <i>Organic waste from one production</i> is a resource which can be valorised into in another industrial production system. (ii) <i>Biogas is a renewable energy carrier</i> which can be used for heat, electricity or upgraded into biomethane for transportation. (iii) <i>Biogas production is a multi-functional</i>, cutting across several sectors, involving several actors, and institutions and thus has different configurations in different geographical contexts. • Key actors: Organic material producers, biomethane producers, biomethane distributors, biomethane users • Exemplary research field: Industrial ecology
<p>Product-Service Systems</p> <ul style="list-style-type: none"> • Analytical focus: technology provider developing a business model for biomethane production, distribution and use that meets the needs of different customers, from a lifecycle perspective with resource efficiency and cost effectiveness. Starting unit of analysis is often a product and or service core to the business model. • Key concepts: <ul style="list-style-type: none"> (i) <i>Life cycle thinking</i> encompassing appropriate business model and strategy throughout the lifecycle from design to provision, and end-of-life management e.g., remanufacturing of anaerobic digestion technology. (ii) <i>Integrated product and service offering</i> – products, services, supporting networks and infrastructure designed to satisfy different customer needs in this case for renewable energy, waste management, nutrient recycling. 	<p>Entrepreneurial ecosystems</p> <ul style="list-style-type: none"> • Analytical focus: on a set of interdependent actors and factors that are governed in such a way that they enable entrepreneurship within a particular territory. Starting unit of analysis is often the entrepreneur(s). • Key concepts: <ul style="list-style-type: none"> (i) <i>Co-evolutionary</i> rise and fall of diverse entrepreneurial organizations (new ventures and incumbents) and their related institutions in a territory e.g., in a region related to the biomethane industry. (ii) <i>Mutually interdependent</i> entrepreneurial organizations and their institutions that perform related but differentiated activities to enable emergence, growth, and survival of new ventures in the biomethane industry.

<ul style="list-style-type: none"> • Key actors: Technology and or service providers and their customers • Exemplary research field: Engineering design 	<p><i>(iii) Complex nested structure</i> of diverse organization and actors competing and collaborating while pursuing their own interests in the ecosystem.</p> <ul style="list-style-type: none"> • Key actors: Entrepreneurs, New ventures, Incubators, Science Parks, University, Funders, intermediaries • Exemplary research field: Entrepreneurship
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A systems perspective, rooted in systems theory, highlights the interconnectedness, hierarchies, and feedback loops within complex systems. It recognizes the need for deep and wide-reaching fundamental change in multiple socio-economic pillars of the linear economy to make progress towards a circular economy. On the other hand, ecosystems, rooted in ecology, emphasize the relationships, interdependencies, and co-evolutionary interactions among different entities and their external environment. Both concepts encompass the flows of economic value, energy and materials resources, or knowledge within a defined scope among a constellation of actors over time. However, they differ in their specific analytical focus, key concepts, and core research fields using them. The concept of systems seems to be dominantly used in technology and engineering related fields (with the exemption of socio-technical systems which are often used in science and technology studies), while ecosystems is commonly used in the business strategy, innovation, and management literature. Systems and ecosystems are not mutually exclusive; rather, they offer nuanced perspectives to describe, analyse, and facilitate complex interactions among entities and their external environment. The disparities between the concepts of systems and ecosystems can be attributed, in part, to their origins, evolution, and the specific research communities that use them. Indeed, ecosystems are a specific type of systems. Thus, researchers need to carefully clarify the distinctions between the concepts of systems and ecosystems when using them, and more importantly reflect on the potential benefits and drawback of using either of the concepts and its variants as analytical lenses (see Table 2). By doing so, we can enhance our understanding of how to facilitate a transition towards a circular economy and deploy the most effective intervention strategies. Future research should aim for a complementary approach that combines insights from systems and ecosystem perspectives including the agency and governance of actors in these different conceptualizations. This approach would involve developing analytical approaches that leverage the strengths of both viewpoints while mitigating their respective limitations. Researchers are encouraged to collaborate across disciplines to create a more robust understanding of the transition towards a circular economy.

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AUTHOR CONTRIBUTIONS

Wisdom Kanda: Sole author of this article. Responsible for the conceptualization, writing and review of this article.

DECLARATIONS

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