Perspective

The Circular Economy: The Butterfly Diagram, Systems Theory and the Economic Pluriverse

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Abstract

One of the most significant challenges facing policy makers and business alike is how to integrate sustainability policy and practice across economics, environment and society. The linkages between these arenas are fundamental to determining the direction of change required. The circular economy (CE) is seen as a part of the solution in terms of reducing natural and technological source-and-sink concerns, but significant issues arise concerning biological nutrients and with the concepts of resilience, regeneration and restoration, when viewed through the lens of systems theory. Supply chains represent essential elements in this process, having played active roles in shaping environmental and social history. The role of trade in cultural evolution is explored, highlighting socio-economic linkages. Challenges related to the classic butterfly diagram are identified and a further metamorphosis of this analogy is presented. The concept of an economic pluriverse, nested within a social and ecological pluriverse, is developed.

Keywords: Earth System, Non-linearity, Emergence, Regeneration, Resilience, Restoration, Supply Chain Network

Till Sundown crept, a steady Tide,

And Men that made the Hay,

And Afternoon, and Butterfly

Extinguished in the Sea.

—Emily Dickinson, *From Cocoon Forth a Butterfly*

1. INTRODUCTION

The consequences of our recent economic activity, centred around economic growth, consumerism, progress and development, have led to serious concerns in terms of environmental, social and economic sustainability. As Ashby (2021) pointed out, globally, humanity consumes approximately twenty billion tonnes of engineered materials annually, equivalent to 2.7 tonnes per capita per year. Additionally, it is noted that the usage of hydrocarbons for energy purposes amounts to around nine billion tonnes each year. These examples are the consequence of population growth, global development, economic expansion and evolving consumer habits.

Luxury consumption and waste throughout the production line, particularly in agriculture, contribute significantly, while luxury goods and pressures from advertising, peers and rapidly changing technological innovations result in accelerating product turnover and shortened product lifetimes (Gifford, 1990). Extractive industries are responsible for fifty percent of global carbon emissions and for ninety percent of loss of biodiversity, negatively impacting the environment, human rights and economic and social stability

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(IPCC, 2023; Safi et al., 2023). The trend of intensifying resource exploitation and waste generation is projected to persist and increase (UN, 2018).

2. ROADMAP AND TARGET AUDIENCE

One of the most significant challenges facing the academy, policy makers and businesses alike is how to integrate sustainability policy and practice across economics, environment and society in order to ensure that we, and future generations, can continue to achieve our full potential without diminishing the potential of others. This paper sets out to examine how we can properly address the manifold challenges across these three arenas for a sustainable future. At the outset we contend that these three arenas are tightly interconnected, representing a system of systems, each impacting on the other.

The paper begins by asking if the CE is fit for purpose in terms of meeting these challenges (Section 3). We then suggest changes to the concept, as represented by the butterfly diagram and its underlying thinking, to address previously identified issues (Section 4). At this point we explore local and global aspects related to practical implementation across all three arenas, a foundation for the economic pluriverse concept to be introduced later.

We then explore supply chain networks, building on previous work based on systems thinking (Section 5). A case study from the Bronze Age highlights not only the historic importance of supply chains but the integrated way in which the three arenas have always operated. The importance of this in terms of the dynamic relationship that exists, particularly in the current age of anthropogenic perturbation, is emphasised.

We address Dasgupta's (2021) concerns relating to the silence of the Earth system, before asking how the Earth system actually works (Section 6). This, we suggest, must be a starting point for any consideration of sustainability, given that economies and societies are sub-systems within the Earth system. Systems theory is briefly explored in order to pave the way for the concept of the pluriverse as a framework for integrated sustainability thinking (Section 7). A brief review of the historical context of the pluriverse is set out, critiquing issues relating to its applicability to sustainability thinking and economics. We ask if there is any evidence that a pluriverse could exist or work.

We suggest that the answer is found in the Earth system, a fully functioning pluriverse. Given that the Earth system represents the functional context for a sustainable future, running through supply chains, society and ecology, then the pluriverse concept is presented as a blueprint for economic, social and environmental sustainability. We finish with a consideration on connectivity across the three arenas (Section 8), bringing together the CE, circular supply chain management, social well-being, and the importance of inclusive wealth, concluding with suggestions for further work (Section 9).

The target audience covers civil society, policy makers, business leaders, students of sustainability (both undergraduate and postgraduate) and the academic community. Policy makers and businesses will hopefully gain a new perspective in terms of how sustainability can operate across economics, society and environment, empowering them to imagine and develop a better world within their own contexts, participating in the pluriverse themselves.

3. THE CIRCULAR ECONOMY

The CE is an umbrella term encapsulating many ideas that has become a key governance framework with the goal of restructuring how value is extracted from resources (Hobson, 2020). The concept aims to encourage and normalise a range of mechanisms directing resource flows into continuous loops, such as repair, re-use and recycling, with the intended goal of minimising waste and pollution from existing systems (EMF, 2017).

The CE is a dynamic and, indeed, plastic (sensu Pörksen, 2010) term, and while its potential role in sustainable development through the circularity of resources holds value, the concept shapeshifts at regional, theoretical and practical levels. Kirchherr et al. (2023) examined over two hundred different definitions of the circular economy, warning that "a concept with multiple fragmented and often contested understandings may experience conceptual deadlock and eventual collapse".

While Blomsma and Brennan (2017) refer to the CE as an umbrella concept, attempting to cover a broad set of phenomena, Valencia et al. (2023) warn that this flexibility "may account for its popularity in academia, management, and governments but it questions the effectiveness of its adoption and societal impact. Therefore, situating a CE initiative by rethinking the discourse around it is crucial for setting adequate expectations in different contexts."

Among its limitations, CE encounters numerous biophysical challenges such as high energy demands for resource recovery (particularly in product lifetime extension), losses in resource quality, ongoing demand for virgin resource extraction and the inherent mix of organic and inorganic elements in resources (Skene, 2018; Velenturf et al., 2019a,b; de Oliviera et al., 2021; Bianchi and Cordela, 2023).

In addition, difficulties exist relating to gathering quantifiable evidence of its benefits in the economic, environmental, and social domains (Mies and Gold, 2021; Corvellec et al., 2022). Furthermore, it has become the home of a number of often misconceived metaphors (Fromberg et al., 2023).

Cooper (1999, p.10), one of the earliest protagonists of the circular economy, contrasted it with a linear economy, writing: "The model of a linear economy, in which it is assumed that there is an unlimited supply of natural resources and that the environment has an unlimited capacity to absorb waste and pollution, is dismissed. Instead, a circular economy is proposed, in which the throughput of energy and raw materials is reduced".

Noteworthy here is the recognition that the environment cannot absorb waste and pollution without limit. However, more recent definitions of the CE suggest that it has an unlimited capacity to absorb recycled biological materials without perturbation. The Ellen MacArthur Foundation (EMF, 2017) claimed that: "Compared to technical materials and products, biological materials have the ability to become nutrients in the soil and other ecosystems in the biosphere, creating natural capital for reuse".

This expectation of the Earth system acting as a sink for recycled biological materials without any impact is problematic. Releasing nutrients into the lithosphere, hydrosphere and atmosphere can have catastrophic effects, as these spheres are finely balanced, generally with low levels of available nutrients (Smil, 2000; Smith, 2003). Perturbation can lead to non-linear responses (tipping points) (O'Keeffe and Wieczorek, 2020) and the impact is very much biome-related (Carrier-Belleau et al., 2023).

Nutrients are the gatekeepers of energy flow and an inappropriate nutrient flux from biological recycling must be avoided at all costs. This is not bucket chemistry, but a finely tuned system. Indeed, biological nutrients can be extremely toxic, as red tides and fertiliser-linked fish deaths testify (Renaud et al., 2013). Another point is that the location of extraction of biological nutrients for manufacturing may be geographically far removed from the location of the return of these nutrients to the biosphere, leading to displacement and dislocation of materials. These examples point to an important point: unless the CE is contextualized within the Earth system in terms of its definition and policies, it will fail to contribute meaningfully to a sustainable future.

Balanay and Halog (2021) note that "at the outset CE is already pronounced as systemic in nature."

The CE has been promoted by the EMF (2015) as an industrial system that is restorative and regenerative by design. Yet any concept of designing change in a complex system such as the Earth system is likely to fail, as discussed below, due to the emergent nature of its self-organisation.

Increasingly, it has been recognized that if the CE is to deliver a sustainable future, it must, fundamentally, contribute positively to social sustainability and environmental stability. Murray et al. (2017, p. 377) defined the ideal sustainable economic approach as being "an economic model wherein planning, resourcing, procurement, production and reprocessing are designed and managed, as both process and output, to maximise ecosystem functioning and human well-being."

Farooque et al. (2019, p. 884) write that: "Circular supply chain management is the integration of circular thinking into the management of the supply chain and its surrounding industrial and natural ecosystems. It systematically restores technical materials and regenerates biological materials". Yet exactly how this applies to social and environmental sustainability is less clear.

Morseletto (2020) defined restoration as the return to a previous or original state. A similar approach has been taken in conservation biology in terms of active rewilding, re-introducing species that were locally extinct for centuries, such as the beaver. However, Earth system restoration is much more complicated. Complex system properties emerge from the system. Systems are dynamic and unlikely to be completely reversible (O'Keeffe and Wieczorek, 2020). Also, to what point do we restore something to?

Morseletto (2020, p. 769) defined regeneration as “the promotion of self-renewal capacity of natural systems with the aim of reactivating ecological processes damaged or over-exploited by human action.” This definition, connotating a rebirth, is important in that it reflects systems theory, wherein the best we can do is to release the system to pursue its own self-reorganisation. Again, this is unlikely to return to some Garden-of-Eden state and the question arises as to when this garden existed in time, and what it looked like in spatial terms. This Miltonian ‘paradise lost’ is unlikely to be regenerated.

Since the act of resource exploitation can only lead to perturbation and destabilisation of the Earth system, then reducing exploitation, rather than finding ‘greener’ ways to exploit, is likely to be the most sensible option. As noted earlier, much of the technology targeting carbon reduction has significant repercussions for the Earth system in other ways.

This brings us to resilience, another term often encountered in the CE, and defined, by Walker et al. (2004), as “the capacity of a system to absorb disturbance and reorganise while undergoing change so as to still retain essentially the same function, structure, identity, and feedback”. However, while functionality is maintained in the Earth system, structures are often very different over time.

The planet is not a museum which preserves a given set of structures over time. Following a mass extinction, a completely different suite of morphotypes (species) arrives. These new species carry out similar functions in terms of trophodynamics. New carnivores, herbivores, primary producers and detritivores appear. The actors in the new play are quite different, but the script remains the same, governed by the properties of complex systems and thermodynamics (Skene, 2023). Thus, our expectations of a resilient Earth system should be such as to expect radical environmental change married to conservative function, which will potentially demand quite radical changes in society and in economics.

The CE is often seen as delivering change across the three arenas of economics, society and the environment. Yet at its essence, it operates at the level of the material world, in terms of the sources, journey and fate of resources. While this is, of course, vitally important, there are many more aspects to a sustainable future, and many players within the game. The design of products, consumer behaviour, transparency, accountability, human rights, systems theory, politics, de-materialism, energy, flux, flow, business ethics, the measurement of economic growth, cultural differences and biogeography all form part of the challenge in achieving a better future for all. Together they form a complex, dynamic and wicked problem, and a much greater breadth of approaches, encompassing all of these important elements, from a systems perspective, must surely be adopted. We will explore this, in terms of an economic pluriverse, later.

We suggest that the CE should not be expected to cover everything, or it will become unworkable. Rather, we need parallel schools of thought to cover social and environmental issues, and the many other economic issues, working alongside the CE, and actively operating in a cohesive, interconnected and enhancing way. One suggestion in terms of addressing social issues is to promote a ‘circular society’ (Jaeger-Erben et al., 2021). Leipold et al. (2021) comment that: “Narratives calling for a ‘circular society’ instead of a ‘circular economy’ could help to place social problems center stage and acknowledge the significant social changes required for CE transformations.”

Furthermore, the CE alone is not sufficient to deliver economic sustainability in the whole sense of the term (i.e. an economy that contributes to the sustainability of the Earth system and society).

4. THE BUTTERFLY DIAGRAM

In recent years, the principles of the CE have been influenced by the EMF’s butterfly diagram, which has become a primary and totemic catalyst in numerous recent discussions in business, policy and academia. The diagram, based on cradle-to-cradle thinking (Braungart and McDonough, 2009), is a visualisation tool that depicts the division between biological (open-loop) and technical (closed-loop) material flows, in a scheme with a particular shape, that of a butterfly. In recent years, closed-loop strategies have become prominent in the literature (Bocken et al., 2016).

The technical cycle of the diagram is a closed-loop system, run through sharing, maintenance, reuse, remanufacturing, and recycling. On the other side is the biological cycle of materials that are renewable and operate in an open-loop system, cascading through extraction, bio-based material production, energy recovery and nutrient return to the biosphere for the next cycle of primary production. As influential as it became, there are a number of concerns with the diagram that need to be mentioned. A summary of selected challenges is presented in Table 1. Given these problems with the butterfly diagram, we advocate for an enhancement to broaden the scope of the CE paradigm (Figure 1). Rather than delineating the biological and technological cycles separately, we suggest an integrated approach that prioritises the environmental aspects, and further consists of a conceptual framework, socio-economic changes and implementation processes.

Table 1. Overview of the Challenges Identified Within the Butterfly Diagram

Limitations	Summary	Reference
Environmental aspects	Does not fully embrace ecosystem stewardship, as it depicts an ideal natural environment without acknowledging people as integral parts. Oversimplifies the relationships between people and nature.	Velenturf and Purnell, 2017 Velenturf et al., 2019a van Bueren et al., 2022
Biophysical constraints	Does not acknowledge the limitations of a fully closed-loop economy, lack of recycling routes, energy intensity of recycling and recirculation, thermodynamic constraints, difficulties in reusing and remanufacturing, and the potential for a rebound effect.	Velenturf et al., 2019a Lambert, 2020 Haas et al., 2020 Kara et al., 2022
Resource flow representation	The separation of "biological" and "technical" cycles does not accurately represent the combination of organic and inorganic materials in resource flows.	Velenturf et al., 2019a Schoenmakere et al., 2018
Extractive sectors	Excludes extractive sectors and initial processing, which are significant waste producers and energy consumers, and could benefit from CE thinking.	Velenturf et al., 2019a Velenturf et al., 2019b Gedam et al., 2021
Heterogeneous nature of materials and products	Oversimplifies the complexity of resource flows by not considering that they are usually made of more than one type of resource.	Velenturf et al., 2019a Navare et al., 2021

Consumer focus and roles	Primarily focuses on products, materials, markets and value extraction but neglects the pivotal role of consumers and their culture, inadequately addressing the framing and implementation of consumer roles crucial for CE intervention success.	Hobson, 2022 Savini, 2023 Mangers et al., 2021 Morais, 2020
Simplification, specificity and implementation within the supply-chains	Oversimplifies real-world supply chain complexities and their dynamic nature, overlooking industry or regional nuances, lacking explicit incorporation of stakeholder perspectives. Lacking the view on the potential social impact of transitioning to a CE within supply chains.	Mangers et al., 2021 Kara et al., 2022
Operational tools	No indication of tools available to explore the potential, likelihood and desired futures in the built environment in a systematic manner.	Vanhuyse et al., 2021; Gasparri et al., 2023
Foresight capacity	Limited in foreseeing future uncertainties within the CE discipline, a mistake made by the linear economic model.	Calisto Friant et al., 2023
Unrealistic assumptions	Optimistic assumptions about innovation pace and welfare outcomes may need more empirical evidence and realistic assessment for CE model transition challenges.	Dufva et al., 2016; Calisto Friant et al., 2023

In light of our deep connection with the Earth system and our dependence upon natural resources, we suggest that it is crucial to re-evaluate environmental considerations and amplify their importance within the CE framework. Prioritising environmental sustainability entails revisiting concepts such as natural resource conservation and ecosystem well-being. Moving forward, efforts should focus on enhancing communication and collaboration across supply chain phases to minimise environmental impact and optimise resource recovery. Within the conceptual framework, the scope of the CE concept is redefined to include extractive industries and the appropriate restoration of materials to natural reserves. The conceptual space is restructured to facilitate comprehensive resource management and the effective consideration of environmental interconnections. Given the criticisms detailed in Table 1, a new visual representation of the butterfly diagram is presented (Figure 1), incorporating the changes suggested in this section, highlighting and prioritising the fluid, appropriate flow of materials across the biophysical environment and the production-consumption continuum.

For practical implementation, strategies must be customised to suit local contexts while upholding a comprehensive systems perspective. Recognizing that strong social interactions with the environment lead to sustainable economic practices, environmental, social, economic and technical considerations should be harmoniously woven into supply chains to guide the development of circular business models and policies. Advocacy for enhanced coordination and policy coherence among governmental entities is emphasised to expedite the shift towards increasing resource circularity. Inter-sectoral strategies should be employed to interconnect various industries and propel the transition to a CE, while fostering improved communication and collaboration between the end-of-life and beginning-of-life stages within supply chains, facilitating a consistent transition.

Guidelines for circular product design are formulated to align with collection, sorting and reprocessing infrastructure, thereby supporting the efficient flow of resources within circular systems. Additionally, the alignment of design principles and infrastructure enhancements with sustainable production practices is crucial for implementing systemic change without compromising environmental sustainability. Integrating environmental criteria into circular product design guidelines is essential to promote sustainable material usage, energy efficiency, and waste reduction. Furthermore, infrastructure upgrades must be aligned with environmentally sound practices to ensure that sustainable principles are applied in practice.

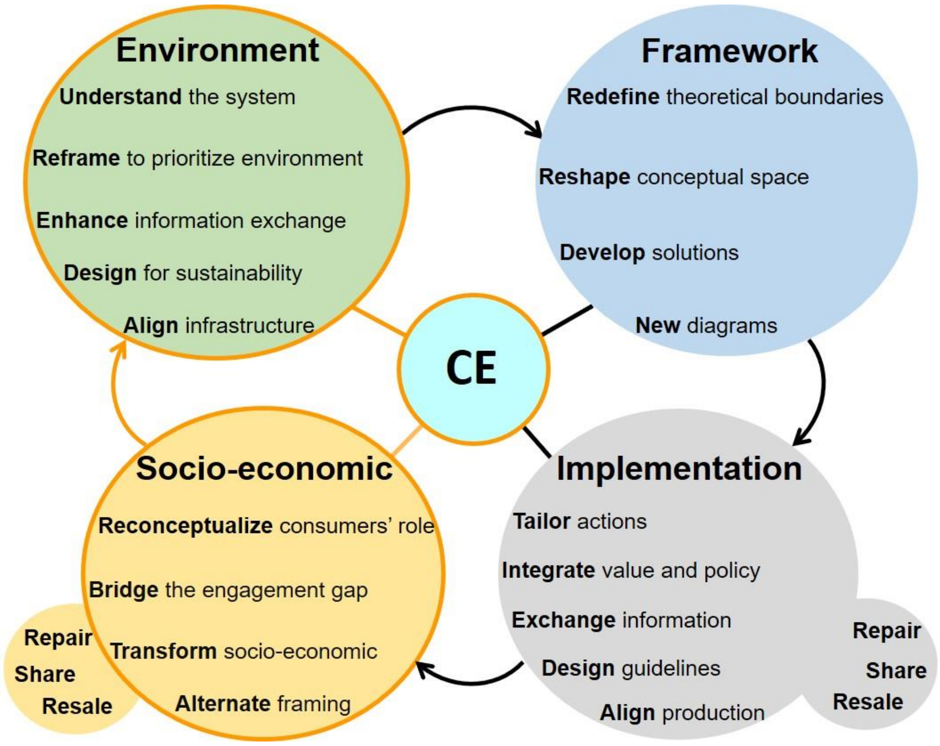

Figure 1. Integrated Approach to Circular Economy Paradigm. Orange Lines Illustrate Positive Social Interactions With the Environment, Fostering Sustainable Economic Practices

A final point to note is that none of this thinking can be framed as a one-size-fits-all (OSFA) approach. We are dealing with a system of systems in terms of the emergent properties from the interactions between the three arenas, with feedback leading to dynamic outcomes across space and time.

A core issue in terms of the impact of our activities upon the Earth system are supply chains and networks. We now consider the significance of these across the three arenas.

5. CIRCULAR SUPPLY CHAINS AND NETWORKS

In this section, it is proposed that supply chains represent a readily relatable concept that has the potential to act as a focal point around which broader sustainability thinking can be communicated. The interconnectivity of supply networks with culture and environment, stretching back over millennia, is explored, with the role of systems theory highlighted.

Handfield and Nichols (1999, p.2) define the supply chain in terms of all parties involved in "activities associated with the flow and transformation of goods from raw materials stage (extraction) through to the end user, as well as the associated information flows". Here, all parties can be seen to refer to the three arenas (economy, society and the environment). The term supply chain network is commonly encountered in the literature (Lambert et al., 1998). The supply chain network concept differs from the supply chain concept in a number of ways. It takes a more systems-based approach including real time feedback such as two-way exchanges, reverse loops and lateral links, while covering transformation, management and development, in addition to resource flow.

Consumer awareness of supply chain networks has increased, often driven by the consumer, as people endeavour to understand the implications of their choices. Lang et al. (2023) identify five roles that consumers can play: (i) influence upon circular business models with their purchase decisions; (ii) actions as influencers and lobbyists (iii) incentivization of organizations to adapt their business models to their needs; (iv) becoming key partners in defining the normative orientation of the innovation paradigm for a circular bioeconomy; (v) co-creating value through co-ownership.

Knowledge requires transparency, and we can see that accountability as well as materials can flow through such chains (see, for example, Phillips and Caldwell, 2005; Hofmann et al., 2018; Gualandris et al., 2021). We suggest that transparent supply chains and networks can be utilized in the fight for a sustainable future by communicating good practice and empowering the consumer, drawing them closer to the landscapes and people linked with production.

Carter and Rogers (2008, p. 368) define sustainable supply chain management as “the strategic, transparent integration and achievement of an organisation’s social, environmental, and economic goals in the systemic coordination of key interorganizational business processes for improving the long-term economic performance of the individual company and its supply chains.”

Currently, supply chains and networks often focus on source-to-sink relationships, ending with the consumer. We would argue that supply chains and networks need to be extended beyond the end-point consumer, in order to cover the afterlife in terms of the re-use, recycling and repair stages: the ghost of Christmas future. In Ghana, where some forty percent of waste clothing is exported, sent in good faith by Western recyclers, this accumulation has led to significant pollution issues (Priya, 2022). Large amounts of plastic wastes are exported to Southeast Asia (Ng et al., 2023), again with damaging consequences. A fully accountable supply chain network should not only enlighten the consumer in terms of origins but also destinations, thus informing local councils and ratepayers, who currently fund recycling.

Schultz et al. (2021) identify two approaches to sustainable supply chain management: vertical and horizontal. While vertical management tends to lead to optimization of the individual, linear supply chains, horizontal management involves broader collaboration with competitors and other actors. Certainly, this represents an important first step towards a system-based approach. They call for a ‘radical shift’ re-designing the supply chain structures to produce a functional CE. The next steps will include open and transparent feedback across social, economic and environmental subsystems, in order to track emergent outcomes within the Earth system as a whole.

Supply chain networks now stretch around the world, reaching across cultures and ecologies, as design processes incorporate an increasingly diverse range of materials. Each new technology leads to a new part of the planet becoming the focus of intense resource extraction. The ‘green’ revolution has massively increased the use of lithium, cobalt, copper and rare earth metals, each delivering significant damage to environments and societies (ILO, 2017; Narins, 2017; Sun et al., 2017; Liu et al., 2019). There should be accountability in terms of understanding the full ecological and social footprint of new sustainable technologies and increased focus upon reducing their supply chain impacts (Skene, 2021b).

Early in the history of humanity, a limitation of resource availability led to a waste-is-food approach, wherein upcycling, reuse and reduction of use were essential components (Desrochers, 2002; 2008). Supply chains were extensions of the natural world, and of the Earth system, locally based, short, immediate, and with tight cycling. There was little trade and accountability was high, given that consumer behaviour immediately impacted on resource base viability, rapidly impacting upon the same consumers. Circular supply chains were essential for survival.

Trade routes began to emerge, wherein transhumance facilitated movement of unavailable resources between early settlements, beginning the expansion of supply chain networks from the local to the global (Evans, 1940; Metzner-Nebelsick et al., 2017; Srichandan et al., 2021). Supply chain networks are not passive, nor are they limited to the material world. They have had significant ramifications, both for social and environmental history, over millennia. This is important to recognize, in terms of their significance in the path moving forward, as a clear example of linkage between the three arenas.

From the onset of the Bronze Age some three thousand years ago, and even earlier, complex trade routes evolved to bring together materials that were found in different regions. Bronze itself is an alloy of tin and copper, with tin being particularly scarce. Kristiansen (2018, p. 108) notes that: “The international dependency on bronze during the period 3000 BC to 1000 BC of the Bronze Age would thus have its closest parallel in the present world system’s dependence on oil.”

For example, Cornwall, in southwest Britain, became an important centre for tin, and was a target for Roman invaders for this reason. The area had traded tin for millennia. Pollution records here stretch back some four thousand five hundred years (West et al., 1998; Martin, 2017; Asare and Afriyie, 2021), indicating peaks of pollution during major export periods.

As long as three thousand years ago, there is evidence of supply networks becoming destabilised due to overexploitation, natural disasters and war, with dramatic changes in trade routes. Tin from Cornwall and copper from the Copper Coast of Ireland became more important following the collapse of trade routes in the East, due to the volcanic eruption of Thera (Santorini) in the Aegean Sea (impacting the Minoan trade empire) and unrest from the expansion of the Hittite empire (Kristiansen, 2018).

Supply chain networks do not merely have an impact upon society in terms of employment and pollution. They can also have fundamental and profound impacts on cultural evolution (Swadling 2010; Kristiansen et al., 2018). It has been argued (Ratnagar, 2001; Sherratt, 2016; Vandkilde, 2016) that supply chains formed the means and motivation for connections across Europe and the Far East, in terms of creating an early form of globalisation, replete with wealth and cultural exchange. Giddens’ (1990, p. 64) defined globalisation as “the intensification of worldwide social relations which link distant localities in such a way that local happenings are shaped by events occurring many miles away and vice versa”. Warburton (2023) describes how trade underpinned the earliest example of globalisation centred around Ancient Egypt and impacting everything from cosmology to technology.

Overexploitation was also an issue, with tin shortages impacting greatly on bronze production, leading to cultural collapse (Svizzero and Tisdell, 2018). Cultural transmission and linguistic evolution in the early Celtic nations is thought to be linked to trade routes (Cunliffe, 2009; Donnelly, 2015), with some form of the Celtic language likely becoming the *lingua franca* (shared trading language) (Mostert, 2020) accompanying the flow of goods and technological information (Mikhailova, 2016).

Thus, we see supply chain networks as playing significant roles in cultural evolution, going back millennia. This is important as it highlights the essential relationship between economy and society on so many different levels. We also see this relationship being impacted and transformed by environmental changes, such as volcanic eruptions, in addition to wars. Hence, the three arenas have never been isolated, and their connectivity represents a significant, shape-shifting and dynamic power, often centred around supply chain networks.

Given the potentially existential threat of current environmental disruption, responsive supply chain management may well become, once again, an essential component for survival and lead to geopolitical power shifts. Increasing resource vulnerability due to non-linear environmental impacts are likely, much as they were over the past millennia.

Each arena (economics, environment and society) impacts upon the others in a dynamic way, with information, language, culture, cosmology and technology all diffusing across the supply networks, helping to write the history of humanity. Now the challenge is to respond to the current sustainability crisis. Our history clearly demonstrates that there is an important connection between economy, environment and society, and so there is no doubt, surely, that the journey to sustainability across the three arenas will involve interactions and feedback across them.

Elkington (1997) discussed the paradox that given the political and social complexities, and that environmental problems stretch far beyond the borders of any particular nation, although corporations are best placed to achieve sustainability, in terms of resources, technology and global reach, the corporate structure and market competition, in addition to the complexity and interconnectivity of the problems, mean they lack the mandate and capabilities to do so.

In order to begin to address this paradox, we must understand the relationships between the Earth system, the economic system and the human system. This, in turn, requires an understanding of natural, human and social capital.

These relationships can take many forms, ranging from supply chains through to feedback loops and emergent behaviour. Dasgupta (2021, p.498) claims that: “The three pervasive features of Nature – mobility, silence, and invisibility – mean that the consequences of actions which desecrate Nature are often untraceable to those who are responsible”. However, the technology exists, ranging across billions of smart devices, remote sensing and the internet of things, to visualise and monitor what impacts our actions have upon our planet, measuring the pulse of the Earth system’s physiology (Skene, 2020).

6. THE EARTH SYSTEM

As we have noted, systems theory must surely play a central role in any conception of a transition to a sustainable future. At the heart of all of this lies the Earth system, within which all of life exists, has evolved from and relies upon. Our economic activities and our social interactions are sub-systems within this overarching reality. Unless we understand how it works, then any effort to deliver a path towards recovery, regeneration, resilience and restitution will be without foundation.

So, what is a system? A system is a network of interconnected and interdependent components comprising a unified whole (Trewavas, 2006), whose properties belong to the system, not its components (Bedau and Humphreys, 2008). The properties of systems result from two key elements: their structure is held together by numerous linkages, producing very complex networks (von Bertallanfy, 1950; 1972) and systems have a hierarchical structure (Woodger, 1929).

Much has been written on systems theory in terms of economics (Skene, 2022; Kanda, 2023), society (Jackson, 1985) and the environment (Jørgensen et al., 2011), but to summarise, five particular properties of any complex system are important.

Firstly, complex systems self-assemble, self-organise and self-reorganise. Thus, the outcome of perturbation, for example from anthropogenic disruption, will have reverberations throughout a given system. The second characteristic is emergence, which means that the properties of a system belong to the system and not to any given component of the system, such as humans or their economic activities. Thus, the solution space, in terms of the current crisis, is essentially the property of the Earth system. The third characteristic, feedback, works across many temporal scales, from seconds to millennia, and so the average grant-funded academic research project or government study, lasting between three and five years without guaranteed continuity, is unlikely to record the full implications. There is temporal variability due to the multitude of timescales involved.

Non-linearity, the fourth characteristic of complex systems, means that there can be tipping points, where a small level of change can lead to drastic alterations, and where the system can completely re-organize, undergoing a regime shift (Cooper et al., 2020). Non-linear regime shifts can also occur in economic and social systems (Scheffer, 2009). There is no certainty in reversing such shifts, due to their emergent nature, and the results can be catastrophic for many components, representing an existential threat (Hastings and Wysham, 2010).

The fifth characteristic, sub-optimality, is an outcome of trade-offs that are necessitated by the multiple challenges requiring resolution at any given time. Thus, a silo approach, with specialists working on a particular issue in isolation (a common practice in business, government and academia), will be unlikely to provide solutions that will work across the system. There is a need to embrace trade-offs as key characteristics, not inconveniences that should be designed out of a given system (Valentinov, 2014; Lu et al., 2021; Skene, 2021a).

Given that all complex systems are emergent, self-organising and non-linear, outcomes rest within the system, and not with any component of that system. The Earth system cannot be repaired by building blocks, assembled to replace that which is damaged. This paper will argue that any conceptualizations of regeneration and of restoration lie within the realm of the Earth system as a whole, rather than within the auspices of humanity alone. This has significant implications for sustainability thinking and for the circular economy. De Angelis and Ianulardo (2024, p.1) suggest that “the potential for the circular economy to provide a sounder basis to sustainable management theory rests on its capacity to propose a socio-eco-systemic framework”.

This brings us to the concept of the pluriverse.

7. THE PLURIVERSE

The concept of a pluriverse was first conceived by James (1909, p. 125), who wrote that: “Things are with one another in many ways, but nothing includes everything or dominates over everything”. Fundamentally, this quote encapsulates both the opportunities and challenges of sustainability. This idea has been developed more recently, within post-development, post-colonialism and post-globalization literature, as a world where many worlds fit, arguing that there are more ways of approaching societal and economic theory than that of Western enlightenment thinking alone, while asserting that different approaches can exist concurrently (see, for example, Escobar, 2011; Savransky, 2021). Different ontologies produce different realities, materialities, natures and worlds. Hence, our world is composed of a ‘pluriverse’ of many different overlapping worlds with no clear boundaries or overarching principles that would turn this multiplicity into a singular world (Blaser, 2013; Escobar, 2020).

In many ways, the pluriverse can come across as a ‘biverse’, wherein there appear to be two cosmovisions: a globalised one-world world (OWW) economy and a set of alternative economies, rooted in localism, ecology and indigenous thinking, where the natural, religious-spiritual, political and social are not separated (Law, 2015; Querejazu, 2016; Hutchings, 2019). Furthermore, since modernity eschews Nature as one with humanity and focuses upon individualism rather than a more-than-human conceptualization, there would appear to be little consensus between these two schools of thought (Bastian, 2009; Nieto-Romero et al., 2019).

Thus, the concept of the pluriverse risks becoming a socio-political divide, and there are many questions surrounding how such differing worldviews can fit into a single world, given the philosophical differences underpinning them (Querejazu, 2016). The local is not immune to the global. Connections exist that cannot be easily separated in terms of many worlds within one world.

At the economic level, it can be difficult to imagine a global and local economy functioning simultaneously. Stark differences in ethical philosophies in terms of local legislation and culture could be even more diverse than currently, impacting supply chain accountability, and governance of the infosphere and sustainability (Prabhu, 2015; Skene, 2020). This can also be seen in attempts to implement policies globally, such as the Sustainable Development Goals (Skene, 2021a). Many necessary responses to the multitude of current human crises require global consensus. What does this ‘world within which many worlds fit’ actually look like? Is it possible or even desirable? Is there any evidence that a pluriverse could work?

We do have a fully functioning pluriverse on our planet: the Earth system. We have a series of biomes, determined by differences in the density of incident solar radiation (due to the curvature of the surface), each with its own set of ecosystems. These vary from Arctic habitats to tropical rainforests. Within each of these energetic landscapes, indigenous humans and all of life have developed ways of being, tuned to the patterns and boundaries of the available ecological space. This array of worlds within one world celebrates both the global and the local (Figure 2). From within the intimate relationship between humans and environment emerges an economy that is both appropriate and sustainable. Within the Earth system, the pluriverse does work. These biomes and ecosystems operate within a global whole.

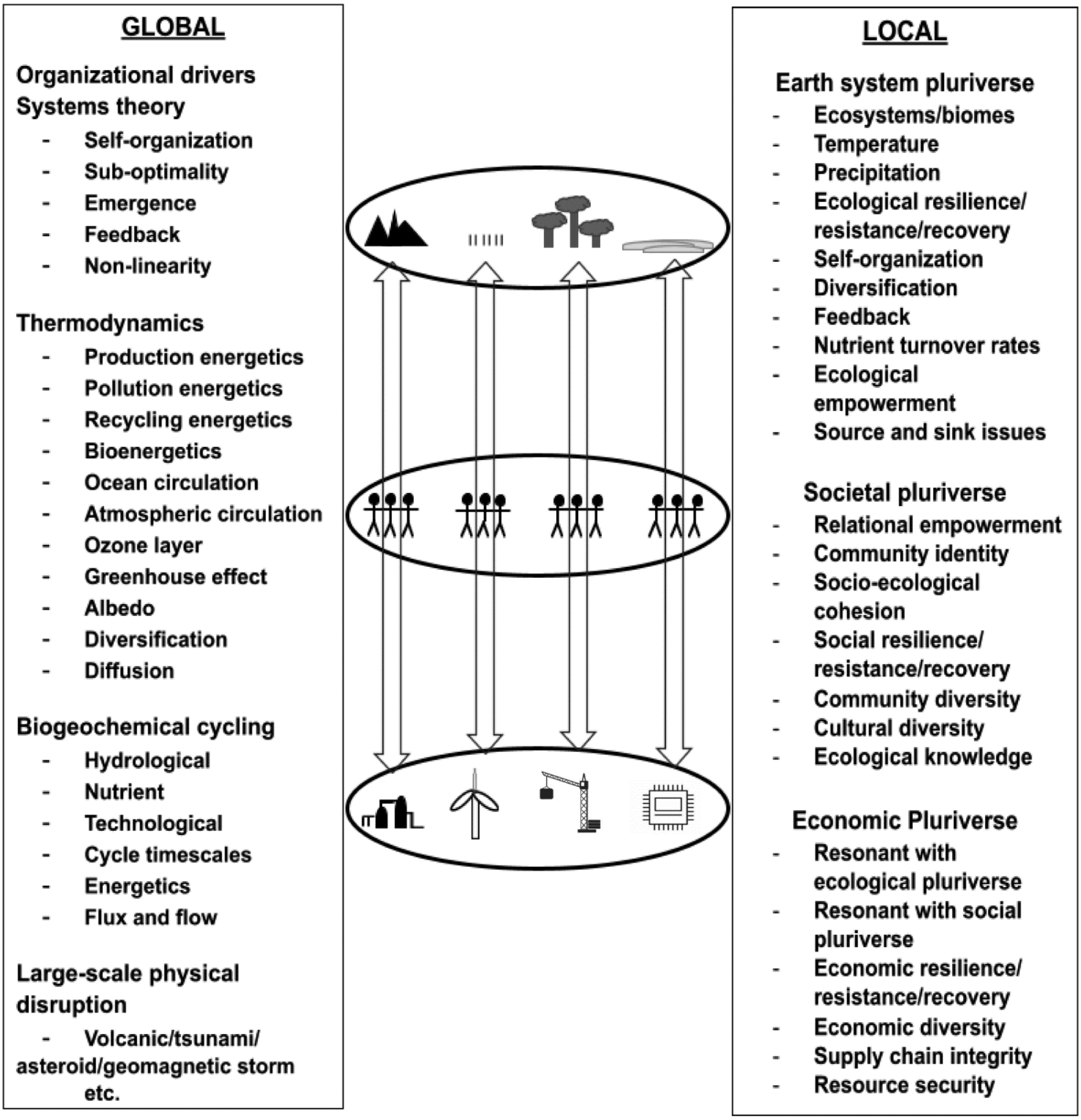

Figure 2. The Interactions Between the Earth System, Societal and Economic Pluriverse, Highlighting Global and Local Characteristics

Each world has its own economy, tailor-made for the environmental challenges posed. Yet there are universal global aspects at work, namely thermodynamics and the properties of complex systems (Skene, 2022), both of which shape each ecosystem. Indeed, this pluriverse is an emergent reality, the consequence of self-organisation within the greater whole. Thus, we suggest, it provides the functional context within which sustainability rests. Therefore, as a starting point, it would surely make sense to explore mapping an economic pluriverse upon the ecological and cultural pluriverse (Figure 2).

The pluriverse can be seen in socio-ecology as representing a reflection of cultural emergence from an ecological basis. Cultural identity across history, in terms of practice, beliefs and community, can be seen to reflect interactions with the biogeographical context within which the particular culture exists (Atkins et al., 1998; Wu, 2010; Nassauer, 2013; Ní Mhathúna, 2021; Beamer et al., 2023).

Thus, by exploring how the natural economy in each of these biomes and ecosystems operates, and relating this to the human economies that would be appropriate, we can gain an insight into what an economic pluriverse could look like, based on the ecological pluriverse that exists, and what this means for sustainable economics, embedded within the Earth system.

Importantly, this is not a form of biomimicry, where, for example, in the Arctic, we learn lessons from how the Arctic fox goes about its life, transferring these lessons into our economic thinking. Rather this is a process of bio-integration, where economic activity is in resonance with the ecological processes actually operating in that given habitat.

There is a global unity and a local plurality within the Earth system: unity in terms of thermodynamics and systems theory, and plurality in terms of the importance of spatial and temporal conditions (Figure 2). This is a form of glocalism, combining the global and the local (Cecilia de Burgh-Woodman, 2014; Roudometof, 2015; Goffman, 2020).

We suggest that an economic pluriverse, related to localised supply chains informed by the particular recovery, regeneration, resilience and adaptability properties of the particular ecosystems within which the economic activities occur, would lead to a much more compatible and resonant economy. Of course, trade-offs will be a core component, as in any system. But an economic pluriverse is a directional pointer, as is thermodynamics in the Earth system, rather than a detailed structural road map. Within an emergent Earth system, direction is what matters, as any detailed road map is most probably unachievable, given the dynamic and emergent nature of the whole.

It was Humboldt who developed the concept of *Zusammenhang* (‘hanging together’). He wrote: “In considering the study of physical phenomena, not merely in its bearings on the material wants of life, but in its general influence on the intellectual advancement of mankind; we find its noblest and most important result to be a knowledge of the chain of connection, by which all natural forces are linked together, and made mutually dependent upon each other” (von Humboldt, 1997, p. 23). Here, Humboldt highlights the importance of the natural forces expressed both in ecology and society. By approaching economics as an embedded set of processes, we can bring our activities into line with the Earth system, hanging together (Figure 2).

8. CONNECTEDNESS

The connectedness of the three arenas is essential if the overall system (the Earth system) is to function in such a way as to be inclusive to our species. This connectedness has been highlighted in recent work in relational economics (Biggiero et al., 2022), embedded economics (Skene, 2022) and in the field of socio-economic metabolism (Pauliuk and Hertwich, 2015). This *Zussammenhang*, or hanging together, hinges on feedback and appropriate response, as in all complex systems. We cannot construct the system, as its properties are emergent, but we can listen to the impacts of our actions, learning from them.

De Angelis and Ianulardo (2024, p.1) suggest that: “the circular economy can be thought of as an exercise in moral imagination”, emphasising an additional, ethical element in terms of a social conscience, while testifying to the deep-set connectivity that exists between humanity and the Earth system. Robinson (2022, p.35) writes: “While leverage points come in several categories, the most powerful for achieving a circular economy is assessed to be mindset change; one based on sufficiency and closeness with nature, achieving wellbeing without necessitating constant growth.” Work on social ecological systems (e.g. Ostrom, 2009) and on social metabolism (Fischer-Kowalski & Haberl, 1998; Haberl et al., 2023) can be seen to link systems theory and thermodynamics, showing how social and ecological systems co-evolve.

One of the significant challenges is that our activities have repercussions in unexpected ways, as feedback ripples through the networks and components of the Earth system, across a temporal spectrum, from seconds to years. Furthermore, each component inputs its own perturbation and so listening, responding and listening again, in real time, is all that we can do. Because the system is dynamic and process-based, our efforts towards sustainability must be too. Destinations do not exist here in these ever-shifting sands, only directionality.

Dasgupta (2021, p.497) emphasised the role of communities in the economics of biodiversity, observing that: “If contact with the natural world is a means to furthering personal well-being, connectedness with Nature is an aspect of well-being itself.” Murray et al. (2017, p. 377) note that “Humans, their activities and their environment are all loci on the one circle, thus a circular economy recognizes this relationship”. Economics will always be part of the greater system and, as we have seen from our brief discussion on supply chain networks, there is a large body of evidence indicating this. Thus, only an Earth system-based approach can truly inform economics in terms of how it can contribute to sustainability.

Of prime importance in terms of economics is the measure of economic growth in terms of human-made capital. There is, currently, little inclusion of social and natural capital within contemporary models of economic growth and development. Dasgupta (2021, p. 493) observes that: “Standard economic measures such as GDP can mislead badly. If the societal goal is to protect and promote well-being across the generations (i.e. ‘social well-being’), governments should measure inclusive wealth (societal means to those ends). Inclusive wealth is the sum of the accounting values of produced capital, human capital and natural capital.”

Indeed, we would suggest that by having an inclusive measure, then any improvement in social and environmental functionality will increase economic growth rather than decrease it. Thus, any perceived ‘green economy’ would likely deliver increased overall profit because the losses in terms of natural and human capital would be reduced. Given the baggage that terms such as ‘green economy’ and ‘degrowth’ carry with them, and the concerns related to greenwashing, an inclusive reconceptualization of economic growth and GDP to realistically reflect the true costs and profits of our economic activities across the arenas would provide much firmer foundations and incentives.

Schultz and Pies (2023) note that “Two contesting perspectives have dominated this prospering debate: post-growth circularity, leading ultimately to degrowth and pro-growth circularity approaches.” While Stern (2009, p. 3) observed that “it is neither necessary nor ethically responsible to stop or drastically slow economic growth to manage climate change”, Jackson (2009, p.5) warned that the pursuit of economic growth has “failed the fragile ecological systems on which we depend for survival. It has failed, spectacularly, in its own terms, to provide economic stability and secure people’s livelihoods”. Ki-moon (2012) concluded that “We need to move beyond gross domestic product as our main measure of progress”. Bauwens (2021, p. 2) has called for “appropriate policies, which include, but are not restricted to, abandoning the blind pursuit of GDP expansion.

Attempts have been made to incorporate environmental and social growth/degrowth into an inclusive measure of economic growth. The Integrated Economic and Environmental Satellite Accounts (IEESA) was developed in the USA, but abandoned in 2005 (Abraham and Mackie, 2005). More recently, the OECD’s greening productivity measurement workstream (OECD, 2017) has been developed. The Integrated Reporting Framework originally developed, in 2013, by The Value Reporting Foundation, now consolidated into the International Financial Reporting Standards Foundation, sought to enhance accountability and stewardship for financial, manufactured, intellectual, human, social and relationship, and natural capital, while promoting the understanding of their independencies (Quattrone et al., 2013).

The importance of such an inclusive measure is an urgent priority, not in order to make environmental and social ‘interference’ with economic activities look positive, but to honestly reflect the true cost of economic activity and to provide a realistic, transparent reflection of the reality of interconnectivity across the three arenas. Furthermore, it will enable policy makers to demonstrate that ‘green is good’ and ‘green is profitable’ rather than the current, misleading notion that social and environmental sustainability involve crippling costs.

An interesting attempt to find a middle ground between post-growth and pro-growth circularity, a debate that is currently raging, can be found in Schultz (2022), who suggests a move from an optimization paradigm, where there is a choice between constraints, to a choices-among constraints approach, where profit-making can enhance environmental recovery. This would involve moving firms from being rule-takers to being active rule-designers, taking ownership.

9. CONCLUSIONS

As Kirchherr et al. (2023) observe, the landscape is a dynamic one and so the concept of CE is likely to continue to evolve through time. How resilient it will be remains to be discovered, but its adaptability and resilience, much like the Earth system, will depend on diversity and a pluriverse of circles, each co-existing and providing the redundancy and trade-offs necessary to contribute to the overall system of systems.

In order to foster economic, social and environmental sustainability, a unified approach must operate across the three arenas: economy, society, and environment. Deeply embedded in the Earth system, this integration should embrace a diverse suite of strategies, informed by landscape and culture (see Weisz, 2011; Onyeali et al., 2023). The emergent character of the Earth system requires that real-time feedback is a priority and that process, rather than structure, lies at the heart of policy and practice.

Systems theory, accountability and transparency all must provide solid foundations for effective decision-making. We advocate for the improvement of the CE paradigm by addressing various challenges with the butterfly diagram. Instead of separate cycles, we recommend an integrated approach, prioritising environmental aspects, alongside the conceptual framework, socio-economic changes and implementation processes. New visual representations of the uninterrupted and dynamic flow of materials are important, and guidelines for circular product design should align with infrastructure to promote resource efficiency. Integrating environmental criteria into design guidelines is essential for sustainability, energy efficiency and waste reduction.

In putting this integrated approach into action, the focus prioritises dynamic processes over rigid structures, leveraging real-time feedback for adaptation strategies and establishing localised supply chains, based on ecosystem characteristics, to enhance economic resilience.

This alignment ensures that economic activities resonate with the evolving Earth system rather than being constrained by complex, static blueprints. As we have seen, there is clear evidence of linkages between the three arenas across history and in more recent thinking. Recognizing the interplay between global and local economies across the pluriverse underscores the significance of embracing trade-offs and showcasing adaptability in decision-making. Sustainability across the three arenas requires directing economic activity towards facilitating the recovery, regeneration and adaptability of ecosystems, all while fostering compatibility and resonance across the pluriverse.

We believe that the pluriverse concept opens up numerous research paths, rooted in system theory, in terms of providing a proven means of combining the global and the local, as seen in the Earth system pluriverse. A system of systems, connecting societies, economics and ecology, can be researched within this framework, with the development of parallel schools in all three arenas, complementing the CE. It is important to acknowledge that the CE, while crucial in terms of delivering sustainable resource use, cannot be expected to deliver everything in terms of a sustainable future. By establishing and developing these other fronts, across economics, social studies and ecology, all working in parallel, we will avoid disappointing our citizens by promising outcomes that the CE is not designed to address, while avoiding the danger of conceptual collapse and confusion caused by overextension.

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Keith R. Skene: Responsible for the conceptualisation, writing, figure design and editing of first and second drafts.

Andreea Oarga-Mulec: Responsible for conceptualization, figure design, table composition, writing and editing of first and second drafts.

DECLARATIONS

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