

“The Stone Age did not end because humans ran out of stones.
It ended because it was time for a re-think about how we live.”
William McDonough

A PARADIGM SHIFT IN SUSTAINABILITY: FROM LINES TO CIRCLES

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Abstract

The concept of sustainability is attracting great attention as societies become increasingly aware of the environmental consequences of their actions. One of the most critical challenges that humankind is facing is the scarcity of resources, which are expected to reach their limits in the foreseeable future. Associated with this, there is increasing waste generated as a consequence of rapid growth in the world population (particularly in urban areas) and a parallel rise in global income. To cope with these problems, a linear strategy has been applied to increase efficiency by reducing the use of materials and energy in order to lessen environmental impacts. However, this cradle to grave approach has proven inadequate, due to a lack of attention to several economic and social aspects. A paradigm shift is thus required to re-think and innovate processes (as early as in the design phase) in such a way that materials and energy are used more effectively within a closed-loop system. This strategy, known as the cradle-to-cradle approach, relies on the assumption that everything is a resource for something else since no waste is ever generated in nature. In line with the cradle-to-cradle approach, the bio-inspired circular economy concept aims at eco-effectiveness, rather than eco-efficiency. While the circular economy has neither a confirmed definition nor a standardized methodology, it nonetheless carries significant importance, since it “is restorative and regenerative by design and aims to keep products, components, and materials at their highest utility and value at all times, distinguishing between technical and biological cycles,” in accordance with the goals of the 2030 Agenda for Sustainable Development. Despite some controversial opinions that “circles are not spirals, and for growth to occur, spirals with ever-increasing radii are required,” the circular economy concept is taking a central role in the sustainable development debate and, for this reason, deserves attention. The aim of this paper is to shed light on this debate, pointing out the main features of the emerging circular paradigm along with sustainability transition theories and circularity evaluation tools.

Keywords

circular economy; circularity metrics; sustainability transition; paradigm shift.

Introduction

Humankind is facing difficult challenges associated with our increasingly unsustainable lifestyles (involving, e.g., mass consumption, aggressive industrialization, and increased energy demand and urban waste generation), aggravated by an ongoing exponential increase in the global population. In response to these threats, societies are becoming ever more aware of the consequences of their actions on ecosystems. Thus, there is ongoing search for sustainable ways of producing goods used in everyday life and also in modern technological applications. In the search for cleaner technologies, raw materials are of crucial importance. Especially, critical raw materials (i.e. materials that have high economic value coupled with a high risk of supply) draw great attention since they are linked to all industries across all supply chain stages [1]. In addition to the scarcity issues, the low recycling rate of these materials results in the loss of significant economic opportunities that, in turn, pushes practitioners to develop holistic approaches to evaluate elemental sustainability [2,3]. Due to the scarcity of raw materials along with the related economic and environmental impacts, a sustainability debate has flourished among

academics, analysts, and policymakers. A commonly proposed solution for the problems associated with unsustainable human behaviour is the triple bottom line (TBL) strategy, which aims at evaluating economic performance alongside social and environmental impacts. However, TBL strategies do not seek to balance economic, environmental, and social aims; rather, they – predictably – hold economic objectives as paramount. Thus, a different perspective is required to assess sustainability. A potentially useful strategy could be obtained by translating TBL strategies to their triple top line (TTL) counterparts, which aim at enhancing the well-being of nature and culture while generating economic value. TTL strategies enable companies to assess the environmental and social impacts of their activities while minimizing their ecological footprint [4].

In the TTL approach, linear *cradle to grave* strategies are replaced with circular *cradle-to-cradle* strategies. Traditionally, cradle to grave systems focus on reducing energy and material demand, and thus decreasing the environmental footprint by increasing eco-efficiency; this strategy is also known as the *take-make-waste* approach. On the other hand, the cradle-to-cradle approach shifts the paradigm by re-thinking the processes in terms of material and energy, implementing innovations as early as in the design phase to create a closed-loop system for eco-effectiveness [5,6]. This strategy suggests that everything is a resource for something else, given the principle that no waste is ever generated in nature. The cradle-to-cradle approach is an idealized pattern for sustainability that requires support from driving tools such as the circular economy (CE). Therefore, the focus of this paper is on the bio-inspired circular economy concept, which aims – much like the cradle-to-cradle approach – at achieving eco-effectiveness, rather than eco-efficiency.

As the CE is the manifestation of a paradigm shift, it implies significant changes in societal legislation, production, and consumption, taking nature as an inspiration for responding to social and environmental needs. CE systems maintain the added-value of products by innovating for as long as possible and eliminating waste. This requires full systemic change, involving innovation in not only technologies but also organizations, society, finance, and policies [6].

The CE is key to achieving the Sustainable Development Goals of the 2030 Agenda, which rely on a new paradigm integrating techniques, tools, and frameworks under principles of circularity, eco-effectiveness, and harmlessness [7]. The CE is expected to promote economic growth by creating new businesses and job opportunities, reducing material costs, dampening price volatility, and improving supply security, while simultaneously reducing environmental pressures and impacts [8,9].

Literature on the CE is increasing rapidly, covering both its conceptualization and its implementation. Korhonen et al. made a significant contribution to CE studies with their critical analysis of the role of the CE in sustainable development [10]. The study evaluated the CE concept, as well as its limitations, in terms of environmental sustainability. Pesce et al. identified the basic drivers and barriers to implementing CE principles at the corporate micro level and the organization of CE principles [11]. Beyond these examples, many other studies have considered specific CE cases [12-14].

Some authors have predicted the timing of the sixth Kondratieff cycle, suggesting that it will be driven by resource efficiency and clean technology – indicating sustainability [15]. However, a transition to a more sustainable regime implies more than simply a shift from one technological configuration to another, but “a change of the underlying structure which regulates technical change” [16]. A regime shift arises through changes to the regulative (i.e. formal rules, laws, etc.), normative (i.e. values, norms, etc.) and cognitive (i.e. priorities, problem agendas, beliefs, etc.) rules guiding behaviour in practice [17]. Such changes may affect changes within a particular value chain (i.e. vertical change) or in each part of a particular value chain (i.e. horizontal change). In fact, they might even change the entire configuration of an established value chain [18].

As the linear nature of cradle to grave life cycle assessment (LCA) strategies has urged practitioners to adopt circular cradle-to-cradle approaches, and as the number of evaluation tools has increased, the need for a standardized methodology to measure circularity has arisen. Although some standards for implementing CE principles exist (e.g. the British Standard BS 8001:2017 [19], CEN and CENELEC Standards EN45558 [20] and EN45559 [21]), none has achieved consensus among practitioners. The latest development to establish a common basis was the action plan published by the European Commission on March 11, 2020 [22]. This plan

proposed a roadmap for making the EU economy sustainable via “turning climate and environmental challenges into opportunities across all policy areas and making the transition just and inclusive for all.” Moreover, some organizations and private companies have tried to establish their own circularity measurement tools (e.g. the Material Circularity Indicators [23] and Circulytics [24] proposed by the Ellen MacArthur Foundation; the CirculAbility Model [25] proposed by Enel); these tools may offer practical potential, and they are examined in detail in a later section of this paper.

Before entering into a deep methodological discussion, it should be mentioned that some objections to the CE concept have been raised. For example, in his controversial paper, Skene questioned the biological basis claimed for the principles underpinning the CE (i.e. thermodynamic and ecological principles) and argued that the natural world operates in a very different way from that portrayed in the CE literature [26]. Skene concluded that the CE is unfit to deliver both sustainability and growth. Specifically, he held that the CE works against both the laws of thermodynamics and the underpinning principles of nature; hence, it can hardly be considered sustainable. Moreover, circles do not lead to growth, as this requires ever-increasing spirals. Despite this controversial position, the CE has taken a central role in the debate over sustainable development and the sustainability transition, and, in this respect, its definition and measurement deserve attention.

This paper has the following structure: Section 2 provides a literature review to introduce the CE concept; Section 3 explains transition theories with respect to the move from a linear to a circular model; Section 4 introduces the tools used for measuring circularity; Section 5 mentions the impacts of CE on sustainability dimensions and, finally, Section 6 provides concluding remarks and recommendations.

Literature review: Introducing the cradle to cradle CE concept

Until recently, sustainability assessment strategies used the linear approach of measuring cradle to grave material flows in order to model typical take-make-waste behaviours. This strategy aimed at minimizing material and energy consumption and thereby reducing the environmental footprint in an attempt to increase efficiency. However, as the sustainability concept has widened its perspective to include economic and social aspects, the need for a fundamental conceptual shift has emerged, supporting a cradle-to-cradle system. Cradle to cradle systems are powered by renewable energy, whereby materials flow in safe, regenerative, closed-loop cycles [5,6]. Through this perspective, processes must be re-thought and innovated (as early as in the design phase) to ensure that benign, valuable, high-tech synthetics, mineral resources, and energy are used effectively in cycles of production, use, recovery and remanufacture.

The cradle-to-cradle approach is an eco-effective strategy that holds that everything can be converted into valuable nutrients (value-added products) at the end of its life. The approach involves the design of “commercially productive, socially beneficial, and ecologically intelligent” processes [2]. One eco-effective strategy is known as *stock optimization*, which is based on the recognition of the limited nature of Earth’s resources and the need to maximizing their value. As summarized by Kalymkova et al., the stock optimization concept is directly linked to various economic theories such as spaceman economy, steady-state economy, industrial ecology, and cradle-to-cradle [27]. In particular, the cradle-to-cradle perspective has significant potential to create a new paradigm for industry, whereby human activity can generate a wide spectrum of ecological, social, and economic value.

Similar to the cradle-to-cradle concept, some bio-inspired concepts (e.g. CE, green economy and bioeconomy) aim at eco-effectiveness, rather than eco-efficiency. Although these concepts are often used interchangeably, there are slight differences between them that should not be overlooked [28]. Geisendorf and Pietrulla conducted a comparative assessment of CE concepts, concluding that – even though they do not indicate precisely the same thing – the cradle-to-cradle approach is the most aligned with the CE perspective [29].

The CE concept is mainly based on the idea that products or processes should be designed to turn materials into nutrients via two distinct metabolisms defined by the creators of the cradle-to-cradle concept [6]. The biological metabolism (or cycle) considers products with the potential to be consumed (i.e. *products of consumption*). At the end of their lives, products of consumption may serve as nutrients for living systems and return to the natural environment to feed biological processes. The second metabolism – the technical metabolism (or cycle) – considers durable goods that provide a service to customers (i.e. *products of service*). Products of service can

remain safely in a closed-loop system of manufacture, recovery, and reuse, maintaining their highest value through many product life cycles. As a result, circular economy systems keep the added-value in products for as long as possible and eliminate waste.

Owing to its high potential, the CE approach has gathered great interest from a variety of disciplines, including economics, chemistry, engineering, and architecture – despite the lack of an agreed-upon definition and a standardized implementation methodology. In their comprehensive review, Prieto-Sandoval et al. provided one of the most extensive definitions of the CE as “an economic system that represents a change of paradigm in the way that human society is interrelated with nature and aims to prevent the depletion of resources, close energy and materials loops, and facilitate sustainable development through its implementation at the micro (enterprises and consumers), meso (economic agents integrated into symbiosis) and macro (city, regions, and governments) levels [30].” The idea of paradigm shift relates closely to transition theory and, more specifically, to the growing debate over the transition to sustainability.

Transitioning from a linear to a circular model

For many years, environmental impact assessment studies – based on the implementation of technological innovations – were considered sufficient to evaluate sustainability. To set a global standard for sustainable development, the United Nations proposed 17 Sustainable Development Goals (SDGs) in their 2030 Agenda [7]. As a result of their conceptual analysis of each SDG, along with five case studies set across the world, Leal Filho et al. noted that all of the SDGs are strongly interlinked in terms of their ability to tackle environmental sustainability challenges [31].

Nonetheless, even if a product’s environmental performance (i.e. eco-efficiency) is improved, this may not always generate greater environmental sustainability [32–35]. By the same token, a greater circularity of products or production systems does not always correspond to greater social inclusion (e.g. human rights, gender equality, fair trade, etc.). The solution is therefore to identify the best compromise. A *global* list of environmental and/or social priorities should be drawn up and the response strategy built around it. In his pioneering study, Geels performed an analysis stemming from the sociology of technology, building upon the fact that “technology, of itself, has no power, does nothing. Only in association with human agency, social structures, and organizations does technology fulfil functions [36].” Following this line of reasoning, a comprehensive sustainability assessment approach would require the evaluation of all societal and economic practices, values, and attitudes that result from or lead to technological, social, ecological, and political innovations [37–40]. Accordingly, a growing number of studies have examined the sustainability transitions of socio-technical systems, especially in the areas of sustainable policymaking and planning activities for a low-carbon future [41–44].

Before discussing transition theories, it is worth defining socio-technical systems as “a configuration of products, processes, services, and infrastructures, regulations, skills, preferences, expectations, and actors (e.g., producers, suppliers, policymakers, users) that fulfil societal needs such as energy, food, or mobility provision” [41]. Theories of the transition to sustainability are predominantly based on the ways in which system innovations (i.e. transitions from an incumbent socio-technical system to a new and more sustainable system) occur and how transition interventions can be organized [46].

Although the literature on sustainability transition theories is increasing², this paper focuses on the multi-level perspective (MLP) developed by Rip and Kemp [47], Geels [36], Geels and Schot [48] and Grin [49]. The MLP is one of the most significant analytical frameworks in the field, owing to its flexibility and usefulness in identifying transition patterns and factors contributing to inertia in existing systems [17]. In the remainder of this section, the conceptual basis of the MLP is explained; following this, some controversial opinions about its application are introduced.

Originally, the MLP was constructed as a multi-dimensional approach fostering ideas from evolutionary economics, the sociology of innovation, and neo-institutional theory to understand technological transitions (i.e. “technological changes in the way societal functions are fulfilled”) [36]. Later, it was improved to serve as a heuristic device for sustainability transition studies [50-52].

² See, for instance, Bergek et al. [87], Hekkert et al. [88] and Jacobsson and Bergek [89] for the basics of the methodology; and Hacking et al. [90], van Welie et al. [91], Sawulski et al. [92], el Bilali [93] and Kushnir et al. [94] for recent case studies.

According to the MLP, a socio-technical transition emerges from the interplay between processes at the three levels of a nested hierarchy: (i) niche innovations, (ii) socio-technical regimes, and (iii) the exogenous socio-technical landscape [36]. Niche innovations occur at the micro-level, where path-breaking transitions tend to develop and receive nourishment; the niches function as protective spaces that shield innovations from mainstream selection pressures. Socio-technical regimes represent the meso level unit and refer to the semi-coherent set of rules pertaining to different social groups; the socio-technical landscape refers to wider technology-external factors.

Existing regimes are pressured by niche innovations and landscape developments, which open so-called *windows of opportunity* for transitions, in general, and sustainability transitions, in particular [53]. However, socio-technical transitions do not occur overnight; rather, they progress through four developmental stages, which may take several decades to complete [54]. The first phase is characterized by *experimentation* and trial-and-error learning, with radical niche innovations that gradually build up internal momentum. In the second phase, innovations *stabilize* in one or more market niches, providing a more reliable flow of resources and placing pressure on the system and regime. In the third phase, the radical innovations *diffuse* into mainstream markets. Finally, in the fourth phase, the new socio-technical system disrupts the existing system (fully or in part) and becomes *institutionalized* and anchored.

The MLP perspective forms a bridge between evolutionary economics and technology studies. Its strength is simultaneously its weakness. It is a fairly complex perspective, requiring much data – often of a qualitative nature [36]. Nevertheless, there are some controversial debates about the ontological and epistemological perspectives via critical realism [17,41]. Critics claim that an understanding of why certain developments happen requires examination of the relational interplay between the multiple structural factors relevant to the specific conjuncture. To understand whether a sustainability transition will occur or not, it is vital to assess both landscape pressure and niche readiness, as the first destabilizes the incumbent regime and the second provides a viable alternative [15]. However, the MLP approach does not provide an exact solution to such problems.

Another important critique states that transition studies do not necessarily indicate sustainability outcomes or impacts. Assuming that “green” innovations are intrinsically positive, their degree of sustainability improvement is not determined. Geels accepts that the outcomes of impact assessments are often determined by the interpretations of life-cycle analysts or modellers [54]. In the authors’ view, this affirmation clearly states that the implementation of transition theories must be supported by complementary evaluation tools. This need becomes all the more relevant when considering complex transitions such as the transition from a linear to a circular model. In this case, multiple technologies are simultaneously involved, in both complementary and substitute ways. At the same time, behavioural changes are required for the transition to be effective. In order to assess what is truly circular and sustainable (in terms of both production and consumption), specific tools and metrics are needed to reduce the risk of greenwashing or – worse – a transition to unsustainability. A brief history of circularity measurement studies and a closer look at some of the recently developed tools for measuring circularity are presented in the following section.

Tools for measuring the CE

LCA is classified as a unique environmental management framework for sustainable decision-making [55]. As the popularity of the LCA methodology has increased, its potential as a tool to assess circularity has become a matter of debate among practitioners. In their recent publication, Corona et al. provided a comprehensive review of the most used frameworks to assess the circularity of products and services [56]. They indicated that the LCA was the most used framework amongst the seven measurement indices, nine assessment indicators, and three assessment frameworks they considered, and concluded that the LCA is a potentially useful tool for measuring circularity. Furthermore, Lokesh et al. reported an interesting example of how the LCA can serve as a hybridized sustainability metric of circularity [57]. They combined resource efficiency indicators from LCA applications with green chemistry metrics and principles to bridge gaps for both bio-based and fossil-based products.

Despite its great potential, the LCA has limitations that directly affect the quality of its assessment. In particular,

LCA results are difficult to map onto social and economic impacts, as Reap indicated in an extensive two-part review [58,59]. Although Bjørn et al. suggested that LCA indicators could be improved by translating midpoint indicator scores to absolute environmental sustainability indicators, taking *carrying capacity* as a reference, sustainability assessment studies still require a more comprehensive perspective [32].

In addition to enhancing the potential applications of LCA, researchers have also aimed at supporting it with other tools to broaden its perspective to include economic and social (in addition to environmental) aspects of sustainability [60,61]. This challenge has been taken up by a growing number of scholars, analysts, and policymakers, who have proposed decision-making tools such as multi-criteria decision analysis (MCDA) and cost-benefit analysis (CBA) [62–68]. Furthermore, a number of sustainability assessment studies have applied multi-pillar analysis, evaluating economic and social aspects as well as environmental factors [69–72].

Several researchers have combined different sustainability evaluation tools to affect a broader perspective, in line with the concept of circularity. For example, Niero and Kalbar proposed the combination of different circularity and LCA-based indicators to measure CE performance at macro, meso, and micro levels, via MCDA [73]. This indicated a novel approach to assessing circularity at a product level, drawing on CE and eco-efficiency perspectives. Thus, the study provided a significant contribution to the literature, in terms of both its evaluation of suitable metrics and its proposed framework for assessing product circularity.

Numerous evaluation tools and metrics have been reported in the literature. In particular, Elia et al. compared index-based methodologies in macro, meso, and micro levels to assess the capacity of certain environmental assessment tools to satisfy CE requirements [74]. Mesa et al. referenced sustainability measurement in the product development process and existing indicators for the CE [75]. Finally, in their extensive study, Parchomenko et al. identified and assessed 63 circular economy metrics and approaches [76]. Overall, these three papers (appeared on the *Journal of Cleaner Production* over the period 2017-2019) provide a rather comprehensive overview of the theoretical and empirical debate around indicators and tools developed to assess sustainability at various levels (both geographical and technological) with different aspects of the CE.

In light of the increasing number of evaluation tools, the need for a standardized methodology to measure circularity has become evident. The BS 8001:2017 was the world's first CE standard, developed to “help organizations and individuals consider and implement more circular and sustainable practices within their businesses, whether through improved ways of working, providing more circular products and services or redesigning their entire business model and value proposition” [19]. Following this, the European Commission introduced the first of two CE design protocols (EN45558 and EN45559), constituting a framework for standards for “material efficiency that would establish future ecodesign requirements on, amongst others, durability, reparability, and recyclability of products” [20,21]. The most recent development by the European Commission was the action plan introduced on March 11, 2020. This plan proposed a roadmap for making the EU economy sustainable, with the aim of “turning climate and environmental challenges into opportunities across all policy areas and making the transition just and inclusive for all [22].” The framework is expected to boost the efficient use of resources by promoting clean CE, restoring biodiversity, and reducing pollution. While the number of metrics introduced in the literature has steadily increased, no consensus has been reached among practitioners as to which metric is superior. In the remainder of this section, three evaluation tools that the authors hold to offer practical potential are examined in further detail.

The Circularity Indicators Project, proposed by the Ellen MacArthur Foundation in collaboration with Granta Design and financially supported by the EU, represented the first attempt to standardize the methodology [23]. The goal of the project was to develop a measurement system to assess the circularity of products and companies, using the material circularity indicator (MCI). The MCI shares some commonalities with LCA methodologies, such that most of the inventory data required for the LCA are also required for the MCI, and the complementary impact indicators may be derived from an LCA approach. Nonetheless, the difference between these methodologies rests on their scope: the LCA considers the entire product life cycle, whereas the MCI focuses on the material flow in the use phase, only. The MCI had a pioneering role as the first model to assess circularity at both a product and a company level (the company level MCI is calculated as a weighted average of all product level MCIs). However, it focuses exclusively on technical cycles and materials from non-renewable sources, providing very limited insight into consumption products. Thus, a better understanding is required to assess all dimensions of circularity.

The Italian multinational energy company Enel recently developed a tool to assess circularity, known as the *CirculAbility* model [25]. This model is based on a set of key performance indicators (KPIs) used to measure, compare, and improve circularity in the context of the CE. The goal is to combine a number of KPIs to define

a single circularity index covering all circularity parameters of the studied product or project. The tool can be used to measure circularity at a company and/or product level. The model covers all pillars of the CE, via two indicators: flow circularity and usage circularity. Flow circularity considers sustainable inputs and end-of-life activities for materials and energy. Usage circularity, in contrast, pertains to life extension, sharing, and products as service activities. The report published by Enel explains the empirical basis of the application procedure; however, it does not provide adequate detail on the limitations of the model. The documentation should be improved to give practitioners a clearer idea of how to use CirculAbility to evaluate circularity.

To achieve a comprehensive analysis, the material circularity indicator methodology may be enhanced by the introduction of consumption products. To this end, a new tool, *Circulytics*, was recently proposed by the Ellen MacArthur Foundation, in collaboration with various global partners and CE100 member organizations [24]. The tool is useful for measuring both product and company circularity scores. To produce an overall circularity score (i.e. a Circulytics score), a three-step weighting methodology is applied, starting with sustainability indicators. First, a number of indicators (specific to the studied case) are selected and used to calculate a weighted average for each of seven key themes: (i) strategy and planning; (ii) people and skills; (iii) systems, processes and infrastructure; (iv) innovation; (v) external engagement; (vi) inputs; and (vii) outputs. Similarly, the second step calculates another weighted average for two category-level scores: enablers and outcomes. Finally, the third step produces a single representative Circulytics score. Although the methodology has some limitations (such as a limited number of indicators to model the entire mechanism and uncertainties related to the normalization and weighting methods applied), it holds significant potential to assist companies in their transition to the CE. Moreover, the tool has the advantage of acting as an industrial benchmark over the long term, as an increasing number of companies from different industries are adopting the proposed methodology to measure their circularity.

The Impacts of CE on Different Sustainability Issues

The CE approach aims at achieving a continuous, fair, and effective economic system, guaranteed through the sustainable use of finite resources; in other words, it recognises both the presence of ecological limits and ecosystem constraints and the need of reducing waste and emissions due to human activities [77-79]. It is also stated in the EMF report that the CE functions as a value-creation mechanism to “(i) preserve and enhance natural capital by controlling finite stocks and balancing renewable resource flows; (ii) optimize resource yields by circulating products, components, and materials at the highest utility at all times in both technical and biological cycles; and (iii) foster system effectiveness by revealing and designing out negative externalities” [80]. In this respect, the CE has significant impacts on various dimensions of the economic system, offering promising solutions to the problems associated with linear production and consumption behaviours.

Since the CE is an umbrella concept, it is not always possible to draw clear lines between different dimensions of sustainability in the application of CE principles. For example, both economic and environmental impacts are simultaneously improved when resources are used efficiently and the environmental impacts - associated with material extraction and processing, product manufacture, use, and end-of-life activities - decrease. Thus, the CE offers a strategy to decouple resource use and environmental impact from economic growth – even though no conclusive evidence is proposed so far about how the CE fulfils this mission [77]. Some other authors also argue that the CE concept represents a ‘welcome novelty’ because it demonstrates that the linear economy is not sustainable and, at the same time, a ‘worrying novelty’ because it does not seriously engage with a comprehensive understanding of the biophysical roots of the economic process [81].

However, there is a consensus on the idea that “the transition to a more circular economy requires changes throughout value chains, from product design to new business and market models, from new ways of turning waste into a resource to new modes of consumer behaviour. This implies full systemic change and innovation not only in technologies but also in organization, society, finance methods, and policies” [82]. As influential actors of the value chain, retailers have a special role in linking producers/suppliers and consumers. On the one hand, they exert pressure on their suppliers to shift to more sustainable business models while also encouraging changes in consumer behaviour, so as to make positive contributions to the environment and society as a whole [83,84]. Large retailers such as Tesco, Walmart, and Carrefour are increasingly presenting themselves as sustainability drivers that care for the environment, support local communities, provide healthy options to customers, purchase and sell products responsibly, and create jobs; i.e. they promote a CE model in an overall sense. Several studies mention that market driving companies (e.g. IKEA, Southwest Airlines, and Starbucks,

Swatch, Amazon.com, Dell, FedEx, H&M) create a positive public perception and dominate the sector they belong to, by integrating CE principles into their agendas [83,85].

Conclusions

This paper addresses the transition from a linear to a circular model, required to meet global challenges pertaining to sustainability. Specifically, it argues that the linear strategy, that has long been applied to increase efficiency by reducing the use of materials and energy in a cradle to grave fashion, has proven inadequate to effectively tackle sustainability problems, due to a lack of attention to economic and social aspects. A paradigm shift is therefore required to ensure that materials and energy are used more efficiently through innovations (implemented as early as possible in the design phase) to create a closed-loop system. Thus, the cradle to grave approach must be replaced by a holistic cradle-to-cradle approach, which is an idealized pattern for sustainability requiring support from driving tools such as the CE.

The transition to sustainability “must be a qualitative shift, where the new system has qualitatively different emergent properties” [17]. For this to occur, in line with the MLP, combined pressure from the macro-level (i.e. the landscape on which the vision for a new resource-efficient system is shaped and nurtured) and the micro-level (i.e. the niches in which innovations are developed and allowed to mature in a protected space) must be exerted on the incumbent regime (i.e. the dominant linear model of production).

However, not all changes may point in the right direction, and the current lack of metrics to measure circularity may pose a serious hurdle to effective deployment of the new circular economic model. To address this challenge, existing indicators were reviewed and their limitations were noted. The authors hope this work will provide solid ground for the further development of metrics and indicators and pave the way to a truly sustainable transition towards a CE.

This shift from linearity to circularity is all more relevant having in mind the COVID-19 crisis, as it holds a significant number of economically attractive answers to the current situation. For example, the fragility of many global supply chains, seen in response to the need for medical equipment, opened the debate on the need for stock availability and short supply chains to increase systemic resilience. Another important domain is the highly sensitive area of centralized food production and the related long-distance transport via supply chains. Some cities faced problems with food supply during lockdowns and the need for shorter producer-to-consumer models emerged. Some specific measures have already been taken about mobility and transport, i.e. giving more space to pedestrians and cyclists and also limiting the speed of motor vehicles across the city. Therefore, the CE solutions can find the chance to become the mainstream in such a dynamic environment, combining economic regeneration, better societal outcomes, and climate targets [86].

Conflict of interest

There are no conflicts to declare.

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References

- [1] European Commission (2010) Critical Raw Materials for the EU. Report of the Ad-hoc Working Group on Defining Critical Raw Materials. European Commission, Enterprise and Industry. Available at https://ec.europa.eu/growth/sectors/raw-materials/specific-interest/critical_en [accessed May 31, 2020].
- [2] McElroy CR, Constantinou A, Jones LC, Summerton L, Clark JH. Towards a holistic approach to metrics for the 21st century pharmaceutical industry. *Green Chemistry* 17 (2015), 3111-3121.
- [3] Massari S, Ruberti M. Rare earth elements as critical raw materials: Focus on international markets and future strategies. *Resources Policy* 38 (2013), 36-43.
- [4] McDonough W, Braungart M. Design for the triple top line: New tools for sustainable commerce. *Corporate Environmental Strategy* 9 (2002), 251-258.
- [5] McDonough W, Braungart M, Anastas PT, Zimmerman JB. Applying the principles of green engineering to cradle-to-cradle design. *Environmental Science and Technology* 37 (2003), 434A-441A.
- [6] Braungart M, McDonough W, Bollinger A. Cradle-to-cradle design: Creating healthy emissions – A strategy for eco-effective product and system design. *Journal of Cleaner Production* 15 (2007), 1337-1348.

- [7] United Nations General Assembly (2015) Transforming Our World: the 2030 Agenda for Sustainable Development, A/RES/70/1. Available at: <https://www.refworld.org/docid/57b6e3e44.html> [accessed March 11, 2020]
- [8] Kalmykova Y, Sadagopan M, Rosado L. Circular economy - From review of theories and practices to development of implementation tools. *Resources Conservation and Recycling* 135 (2018), 190–201.
- [9] Ávila-Gutiérrez MJ, Martín-Gómez A, Aguayo-González F, Córdoba-Roldán A. Standardization framework for sustainability from circular economy 4.0. *Sustainability* 11 (2019), 6490.
- [10] Korhonen J, Honkasalo A, Seppälä J. Circular economy: The concept and its limitations. *Ecological Economics* 143 (2018), 37–46.
- [11] Pesce M, Tamai I, Guo D, Critto A, Brombal D, Wang X, Cheng H, Marcomini A. Circular economy in China: Translating principles into practice. *Sustainability* 12 (2020), 832.
- [12] D’Adamo I, Falcone PM, Gastaldi M, Morone P. A social analysis of the olive oil sector: The role of family business. *Resources* 8 (2019), 151.
- [13] Ladu L, Imbert E, Quitzow R, Morone P. The role of the policy mix in the transition toward a circular forest bioeconomy. *Forest Policy and Economics* 110 (2020), 101937.
- [14] Morone P, Sica E, Makarchuk O. From waste to value: Assessing the pressures toward a sustainability transition of the Ukrainian waste management system. In: *Innovation Strategies in Environmental Science*, Elsevier, 2020.
- [15] Morone P. The times they are a-changing: Making the transition toward a sustainable economy. *Biofuels, Bioproducts and Biorefining* 10 (2016), 369–377.
- [16] Schot J, Geels FW. Niches in evolutionary theories of technical change: A critical survey of the literature. *Journal of Evolutionary Economics* 17 (2007), 605–622.
- [17] Svensson O, Nikoleris A. Structure reconsidered: Towards new foundations of explanatory transitions theory. *Research Policy* 47 (2018), 462–473.
- [18] Markard J, Truffer B. Technological innovation systems and the multi-level perspective: Towards an integrated framework. *Research Policy* 37 (2008), 596–615.
- [19] The British Standards Institution (2017) BS 8001:2017 Framework for implementing the principles of the circular economy in organizations.
- [20] CEN-CENELEC Joint Technical Committee 10 on Energy-related products - Material Efficiency Aspects for Ecodesign (CEN-CLC/JTC 10) (2019) EN 45558:2019 General method to declare the use of critical raw materials in energy-related products.
- [21] CEN-CENELEC Joint Technical Committee 10 on Energy-related products - Material Efficiency Aspects for Ecodesign (CEN-CLC/JTC 10) (2019) EN 45559:2019 Methods for providing information relating to material efficiency aspects of energy-related products.
- [22] European Commission (2020) Circular Economy Action Plan. A European Green Deal. Available at https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en [accessed March 19, 2020].
- [23] Ellen MacArthur Foundation (2015) Circularity Indicators. An Approach to Measuring Circularity. Available at: https://www.ellenmacarthurfoundation.org/assets/downloads/insight/Circularity-Indicators_Project-Overview_May2015.pdf [accessed March 11, 2020].
- [24] Ellen MacArthur Foundation (2019) Circulytics - measuring circularity. Available at: <https://www.ellenmacarthurfoundation.org/resources/apply/circulytics-measuring-circularity> [accessed March 11, 2020].
- [25] Enel Sp.A. (n.d.) CirculAbility Model. Available at: <https://corporate.enel.it/en/circular-economy-sustainable-future/performance-indicators> [accessed March 11, 2020].
- [26] Skene KR. Circles, spirals, pyramids and cubes: Why the circular economy cannot work. *Sustainability Science* 13 (2018), 479–492.
- [27] Kalmykova Y, Sadagopan M, Rosado L. Circular economy – From review of theories and practices to development of implementation tools. *Resources, Conservation and Recycling* 135 (2018), 190–201.
- [28] D’Amato D, Droste N, Allen B, Kettunen M, Lähtinen K, Korhonen J, Leskinen P, Matthies BD, Toppinen A. Green, circular, bio economy: A comparative analysis of sustainability avenues. *Journal of Cleaner Production* 168 (2017), 716–734.
- [29] Geisendorf S, Pietrulla F. The circular economy and circular economic concepts—A literature analysis and redefinition. *Thunderbird International Business Review* 60 (2018), 771–782.
- [30] Prieto-Sandoval V, Jaca C, Ormazabal M. Towards a consensus on the circular economy. *Journal of Cleaner Production* 179 (2018), 605–615. Leal Filho W, Tripathi SK, Andrade Guerra JBSOD, Giné-Garriga R, Orlovic Lovren V, Willats J. Using the sustainable development goals towards a better understanding of sustainability challenges. *International Journal of Sustainable Development and World Ecology* 26 (2019), 179–190.

- [31] Bjørn A, Diamond M, Owsianiak M, Verzat B, Hauschild MZ. Strengthening the link between life cycle assessment and indicators for absolute sustainability to support development within planetary boundaries. *Environmental Science and Technology* 49 (2015), 6370–6371.
- [32] Rotmans J, Loorbach D. Complexity and transition management. *Journal of Industrial Ecology* 13 (2009), 184–196.
- [33] Frantzeskaki N, Loorbach D, Meadowcroft J. Governing societal transitions to sustainability. *International Journal of Sustainable Development* 15 (2011), 19–36.
- [34] Schot J, Steinmueller WE. Three frames for innovation policy: R&D, systems of innovation and transformative change. *Research Policy* 47 (2018), 1554–1567.
- [35] Geels FW. Technological transitions as evolutionary reconfiguration processes: A multi-level perspective and a case-study. *Research Policy* 31 (2002), 1257–1274.
- [36] Schlaile MP, Urmetzer S. *Transitions to Sustainable Development*. In Leal Filho W. (Ed.). *Decent Work and Economic Growth*, Springer International Publishing, 2019.
- [37] Pyka A. Dedicated innovation systems to support the transformation towards sustainability: Creating income opportunities and employment in the knowledge-based digital bioeconomy. *Journal of Open Innovation: Technology, Market, and Complexity* 3 (2017), 27.
- [38] Cajaiba-Santana G. Social innovation: Moving the field forward. A conceptual framework. *Technological Forecasting and Social Change* 82 (2014), 42–51.
- [39] Patterson J, Schulz K, Vervoort J, van der Hel S, Widerberg O, Adler C, Hurlbert M, Anderton K, Sethi M, Barau A. Exploring the governance and politics of transformations towards sustainability. *Environmental Innovation and Societal Transitions*, 24 (2017), 1–16.
- [40] Sorrell S. Explaining sociotechnical transitions: A critical realist perspective. *Research Policy* 47 (2018), 1267–1282.
- [41] Wesseling JH, Lechtenböhmer S, Åhman M, Nilsson LJ, Worrell E, Coenen L. The transition of energy intensive processing industries towards deep decarbonization: Characteristics and implications for future research. *Renewable and Sustainable Energy Reviews* 79 (2017), 1303–1313.
- [42] Kivimaa P, Kangas H-L, Lazarevic D. Client-oriented evaluation of ‘creative destruction’ in policy mixes: Finnish policies on building energy efficiency transition. *Energy Research and Social Science* 33 (2017), 115–127.
- [43] Rogge KS, Schleich J. Do policy mix characteristics matter for low-carbon innovation? A survey-based exploration of renewable power generation technologies in Germany. *Research Policy* 47 (2018), 1639–1654.
- [44] Schot J. Confronting the Second Deep Transition through the Historical Imagination. *Technology and Culture* 57 (2016), 445–456.
- [45] Walrave B, Raven R. Modelling the dynamics of technological innovation systems. *Research Policy* 45 (2016), 1833–1844.
- [46] Rip A, Kemp R. *Technological Change*. In: Rayner S, Malone EL. (Eds) *Human Choice and Climate Change*, Battelle, Columbus, OH, 1998.
- [47] Geels FW, Schot J. Typology of sociotechnical transition pathways. *Research Policy* 36 (2007), 399–417.
- [48] Grin J, Rotmans J, Schot J. *Transitions to Sustainable Development: New Directions in the Study of Long Term Transformative Change*, Routledge, New York, 2010.
- [49] Hosseinfarhangi M, Turvani EM, van der Valk A, Carsjens JG. Technology-driven transition in urban food production practices: A case study of Shanghai. *Sustainability* 11 (2019), 6070.
- [50] Kompella L. Barriers to radical innovations as stable designs: Insights from an IT case study. *International Journal of Innovation Management* 23 (2019), 1950047.
- [51] Lin X, Sovacool BK. Inter-niche competition on ice? Socio-technical drivers, benefits and barriers of the electric vehicle transition in Iceland. *Environmental Innovation and Societal Transitions* 35 (2020), 1–20.
- [52] Geels FW. *Socio-Technical Transitions to Sustainability*, in: *Oxford Research Encyclopedias Environmental Science*, Oxford University Press, 2018.
- [53] Geels FW. Socio-technical transitions to sustainability: A review of criticisms and elaborations of the Multi-Level Perspective. *Current Opinion in Environmental Sustainability* 20 (2019), 1–15.
- [54] International Organization for Standardization (2006) ISO 14044:2006 Environmental management — Life cycle assessment — Requirements and guidelines.
- [55] Corona B, Shen L, Reike D, Rosales Carreón J, Worrell E. Towards sustainable development through the circular economy—A review and critical assessment on current circularity metrics. *Resources Conservation and Recycling* 151 (2019), 104498.

- [56] Lokesh K, Matharu AS, Kookos IK, Ladakis D, Koutinas A, Morone P, Clark J. Hybridised sustainability metrics for use in life cycle assessment of bio-based products: Resource efficiency and circularity. *Green Chemistry* 22 (2020), 803–813.
- [57] Reap J, Roman F, Duncan S, Bras B. A survey of unresolved problems in life cycle assessment. Part 1: Goal and scope and inventory analysis. *International Journal of Life Cycle Assessment* 13 (2008), 290–300.
- [58] Reap J, Roman F, Duncan S, Bras B. A survey of unresolved problems in life cycle assessment. Part 2: Impact assessment and interpretation. *International Journal of Life Cycle Assessment* 13 (2008), 374–388.
- [59] Curran MA. Life Cycle Assessment: A review of the methodology and its application to sustainability. *Current Opinion in Chemical Engineering* 2 (2013), 273–277.
- [60] Dreyer LC, Hauschild MZ, Schierbeck J. A framework for social life cycle impact assessment. *International Journal of Life Cycle Assessment* 11 (2006), 88–97.
- [61] Guinée JB, Heijungs R, Huppes G, Zamagni A, Masoni P, Buonamici R, Ekvall T, Rydberg T. Life cycle assessment: Past, present, and future. *Environmental Science and Technology* 45 (2011), 90–96.
- [62] Heijungs R, Settanni E, Guinée J. Toward a computational structure for life cycle sustainability analysis: Unifying LCA and LCC. *International Journal of Life Cycle Assessment* 18 (2013), 1722–1733.
- [63] Heijungs R, Huppes G, Guinée JB. Life cycle assessment and sustainability analysis of products, materials and technologies. Toward a scientific framework for sustainability life cycle analysis. *Polymer Degradation and Stability* 95 (2010), 422–428.
- [64] Campos-Guzmán V, García-Cáscales MS, Espinosa N, Urbina A. Life Cycle Analysis with Multi-Criteria Decision Making: A review of approaches for the sustainability evaluation of renewable energy technologies. *Renewable and Sustainable Energy Reviews* 104 (2019), 343–366.
- [65] Hoogmartens R, Van Passel S, Van Acker K, Dubois M. Bridging the gap between LCA, LCC and CBA as sustainability assessment tools. *Environmental Impact Assessment Review* 48 (2014), 27–33.
- [66] Yılan G, Kadırgan MAN, Çiftçioğlu GA. Analysis of electricity generation options for sustainable energy decision making: The case of Turkey. *Renewable Energy* 146 (2020), 519–529.
- [67] You F, Tao L, Graziano DJ, Snyder SW. Optimal design of sustainable cellulosic biofuel supply chains: Multiobjective optimization coupled with life cycle assessment and input–output analysis. *AIChE Journal* 58, (2012), 1157–1180.
- [68] Falcone PM, González García S, Imbert E, Lijó L, Moreira MT, Tani A, Tartiu VE, Morone P. Transitioning towards the bio-economy: Assessing the social dimension through a stakeholder lens. *Corporate Social Responsibility and Environmental Management* 26 (2019), 1135–1153.
- [69] Yıldız-Geyhan E, Yılan G, Altun-Çiftçioğlu GA, Kadırgan MAN. Environmental and social life cycle sustainability assessment of different packaging waste collection systems. *Resources Conservation and Recycling* 143 (2019), 119–132.
- [70] Millward-Hopkins J, Busch J, Purnell P, Zwirner O, Velis CA, Brown A, Hahladakis J, Iacovidou E. Fully integrated modelling for sustainability assessment of resource recovery from waste. *Science of the Total Environment* 612 (2018), 613–624.
- [71] Antonino M, Gutiérrez TN, Baustert P, Benetto E. Implementation of Agent-Based Models to support Life Cycle Assessment: A review focusing on agriculture and land use. *AIMS Agriculture and Food* 3 (2018), 535–560.
- [72] Niero M, Kalbar PP. Coupling material circularity indicators and life cycle based indicators: A proposal to advance the assessment of circular economy strategies at the product level. *Resources Conservation and Recycling* 140 (2019), 305–312.
- [73] Elia V, Gnoni MG, Tornese F. Measuring circular economy strategies through index methods: A critical analysis. *Journal of Cleaner Production* 142 (2017), 2741–2751.
- [74] Mesa J, Esparragoza I, Maury H. Developing a set of sustainability indicators for product families based on the circular economy model. *Journal of Cleaner Production* 196 (2018), 1429–1442.
- [75] Parchomenko A, Nelen D, Gillabel J, Rechberger H. Measuring the circular economy - A Multiple Correspondence Analysis of 63 metrics. *Journal of Cleaner Production* 210 (2019), 200–216.
- [76] Lazarevic D, Brandao M. Prospects for the circular economy and conclusions. in: *Handbook of the Circular Economy*, Edward Elgar, 2020.
- [77] Korhonen J, Nuur C, Feldmann A, Birkie SE. Circular economy as an essentially contested concept. *Journal of Cleaner Production* 175 (2018), 544–552.
- [78] Charonis G, Degrowth, steady state economics and the circular economy: Three distinct yet increasingly converging alternative discourses to economic growth for achieving environmental sustainability and social equity. in: *World Economic Association Sustainability Conference*, 2012.

- [79] Ellen MacArthur Foundation (2015) Growth within: A Circular Economy Vision for a Competitive Europe. Available: <https://www.ellenmacarthurfoundation.org/publications/growth-within-a-circular-economy-vision-for-a-competitive-europe> [accessed June 6, 2020].
- [80] Kovacic Z, Strand R, Völker T. The Circular Economy in Europe: Critical Perspectives on Policies and Imaginaries, Routledge, 2020.
- [81] European Commission (2014) Towards a circular economy: A zero waste programme for Europe. Available: https://eur-lex.europa.eu/resource.html?uri=cellar:aa88c66d-4553-11e4-a0cb-01aa75ed71a1.0022.03/DOC_1&format=PDF [accessed June 6, 2020]
- [82] Youn C, Kim SY, Lee Y, Choo HJ, Jang S, Jang JI. Measuring retailers' sustainable development. *Business Strategy and the Environment* 26 (2017), 385–398.
- [83] Ruiz-Real JL, Uribe-Toril J, Gázquez-Abad JC, Valenciano J de P. Sustainability and retail: Analysis of global research. *Sustainability* 11 (2018), 14.
- [84] Schindehutte M, Morris MH, Kocak A. Understanding market-driving behavior: the role of entrepreneurship. *Journal of Small Business Management* 46 (2008), 4–26.
- [85] Ellen MacArthur Foundation (2020) The Covid-19 recovery requires a resilient circular economy. Available at: <https://medium.com/circulatenews/the-covid-19-recovery-requires-a-resilient-circular-economy-e385a3690037> [accessed June 2, 2020].
- [86] Bergek A, Jacobsson S, Carlsson B, Lindmark S, Rickne A. Analyzing the functional dynamics of technological innovation systems: A scheme of analysis. *Research Policy* 37 (2008), 407–429.
- [87] Hekkert MP, Suurs RAA, Negro SO, Kuhlmann S, Smits REHM. Functions of innovation systems: A new approach for analysing technological change. *Technological Forecasting and Social Change* 74 (2007), 413–432.
- [88] Jacobsson S, Bergek A. Innovation system analyses and sustainability transitions: Contributions and suggestions for research. *Environmental Innovation and Societal Transitions* 1 (2011), 41–57.
- [89] Hacking N, Pearson P, Eames M. Mapping innovation and diffusion of hydrogen fuel cell technologies: Evidence from the UK's hydrogen fuel cell technological innovation system, 1954–2012. *International Journal of Hydrogen Energy* 44 (2019), 29805–29848.
- [90] van Welie MJ, Truffer B, Yap X-S. Towards sustainable urban basic services in low-income countries: A Technological Innovation System analysis of sanitation value chains in Nairobi. *Environmental Innovation and Societal Transitions* 33 (2019), 196–214.
- [91] Sawulski J, Gałczyński M, Zajdler R. Technological innovation system analysis in a follower country – the case of offshore wind in Poland. *Environmental Innovation and Societal Transitions* 33 (2019), 249–267.
- [92] Bilali H-E. Transition heuristic frameworks in research on agro-food sustainability transitions. *Environment, Development and Sustainability* 22 (2020), 1693–1728.
- [93] Kushnir D, Hansen T, Vogl V, Åhman M. Adopting hydrogen direct reduction for the Swedish steel industry: A technological innovation system (TIS) study. *Journal of Cleaner Production* 242 (2020), 118185.