Chapter 2
The Implementation Challenges to Circular Economy Via-Sectoral Exploration

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Abstract A circular economy (CE) is one of the economic systems that uses a systemic approach to eliminate waste and enhance resources utilization through redefining growth for sustainable development of businesses, society, and the environment. It closes the gap between production and the lifecycle of the ecosystems. This study examines and reviews the challenges facing the CE implementation and its associated opportunities through sectoral exploration. The chapter highlights the progress and challenges of implementing CE strategies in the sectors related to food, chemicals, metals and minerals, electronics, and building and infrastructure. The study generates and analyses an association map that indicates four significant clusters in the CE literature over the years. It has established further that much attention had not given to cross-case comparison in the literature of implementing CE models. Also, the future reliable and robust CE strategy is shifting to ICT and digital economy of scope rather than scale. This research is implicative in terms of fundamental research and investment. Industrial actors can achieve these through collaboration and efficient communication with stakeholders and access to data availability.

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1 Introduction

Circular economy (CE) is gaining widespread momentum in sustainable economic growth achievement from the extraction and generation of waste and resource Kalmykova et al. (2018). Several actors engage in exploiting the unique opportunities created by the CE paradigm. They include businesses, policymakers, and the academic community. Recently, the coordinators of CE launched special issues termed 'Advances in the CE' They sought to study the progress through business models, policies, and industrial innovations brought by the CE concepts (Ghisellini et al. 2016; Singh and Ordoñez 2016; Singh et al. 2019). A study recently conducted to highlight the importance of CE applications and establish a possible future direction of research in this domain (Babbitt et al. 2018).

This article aims to contribute within the broader CE context focussing mainly on specific sector-wise challenges and cross-cutting themes. Recently, it has been established that the manufacturing sector, business, construction, and waste electric and electronic equipment have faced challenges (Acerbi and Taisch 2020; Pizzi et al. 2021; Osobajo et al. 2020; Bressanelli et al. 2020). Therefore, a unified CE research is proposed based on these challenges (Borrello et al. 2020; Principato et al. 2019). However, the existing literature neither thoroughly integrates the challenges learned from those sectors nor explores gaps in CE analysis methodology critically. This study aims to bridge these gaps by critically evaluating challenges, assessing existing intersections among them and prioritizing future advancement in research and technology. This work's essential contribution is creating and bringing to the fore the barriers and opportunities for CE implementation across sectors via critically reviewing existing knowledge.

2 Mapping Approach and Themes Identification

This section explores the critical scoring analysis, the opportunities and challenges facing CE themes, and its current trend. The review is focussing on the implementation of CE and its applications in modern society. The terms 'application', 'implementation', 'case study', 'sector', 'operation' are searched in association with 'circular economy' using AND Boolean operator in the Web of Science. The search returned over 300 results. The software for visualizing networks is called VOSviewer version 1.6.16 was used to analyze the downloaded reference terms via the association of keywords. For consistency, similar terms synchronized—the critical challenges and opportunities identified and integrated for evaluating the application and implementation of CE outcomes. The generated association map indicates four significant clusters in the CE literature:

- The industrial symbiosis, ecology, and evolution cluster represented by a yellow colour,
- CE business models, sustainability, supply chain, logistics, barriers, etc., by red colour,
- Bioenergy, bio-economy, renewable energy, biomass, and carbon footprint, etc. denoted by blue colour,
- Metals, minerals, construction, resource recovery, recycling, and other infrastructural systems are shown in green colour (see Fig. 1).

The studies focussed mostly on reuse and recycling, material flow analysis, and cradle-to-cradle perspectives. The blue cluster studies are closely linked with technology to recover the bio-based energy system (anaerobic digestion) and environmental assessment. The fragment in the sectoral studies informed that much attention had not given to cross-case comparison in the literature of implementing CE visa-vee the challenges and opportunities identified.

If critically observing the yellow clusters, more needs to be done in industrial ecologies to link CE research with the existing business models. Industrial

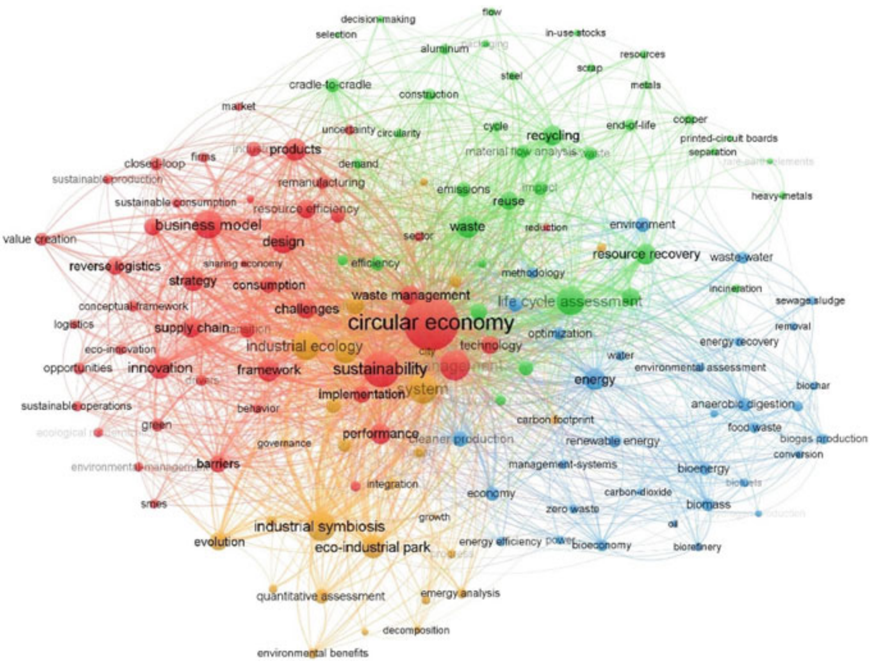

Fig. 1 Keyword association map for circular economy implementation studies

ecology can be seen closely linked to the CE, which is logical considering their standard conceptual bases and the overlapping assessment methodology in that domain. Several industrial ecologies focused on CE studies are revolving around 'Eco-Industrial Parks' and symbiosis from the business perception. Based on the close connectivity of industrial ecology and the assessment methodology such as life cycle assessment, it motivates to analyze key specific sectors like food and its waste, buildings and infrastructure, electronics and associated e-waste, chemicals, metals, and minerals. On the other hand, four primary themes, such as data, models, stakeholder engagement, and business and innovation, will be analyzed regarding the cross-cutting themes.

3 Food Sector and Its Associated Waste

The system of food is central to the studies of CE for two significant reasons. Firstly, the growing global population cannot do without food security. Hence it is critical to living things and economic vitality (Singh et al. 2021). Secondly, because of resources scarcity, they face formidable challenges. Its supply chains consume energy significantly (Pimentel et al. 2008; Del Borghi et al. 2020). The excess nutrients released by freshwater resources contribute to anthropogenic greenhouse gas releases by closely 15%, which is vulnerable to the ecosystems (Singh et al. 2021; Del Borghi et al. 2020). Annually, over 1.3 billion tonnes of food wasted due to the lack of consumption of about 40% of the produced food (Singh et al. 2021). Most food waste is disposed of in landfills, creating environmental degradation and ultimately affecting the climate (Lundie and Peters 2005). CE strategies can transform the food supply chain via the transformation of waste with technological advancement. A considerable literature focuses on a closed-loop supply chain to minimize the loss and maximize potential energy and nutrients (Borrello et al. 2017; Barros et al. 2020; D'Adamo et al. 2020, 2021). Some challenges of the food sector are the inadequate adoption of recovery technologies, stakeholders' disconnection, and streaming of materials. Multi-value streams can be generated by integrating biorefineries as an alternative means; this is an opportunity to explore more in the food sector. Food waste can be converted to biodiesels and biomethane through fermentation and anaerobic digestions (Singh et al. 2021, D'Adamo et al. 2021, Mantalovas et al. 2019, Ferella et al. 2019; Farooq et al. 2021).

The key benefit of environmentally transformed food waste is displacing fossil fuel energy carriers, electricity generation, and synthetic fertilizers. The displacement of fossil fuel, avoiding releases of attendant methane, and landfilling will result in the benefits of the greenhouse gas lifecycle. Stakeholders must show commitments to realizing the environmental benefits of food systems circulation through adopting modern CE strategies. The government, on its part, should provide viable policies to enable stakeholders to overcome the barriers of CE. Certain competing and conflicting objectives have to optimize holistically to pave ways for eco-friendly and economically viable technology-based CE research.

4 Chemicals Sector

The two essential domain of CE implementation in the chemicals sector is the pre and pos consumers (Singh et al. 2021). In the former, feedstock materials are recovered and reused. At the same time, in the latter, the recycling loop is limited to specific non-hazardous waste such as plastics and textile due to challenges facing CE practices (Farooq et al. 2021; Garcia and Robertson 2017). In Europe alone in 2016, the production of plastic materials amounted to about 60 million tonnes annually, and there is a short and midterm increase expectation (Somoza-Tornos et al. 2020). Therefore, on a massive-bases, plastics represent the primary product in the chemical industry. Plastics are versatile, and the most widely demanded type is polyethylene representing 30% of the total production (Somoza-Tornos et al. 2020). The packaging is in the form of bags, bottles, and films. The high percentage of unrecovered plastic packaging renders severe environmental problems. With modern machines and factories, CE practices will enjoy continuity. Practically, the chemical process of conversion gives birth to by-products, side reactions, etc., as wastes during the pre-consumer face. These wastes can be recycled and reused via separation processes such as distillation in petro and biochemical plants (Ioannidou et al. 2020; Kayode and Hart 2019).

In a substantial chemical installation, the linked value chains enable chemical companies to run synthesis processes. One process can be used directly in another. What BASF- a giant chemical company in Germany, calls the '*Verbund* concept'. For instance, in the recycling process of some plastics, it melts and degrades, which can only be reused for lower-valued applications such as building materials, carpets, and clothing. It is challenging to use them in producing new packaging items. Alternatively, incineration can be used as energy valorization even though CO_2 is lost in the volume (Lewtas 2007).

One of the exciting chemical development processes and critical research areas on pre-consumer practices of CE is the valorization of by-products outside its industry. It can be done by industrial symbiosis or eco-industrial parks for environmental and mutual benefits (Chen et al. 2020; Guo et al. 2016). On the other hand, post-consumer most important CE practices barriers are the chemical contamination and its associated risk of life safety (Singh et al. 2021). Contaminants are added by design to enhance product performance but, they inhibit the recycling downstream (Clark et al. 2016). Chemical engineering innovations can be used in chemical industries to promote CE practices, such as valuable metals recovery from e-waste and 'metallurgical waste' and the nutrients recovery from wastewater treatment (Singh et al. 2021; Kalmykova et al. 2018; Zimmerman et al. 2020).

There are four primary challenges to the implementation of CE strategies in the chemical sector. They include chemical mixtures, missing performance and composition data, chemical durability, which is not a desired trait, and hazardous chemical additives that require linear disposal. On the other hand, the opportunities are building on existing matrices and MFG practices for CE, the critical enabler for reusing material in other sectors and green chemistry (Singh et al. 2021).

5 Metals and Minerals Sector

Over the last 50 years, there is a resource-intense decline in the potential for the materials, minerals, and metals industries to move towards a CE—a fewer input with massive production output (Cucciniello and Cespi 2018; Worrell et al. 1997; Cleveland and Ruth 1998). However, the main driver in this sector is economics; as pointed in the literature, dissociating economic growth from resource extraction is fundamental to the foundation of the CE (Behrens et al. 2007; Krausmann et al. 2018; Dorninger et al. 2021; Haberl et al. 2020; Schandl et al. 2020). However, there is increased pressure in this sector due to decreased ore grades and increased total consumption. The focus in the literature for the opportunities in this sector include remanufacturing, recycling, reuse, product redesign, additive manufacturing, and material selection, among others (Singh and Ordoñez 2016; Colorado et al. 2020; Shanmugam et al. 2020; Mesa et al. 2020; Martínez Leal et al. 2020; Dey et al. 2020; Ferrari et al. 2021; D'Adamo and Rosa 2019). However, one of the critical challenges is translating these practices from theoretical to actual production and manufacturing applications (Babbitt et al. 2018; Singh et al. 2021). Recovery rates remain low for most materials; however, recycling remains one of the prime potential areas. Thus, the materials sector can serve as a sink for end-of-life resources. There are three fundamental challenges to the implementation of CE strategies in the metals and minerals sector. They are compositional variability in the stream of recovered resources, inadequate recycling technology, and fluctuation in secondary markets for materials recovered. In comparison, the opportunities can be seen as creating novel by-product streams (Sun et al. 2017; Neves et al. 2020; Henriques et al. 2021).

6 Electronics Sector and Its E-Waste

The electronics sector is an emerging CE case studies related to non-traditional items such as mobile, IoT, clothing, jewellery, toys, household gadgets and appliances, and, of course, healthcare system monitoring tools (Ryen et al. 2015; Hischier et al. 2020; Kasulaitis et al. 2020). Collectively, innovative design and technology strategies influence the strategies of CE in the electronics sector. For example, toxic or emerging containments can be easily eliminated via strategy enhancement. New biodegradable and non-toxic materials such as carbon and pyrene can be integrated to serve as the primary opportunities towards pushing the industry to realize zero-waste sustainable management (D'Adamo et al. 2020; Awasthi et al. 2019). However, the success of these CE strategies in the electronics sector depends on the behaviour and decisions of end-users heavily as a critical stakeholder group. Most attention is given to product lifespan extension and the reuse option in the literature (Coughlan et al. 2018; Wever 2012). Other studies emphasized the link between existing e-waste management and CE strategies in the electronics sector (Gollakota et al. 2020; Kumar et al. 2017). This sector's significant challenges include the evolution of various products and materials, the materials uncertainty and products short lifespan, limited recovery of materials, discourage reusing materials, the lag between waste management infrastructure and existing policies, and the existence of rebound effects.

On the other hand, opportunities in this sector include the availability of data and technology that enhances easy access to information sharing and communication. The uncertainty from the material stream eases with the availability of decision tools. There is a possibility of models sharing in the sector (Singh et al. 2021).

7 Buildings and Infrastructure Sector

Construction sectors consume mega resources, and demolition of the building creates waste in the environment. Heavy-duty construction companies extract minerals exceeding 10 billion metric tonnes annually. It is the only sector with the fastest growth rate during the past century (Cucurachi et al. 2018). Numerous frameworks for CE strategies have been proposed in the built environment. The proposals are with the purview of the Ellen MacArthur Foundation that includes six ways to apply circularity: regenerate, share, optimize, loop, virtualize, and exchange (Foster 2020). Built environment-specific strategies include: reducing construction and design waste and maximizing its value, adaptability design for long life, and component reuse designing. Digital technology can enable construction and design practices in CE.

Research on CE strategies for the built environment is typically focussed on a single strategy, such as using recycled content in new materials, reuse of components, or modularization. New business models will also be required to implement CE strategies in the marketplace. Using the ReSOLVE framework for buildings and infrastructure in new and effective ways will be challenging. However, quantitative assessments of CE strategies' life cycle environmental impacts will be a crucial component of their implementation. The challenges include long life, size and complexity, and a trade-off between CE strategies and cost. At the same time, the opportunities are innovative building materials, new designs and business solutions, the evaluation of life cycle impacts, and analyzing the system implications.

8 Conclusion

There is an increasingly growing interest in CE studies. The literature on this subject matter is extremely significant in terms of works published. For this reason, the proposed critical analysis of CE's impact in several analysis fields is timely and much needed. This study tries to bring some implementation challenges central to the CE topic and opportunities in some sectors implementing CE. It has been established that most at times, the knowledge learnt from one sector do not tend to be useful in another. The literature is relatively fragmented due to a lack of validation in real-life cases studies. In the existing literature of the definition of the CE, few single sectors enjoy the opportunities and CE implementation strategies. Clean technology is expected to facilitate the shift towards the transition to a CE. There is an inadequate methodology for the transition to the CE. This research is implicative in terms of fundamental research and investment. The digital economy can support the development of the CE. It should try to achieve economic scope rather than scale. CE challenges can be addressed through enhanced collaboration with stakeholders and access to data availability.

The results highlight some aspects:

- the point of connection between social change and technological development;
- the need for studies that demonstrate the actual circularity and not the favouring of circular rebound phenomena;
- analysis of consumers to test their willingness to pay for these sustainable products;
- changes in industrial processes not only in developed countries but also in developing countries;
- the definition of indicators that can support decision-makers.

Waste management, waste prevention, and resources efficiency is the direction to implement to foster a circular transformation of resources where political support is required to mitigate the higher costs and encourage implementing these practices to make them competitive in the future.

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