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RESEARCH ARTICLE

Circular economy and frugal innovation: a conceptual nexus

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Abstract
Frugal innovation (FI) and circular economy (CE) are two concepts that are recently being deliberated among researchers, policymakers, businesses, governments, and international organizations. Being a nascent development, both still lack an extant body of theories and data. Undisputedly they both share commonalities in gathering tractions among scholars. But the conceptual relationship between them has been unclear and hence makes it difficult to understand how one can promote the other. The current work constructs a conceptual framework through literature, explicating nexus, characteristics, and indicators of the two concepts and then exploring this framework through case analysis and focus group discussion (FGD). The results of our findings show that the two concepts are outcome of considerations on resource constraints and/or resource optimization; promote redesigning of product and services to minimize resources while achieving core functionality; involve the participation of stakeholders; and are implemented in stages. Most importantly, they foster the three pillars of sustainable development—social equity, economic prosperity, and environmental quality. However, supportive policies and institutions are largely associated with the development of CE which is not the same for FI in most countries. We conclude that FI being mainly operational in the emerging economies could serve as a veritable enabling tool for promoting the CE concept in the developing regions of the globe but will require the support of formal institutions and policies.

Keywords Bottom of the pyramid · Circular economy · Emerging markets · Frugal innovation · Sustainable development

Introduction

The fast growth rate in the global population and the proliferation of developmental strides happening around the world today have continued to exert unending pressure on global resources (Todaro and Smith 2011; Piketty 2014; IRP 2019). This is simply because of man's infinite quest for finished consumer products, explainable by the fact that resources of all kinds are among the major driving forces behind virtually all human activities. Thus, the socio-economic status of any nation has become synonymous with the level of resources and materials available to that nation. It is often perceived to be that all the elements responsible for moving a nation above poverty, towards high social-economic status, and attaining general growth in development at large are associated with adequate and sufficient resource availability (Peterson 2017; Todaro and Smith 2011; Ghisellini et al. 2016; Sanguino et al. 2020).

In recent times, it is becoming broadly accepted among scholars, policymakers, governments, businesses, and international organizations that the world resources are finite in availability and therefore requires equitable distribution and judicious exploitation through state-of-the-art technologies if the world must attain sustainable development. Thus, two forms of resource-based concepts that actively engage in different modus operandi have emerged in the last few decades—circular economy (CE) and frugal innovation (FI)—and they are substantially gathering tractions and making distinctive contributions in defining the sustainable development concept. However, the interconnectivity between them has remained unclear. Opinion has been conveyed that the lack of clarity on new sustainability concepts has a potential detrimental implication for advancing sustainability

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science and the diffusion of practices based on these concepts (Geissdoerfer et al. 2017). It is also argued that a new concept with so much traction is usually applied by many stakeholders and therefore could lead to blurring of the concept (Kirchher et al. 2017). Building a strong theoretical and conceptual framework is therefore important in relatively new concepts like CE and FI to avoid the risk of lacking systemic validity and critical social relevance (Friant et al. 2020). This article is an attempt to make a scholarly contribution by constructing and testing a conceptual framework on the linkages between the two concepts. By constructing a conceptual framework from the literature on FI and CE concepts and then empirically testing this in real-world case studies, the current work seeks to shed light on the nexus between the two concepts. In nutshell, this paper seeks to answer two questions—(i) *What are the linkages between the CE and FI?* and (ii) *How can FI foster a CE?* It is hoped that the framework can both be used as a conceptual lens to better understand the practical connections between the two concepts as well as a heuristic model for further scholarly inquiries.

The rest of the article is organized as follows: in the next section, we will set out some literature on the conceptual meanings, themes, and characteristics of FI and CE and also construct a conceptual framework setting out the convergences and differences between them. The study methodology is explained in section three. In section four, we describe some real-world cases of FI, while the prior-constructed framework is then used as a lens to empirically explore the case studies for the nexus between them and show how FI can promote the CE. The last section concludes with the recommendations on the ways the framework can contribute to policy and future research.

Literature review

The previous research efforts and other relevant grey publications on the subject matter offered us a pivotal base to have an overview outlook on the literature and for building the conceptual framework on the two concepts. Since we aim to find conceptual definitions and indicators for the concepts, we adopted the method applied by Kirchher et al. (2017) to conduct a focused search on Web of Science, Google Scholar, and Scopus on literature to identify the most relevant, recent, and comprehensive reviews, conference papers, book chapters, and original research conducted on the two subject matters. Our initial search identified 341 records for FI and 594 records for CE. We then skimmed the result of these searches specifically for relevant literature with the assumption that the literature will contain definitions and taxonomies. We selected 41 reviews on CE and 25 reviews on FI for in-depth analysis and then 45 and 41 other articles and relevant grey publications on the two concepts, respectively. We arrived at a total of 152 materials, which is comparable to the sample size used in similar works (Khan 2016; Weyrauch and Herstatt 2017; Hossaini 2018). The search terms, inclusion, and exclusion criteria are highlighted in Table 1, while the stages of analysis are presented in Fig. 1. We aim to study the representative number of literature but not exhaustive since the developed framework will further be explored with case studies and focus group discussions. Common knowledge of the two concepts was first synthesized from the literature and present as overviews, and then indicators, characteristics, and other common factors were adopted in constructing the conceptual framework.

Table 1 Search criteria

Search criteria	FI	CE
Material type	Book chapters, conference papers, working papers, academic literature	Book chapters, Conference papers, working papers, academic literature
Study methods	Qualitative and quantitative literature, Review/original paper/commentaries	Qualitative and quantitative literature, Review/Original paper/ Commentaries
Study period	2000–2021	2000–2021
Inclusion criteria	Definition of terms/taxonomies/indicators/mapping/enablers and barriers/targets/implementation methods	Definition of terms/taxonomies/indicators/mapping/enablers and barriers/targets implementation methods
Exclusion criteria	Does not mention performance/studies that mention the concept without detailed discussion/studies reported before 2000	Case comparison that does not report any outcome specified in the inclusion/ Studies reported before 2000
Search word/phrase	Frugal innovation/sustainable Innovation/Jugaad/constraint-based innovation/indigenous innovations/bottom of the pyramid innovation/grassroots innovations, reverse innovation	Circular Economy, Circularity Model/Circular Business Model, Zero-Waste Economy/Closed-Loop Economy/Sustainable Economy/ Waste-Free Economy, Bioeconomy

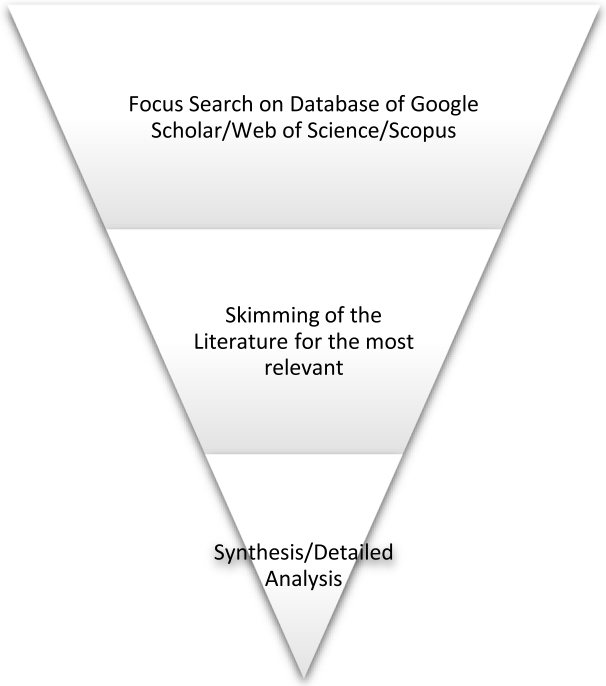

Fig. 1 Stages of the literature review

The circular economy: an overview

The current level of accomplishment attained in human development today across the world could be credited to the linear economy paradigm and mainstream economics (Calzolari et al. 2021; Prabhu 2017; Ezeudu et al. 2021a). These economy models focused mainly on the "extraction-production-consumption-disposal" approach and have been described as wasteful, foster the inefficient use of scarce resources, and increase harmful emissions while yielding increasing amounts of waste from the entire value chain (Meadow et al. 2004; Kiorboe et al. 2015; Ferasso et al. 2020). Apparent disadvantages accruing from the approach are measurable in economical, social, and environmental terms. Associated environmental problems include climate change, loss in biodiversity; pollution of environmental components of air, water, and soil; and resource depletion and compromise of the earth's support system through excessive resource exploitation (European Commission 2020, Jackson 2009, WWF 2014, Salmenpera et al. 2021). Resultant's adverse socio-economic impacts include social vulnerability, an increase in the unemployment rate, the poverty trap, widening inequality, supply risk, and flawed incentive structure (Meadows et al. 2004; Prahalad 2012; Geissdoerfer et al. 2017). The successive world and economic summits of the 1970s and 1980s led to the invention of the concept of sustainable development as a way forward towards finding an alternative solution. This was followed by the advent of several earlier sustainability tools such as life-cycle assessment (LCA), environmental impact assessment (EIA), and risk assessment (RA). These tools have been effective in their own rights. For instance, LCA has been one of the most effective and widely used sustainability tools for evaluating the circularity of products, services, and activities. However, some of these earlier tools (e.g., EIA, RA) still have limitations especially in assigning appropriate market values and underpricing, and more importantly, they are mainly replete with "command and control" and "market-based policy" tools such as taxes and subsidies (Ezeudu et al. 2019). In view of these shortcomings, the current sustainability debates have favored the rethinking of the existing economy model from linear to circular, hence the emergency of the CE concept (Lieder and Rashidi 2016; Sanguin et al. 2020). The CE is proposed to reverse the current unsustainable model of development and create long-term prosperity (Fitch-Roy et al. 2020).

However, according to Ellen MacArthur Foundation (2013), CE has been gaining traction since the late 1970s, but the body of the available literature suggests that the origin of the concept could be linked to the earlier scholarly works which discussed the closed, linear, and open-ended features of the modern economic system (Geissdoerfer et al. 2017). There is also a consensus among scholars that the recent CE concept is largely influenced by the earlier economic school of thoughts which include performance economy concept promoted by Stahel (2010); blue economy by Pauli (2010); cradle-to-cradle by McDonough and Braungart (2002); industrial ecology theory by Graedel and Allenby (1995); laws of ecology by Commoner (1971); and the principle of regenerative design by (Lyle, 1994).

Just like other recent areas of study, there is still no consensus agreement on a common definition for a CE. Influenced by works of Ellen MacArthur Foundation, Geissdoerfer et al. (2017) defined CE as "a regenerative system in which resource input and waste, emission and energy leakage are minimized by slowing, closing and narrowing material and energy loops. This can be achieved through long-lasting design, maintenance, repair, reuse, remanufacturing, refurbishing, and recycling." What seems to be an integrated definition of CE was given by Kirchherr et al. (2017) as " an economic system that is based on business models which replace the 'end-of-life' concept with reducing, alternatively reusing, recycling and recovering materials in production, distribution and consumption processes, thus operating at the micro-level (products, companies, and consumers), meso-level (eco-industrial parks) and macro-level (city, region, nation and beyond), to accomplish the sustainable development, which implies creating environmental quality, economic prosperity and social equity to the benefit of future and current generations". For this work, we would adopt the two definitions.

However, the CE was initially based on 3R (reduce, reuse, and recycle) but later expanded to 4R with additional R (recover), although, currently, 9R has also been proposed which includes refuse, rethink, reduce, reuse, repair, refurbish, remanufacture, recycle, and recover (Van Buren et al. 2016; Potting et al. 2017; Kopnina and Padfield 2021). But the 4R is more widely accepted among the research communities, and we will also base our analysis on it. Transition to CE occurs at three levels; the micro-, meso-, and macro-levels. The macro-level means application of CE across the entire economic system; meso-level focus of eco-industrial park or in some cases refers to as regional levels, while the micro-level deals with the application at the level of products, individual enterprises, and consumer levels. The major enabler to CE transitions is novel circular business models and consumers since the key aim of the CE has been argued to be the operationalization of the business model towards achieving the sustainable development objective (Kirchher et al. 2017, Brennan et al. 2015). More recently, the option of integrating the green human resource management in the circular economy business model at the firm level is also being discussed (Jabbour et al. 2019). This is understood from the point that disregarding the human side of CE could make the adoption and implementation of CE a risky undertaking for firms (Jabbour et al. 2019). The concept of bioeconomy is equally being discussed along with the CE especially at the Europe (Kardung et al. 2021). Bioeconomy is regarded as an economic model dependent on bioenergy products (e.g., biogas, biomethane, biodiesel, bioethanol) produced through novel scientific processes (anaerobic digestion, pyrolysis, fermentation) using biomass as feedstock (D'Adamo et al. 2021). However, the contemporary discussions on bioeconomy have gone far beyond the bioenergy framings to include (i) the replacement of fossil resource-based inputs in various production sectors such as the chemical and constructions sectors; (2) more sustainable, efficient, and integrated uses of biomass; and (iii) "biologization" of processes in food, pharmaceutical, and recycling industries that require low input volumes and yield high-value outputs (Stark et. al 2022). It involves a transition towards an optimal use of renewable biological resources by adopting sustainable primary production and processing systems that can produce more food, fiber, and other bio-based products with fewer inputs, less environmental impacts, and reduced greenhouse gas emissions (European Commission 2021). Effective implementation of bioeconomy will in the long run aid in the decoupling of economic growth from environmental degradation which is a prerequisite for achieving sustainability. This is equally the mutual objective of the CE. It is important to mention that recent scholarships have recognized that due to heterogeneous characterizing features of societies and communities in terms of social, political, cultural, and even demographic, that CE can be flexibly implemented to the suitability of any location (Ferronato et al. 2019; Ezeudu and Ezeudu 2019; Ngan et al. 2019; Ezeudu et al. 2021b).

The frugal innovation: an overview

The word frugal originated from sixteenth century Latin word *frugalis* which according to Oxford dictionary means "sparing or economical as regards money or food." Frugality has been practiced even in ancient times due to deficient economic resources (Soni and Krishnan 2014). Other historic practices of frugality were referenced in Henry Ford's assembly line and post-World War II Japan (Soni and Krishnan 2014). The aftermath of the war left obvious negative impacts on Japan in terms of lack of natural resources, restricted international access, and limited space and economic funds which made the country to challenge some basic processes of manufacturing and adopt some frugal approaches to development which include lean concepts, just-in-time manufacturing, continuous improvement, miniaturization, and kaizen (Womack et al. 1991). In the last few decades, however, FI has been deliberated in the literature in different contexts since it has been researched as an interdisciplinary area of study across several fields such as development/sustainability science (Hossain 2021a; Knorringa et al. 2016; Prahalad and Mashelkar 2010; Levanen et al. 2015); process and product engineering (Knizkov and Arlinghaus 2020; Hossain 2021b; Womack et al. 1991; Sehgal et al. 2010; Kuma and Puranam 2011); business strategy (Winkler et al. 2020; Hossain 2021a, Kuo 2017; Govindarajan and Trimble 2012; Lange et al. 2021); and behavioral science (Krishnan 2010; Radjou et al. 2012). As such, contributions to its conceptual understanding have been made from these fields' perspectives. Nevertheless, there is still an absence of consensus on its definition. According to Levanen et al. (2015), it is being defined as alternative solutions created under the resource-constraint circumstance. Yet another definition defines it as a variant of technology that is chiefly motivated by demand, characterized by imitation, and favored by low-cost competition in the emerging market of the developing economies where enterprises are inventing new resource-constraint solutions for low-income and rising middle-income market segment in a specific developmental issues such as energy, healthcare delivery, and transportation (Zeschky et al. 2011; Cote 2017). From manufacturer's and perhaps marketers' point of view, FI means innovative products and services that seek to minimize the use of the material and financial resources in the complete value chain (development, manufacturing, distribution, consumption, and disposal) to reduce the cost of ownership while meeting or even surpassing certain predefined conditions of acceptable quality (Tiwari and Herstatt 2012). The common phrases associated with FI include

bottom of the pyramid, grassroots, "jugaad," inclusive innovation, reverse innovation, lean innovation, and disruptive innovation. FI and reverse innovation are the most prominently discussed among scholars. But the generally acceptable differentiation is that reverse innovation is the redesigning of a product towards meeting the needs of the emerging markets that would further evolve and finds acceptability even in the developed society as a result of the proliferation of global value chain (Govindarajan and Trimble 2012, Hossain 2021b), whereas FI is defined as the innovations and technologies that are designed specifically by, for, and of the developing nations. In this context, resource-scarce innovations created by poor people themselves in their living surroundings are FIs. However, recent research contributions have posited that success and/or failure of frugal innovation as well as its definition is dependent on the market in which it is launched (developed or developing market) (Winkler et al. 2020).

Soni and Krishnan (2014) researched on the typology of FI and spotted three types which include a mindset or way of life, process, and outcome. Mindset is said not to be limited to entrepreneurs or innovators but also individuals. The process variant involves creating products or value for end-users with minimal wasteful efforts (Womack et al. 1991). Further, the process is aimed at minimizing all non-value adding activities and waste while the end product might not be frugal itself (Soni and Krishnann 2014). The frugal process has also included the influences that resource constraints have on different stages of company's supply chain (Knizkov and Arlinghaus 2020). The frugal process is also associated with phrases like *lean engineering or frugal engineering*. Sehgal et al. (2010) defined the frugal process as a clean sheet approach to product development that aims at optimizing value for customers while minimizing non-essential costs. The main pillars of such an approach are robustness, portability, defeaturing, leapfrog technology, megascale production, and service ecosystem (Kumar and Puranam 2011). The third classification of FI was given in the form of a frugal outcome. One form of it is "appropriate technology" which is defined by Schumacher (1973) as a variant of technology that is considered small in scale, labor-intensive, and easy to operate and maintains with minimal adverse impact on the environment. However, it is argued that the so-called appropriate technology and the modern capital intensive technology should be deemed as complementary, rather than a substitute (Pisoni et al. 2018), since the technology is considered amicable to addressing concerns of sustainable innovation and development even in the developed economies (Akubue 2000).

FI was also analyzed from the perspective of the stakeholders involved. The major stakeholders have been classified according to three domains of operation which includes grassroots, domestic enterprises, and multinational corporations (MCs) (Soni and Krishnan 2014). Grassroots level frugal innovators are individuals or groups of people who create products and services to solve a given problem adopting locally available ingenuity. The majority of these innovations happen with little or no support from formal institutions, and while such a solution is positioned to addressing the local problem, they often fail to scale up (Krishnann 2010). Domestic firms that have reconfigured their resource portfolio, processes, and business model to address the needs of the local market mostly located at the bottom of the economic pyramid are referred to as domestic-corporate frugal innovators. What is common at this level of innovation is that it is aimed at addressing a social cause effectively by adopting process and business model innovations (Hossain 2020; Prahalad 2012; Jayashankar 2012; Prasad 2011). Most entrepreneurs that start such ventures do not intend to solve their problem but rather find a business opportunity to exploit while meeting the needs of a large market which is not the case for grassroots innovators (Levanen et al. 2015; Munshi 2009). The last category is MCs which are called subsidiary innovators. Due to the large domestic market and the cheap and good quality talent available in developing countries, several MCs have arrived the locations, such as General Electric, Unilever, Phillips, and Harman, to set up their research and development units. Some examples of their frugal products include the low-cost ultrasound and electrocardiography (ECG) scanner by General Electric and water purifier by Unilever (Govindarajan and Trimble 2012). Most often than not, the MCs have to forego their tried and tested approaches to manage innovation in favor of a more parsimonious approach characterized by low-cost experiments and improvisations (Radjou et al. 2012).

Nevertheless, understanding of FI is also more than products or services. They also entail exploring new business models, redefining the meaning of value-for-money, striving for radically new cost targets, taking a clean slate approach, and grinding an attitude of parsimony (Prahalad and Mashelkar 2010; Sehgal et al. 2010; Radjou et al. 2012, Soni and Krishnan 2014; Hossaini 2021b; Lange et al. 2021).

The conceptual framework

While the distinction between FI and CE is not always clearly made, in the literature, several inter-connections among them were observed. In this section of the article, we collate these insights and organize them in a loose framework that focuses on (i) product lifecycle which includes resource extraction, product design, consumption, and waste management; (ii) stages of

implementation; (iii) stakeholders' involvement; (iv) policy and institution; (v) enablers and barriers; (vi) limitations; and (vii) services and finally weigh them against (viii) sustainable development indicator pillars of economic, social, and environmental sustainability. The framework is set out in Tables 2–3

Methodology

We adopt a qualitative case study method for the exploration of the conceptual framework because of the following reasons:

(i) When the aim of a study is specifically to achieve an understanding of the richness and complexity of the

Table 2 Framework for FI

Indicators	Details	Reference
(i)Product lifecycle 1. Resource extraction	Limited resources/ resource constraint motivated frugal products	Jha and Krishnan (2013); Cunha et al. 2014; Zeschky et al. 2014; Ploeg et al. 2021
2. Product Design	Products are designed to minimize resource, defeatured, meet basic needs, cost reduction, concentrate on core functionalities, and optimization of performance	Weyrauch and Herstatt (2017); Brem and Wolfram 2014; Zeschky et al. 2014; Ostraszewska and Tylec (2015); Pisoni et al. 2018; Knizkov et al. 2020; Liefner et al. 2020
3. Consumption/consumer	Poor consumers are targeted (bottom of pyramid) in the emerging markets, under-served consumers in the developed countries	Basu et al. 2013, Levanen et al. 2015; Pisoni et al. 2018; Winkler et al. 2020
4. Waste management, 4R (reduced, reuse, recycle, recovered)	Waste is minimized, waste is recycled, reused, recovered	Radjou and Prabhu (2014) Prabhu 2017
(ii) Stages of implementation	Implemented at the grassroots level, domestic-enterprise level, and multinational corporation level	Soni and Krishnan (2014); Brem and Wolfram 2014; Lange et al. 2021
(iii) Stakeholders involved	Local innovators, enterprises, and multinational companies	Prahalad 2012; Soni and Krishnan (2014); Igwe et al. 2020; Ploeg et al. 2021
(iv) Policy and institutions	Policies have been adopted at national levels to promote indigenous innovations in a place like India. Informal policies/institutions exist in some developing countries in support of FI; European Commission has published whitepapers to stimulate FI activities	Soni and Krishnan (2014); Prabhu, 2017; Igwe et al. 2020; Ananthram 2021; Hossain 2021b
(v) Enablers	A large pool of low-income consumers, availability of local ingenuity, failure of government in providing traditional services, free-market structure. Customers at the developed countries demanding eco-friendly products and services. Informal entrepreneurial ecosystem, sustainable business models	Prabhu et al. 2017; Igwe et al. 2020; Hossain 2021a; Lange et al. 2021
(vi) Barriers/limitations	Absence of start-up and scale-up funds for entrepreneurs, lack of formal policies/institutions could lead to poor quality control; the FI concept overlaps with many other concepts that could adulterate the concept	Kuo 2017, Hossain, 2018; Hossain, 2021b
(vii) Services	Services are designed frugally to cut costs while retaining quality services	Hossain 2017; Prabhu, 2017
(viii) Sust. Dev. indicators (i) Economic prosperity	It creates employment at the poor developing regions, provides revenue for Big multinationals and domestic enterprises, govt earns revenue through taxes and levies, builds the informal economy and grows GDP, and triggers cascaded economic growth for other sectors	Knorringa et al. 2016; Hossain 2021a; Hossain, 2020
(2) Social equity	Ensures equal access to goods and services for both rich and poor	Khan (2016); Weyrauch and Herstatt, 2017; Khan and Melkas 2020
(3) Environmental quality	Products are less sophisticated and therefore reduce harmful emissions to the environment. Innovators often consider environmentally friendly material	Kuo (2017); Le Bas 2020

Table 3 Framework for CE

Indicators	Details	Reference
(i) Product lifecycle 1. Resource extraction	Emphasis is not always on the frugal product. Advocates minimization of resource extraction, advocates for substituting virgin resources with waste/recovered products	Kalmykova et al. 2018; Hanumante et al. 2019; Geissdoerfer et al. 2017; Moraga et al. 2019;Suarez-Eiroa et al. 2019; Sauve et al. 2016
2. Product design	Products are designed to ensure recyclability, recoverability, reusability	Murray et al. 2017; Sauve et al. 2016
3. Consumption/consumer	No particular consumer is targeted. All income class consumers are targeted	Urbinati et al. 2017; Sauve et al. 2016
4. Waste management	Promotes the 4R but with more emphasis on recovery, reuse, and recycling. Firms are indifferent in reduce as it might affect marketability	Ghisellini et al. 2016; Urbinati et al. 2017; Blomsma and Brennan 2017; Murray et al. 2017; Sauve et al. 2016; Schoggi et al. 2020
(ii) Stages of implementation	Meso-level (eco-industrial park, regions, etc.), micro-level (product, consumers and enterprises) and macro-levels national/regional/entire economy)	Saidani et al. 2019; Ngan et al. 2019; Ghisellini et al. 2016; Aguilar-Hernandez et al. 2021
(iii) Stakeholders involved	Businesses, policymakers, governments, consumers, enterprises, practitioners, MCs, regional bodies, international organizations; All sector of society	Ghisellini et al. 2016; Leider and Rashid 2016; Ezeudu et al. 2021a
(iv) Policy and institutions	It requires actions and policies. Has been adopted through policies in the European Union (EU), China and Japan	Morseletto, 2020, Ngan et al., 2019; Murray et al. 2017; Sauve et al. 2016; Friant et al. 2021; Fitch-Roy et al. 2020; Henrysson and Nuur, 2021
(v) Enablers	Circular business models, policies and institutions, corroboration among stakeholders, financing mechanism	Mishra et al. 2019; Kirrchhen et al. (2017); Urbinati et al. 2017; Murray et al. 2017, Ferasso et al. 2020; Centobelli et al. 2020
(vi) Services	Services are discussed as part of circular business models. Advocates for improved service delivery	Ellen MacArthur Foundation 2012; Sauve et al. 2016; Han et al. 2020
(vii) Sust. Dev. indicators (i) Economic prosperity	Promotes job creation, conserves global resources, yields revenue for governments, businesses	Kalmykova et al. (2018); Leider and Rashid 2016; Lewandowski 2016; Andronicean et al. 2021; Aguilar-Hernandez et al. 2021
(2) Social equity	Fosters social inclusiveness in environmental management and governance	Kirrchhen et al. 2019; Lewandowski 2016; Murray et al. 2017; Geissdoerfer et al. 2017; Jabbour et al. 2019
(3) Environmental quality	Reduces harmful emissions, minimizes waste generation, reduces pressure on waste management facilities. Safeguards public health	Ghisellini et al. 2016; Leider and Rashid 2016; Sauve et al. 2016; Ogunmakinde et al. 2021; Aguilar-Hernandez et al. 2021
(viii) Limitations	Costs of reconfiguration of resource portfolio, thermodynamic limitations. Poor financial funds and technological development limit its implementation in low and middle-income countries	Lahti et al. 2018; Korhonen et al. 2018; Ezeudu et al. 2021b; Ferronato et al. 2019

phenomenon, quantitative methods of experimental and survey research are less capable of capturing the detail and providing insights which make the qualitative research more appropriate (Lincoln and Guba 1985, Kuo 2017).

(ii) Case research method of qualitative study allows a concept to be developed for further study (Noda and Bower 1996).

(iii) Qualitative research method provides a unique avenue for understanding complex, nuanced situations where interpersonal ambiguity and multiple interpretations exist (Austin and Sutton 2014).

(iv) Multiple data collection sources in a qualitative research is for corroboration and converging evidence as it gives room for triangulation and increases trust in the validity of study's conclusion (Suter 2012).

Therefore, we employ a descriptive case study to extract empirical data on the FI cases to explore the prior-developed conceptual framework. However, three cases were selected to be used as case studies following a purposive sampling methodology as recommended by Patton (2002). The purposive sampling method is a criterion-based sampling method that allows information-rich cases to be selected for the reason that a great deal about the most relevant matters can be learned and therefore worthy of in-depth study (Patton 2002). The criteria for the selection of the first two cases is that the case will be involved in FI that starts from resource extraction to the production process thereby having comparable attributes of the CE. The third case was included as a service-providing FI initiative to enrich the information. The data required for the case description were collected through publicly available archival sources such as company websites, news documentaries, companies' annual reports, project documents of business and development monitoring agencies, company press releases, magazines, news agencies, YouTube interviews NGO reports, and academic literature. The data extracted from different sources were triangulated and shows a high level of consistency as recommended by Denzin and Lincoln (2005) and Miles and Huberman (1984). The case data were analyzed using iterative process of case comparison (Suter 2012; Austin and Sutton 2014; Kuo 2017).

In addition to this, and to complement the case data collected, we also conducted a focus group discussion (FGD) to obtain more information necessary for analysis. Our choice for FGD is hinged on the fact that as a research method, it employs guided and interactional discussion as an avenue of generating the rich detail of complex experiences and motives behind actions, beliefs, perceptions, and attitudes (Carey 1995). Since we are seeking an understanding of the interconnectivity between two concepts (FI and CE), FGD seems more appropriate, since according to Powell and Single (1996), FGD is more suitable where elaboration of pertinent issues is essential on an existing subject with inadequate knowledge. Also adopting a purposive sampling approach, we selected ten professionals on product innovation and resource economics. The purposive selection according to Patton (2002) adds potency to FGD because the information-rich case will be selected and therefore desired data can be generated. Before the group discussion, both invitees and terms of reference were sent to the ten professionals. Also to mention is that the group size of ten was guided according to work conducted earlier by Peek and Fortherhill (2009). The ten professionals include four academic researchers (active researchers on product innovation and resource economics), two public observers, and four product innovation managers working in the industry. The two observers were included to observe the whole process for impartiality as recommended by Powell and Single (1996) and McLafferty (2004). Information was drawn from three layers which include (i) individual, (ii) group, and (iii) group discussion (Willis et al. 2009; Duggleby 2005). The FGD took place at the mini conference hall of Paul's University in Awka, Nigeria. The discussion lasted for 1 h (6:00 pm to 7:00 pm local Nigerian time), was audio-/video-recorded, and was transcribed for further analysis using content analysis method of qualitative research (Onwuegbuzie et al. 2009). The FGD was guided by the themes developed in line with the initial conceptual framework which include:

(i) Product lifecycle assessment under CE and FI
(ii) Stages of implementation and stakeholders involved in FI and CE
(iii) Policy dimensions and institutional frameworks under FI and CE
(iv) Enablers and barriers to implementation and adoption of CE and FI
(v) Sustainable development indicators for CE and FI

Case description

Case 1: WoeLabs tech hub—a technology laboratory in Togo

The short life span of electronic gadgets has mounted pressure on the increase in their production and hence the resultant increase in the e-waste generated (William 2003). Electronic waste is a mounting crisis in Africa. Digital dumps made up of junk phones, computers, and other electronic gadgets shipped mostly from richer western countries are growing in Africa. Moreover, there is also a growing awareness that e-waste embodies new and complex toxic materials that are harmful to the environment and human health at large (UNEP 2013). While the health and environmental risk of e-waste are many, it is still considered an essential resource with a large potential reservoir of valuable material because it is made up of items which have reached its

end of life but still contain useful parts that can be reused. The progress in electronic business in the West African sub-region is mostly driven by used electronic products popularly called as "second-hand." About half of these products that are mostly shipped from western countries to poor west African countries are nonfunctional and are classified as waste on arrival, which are either move straight to landfills/dumpsite or resalable parts are retrieved to be used in repairing faulty ones (Ezeudu and Ezeudu 2019). WoeLab is a community tech hub established by Togolese Architect Sename, Koffi Agbodjinuo, that is producing 3D printers from recyclable e-waste. The lab is located at the Togolese city of Lome. WoeLab was founded in 2012 as a grassroots network of inventors and entrepreneurs with a vision to build a digital democracy. After purchasing a 3D printer for the lab, the young innovators decided to build their own (Africa Tech Rising 2018). According to interview granted to CNN, Agbodjinou said "We wanted to see how we could build a new one but with our own resources." Their 3D printer technology is based on the RepRap low-cost 3D printing model, first designed by experts at the University of Bath. The printer model is said to have the capability of printing plastic objects within a size of 50-cm cubed. As of 2018, WoeLab has about 50 employees working in the space and a second lab opened in Lome in 2017. Their 3D printer called "W.Afate" was made from e-waste scanner, printer, and computer parts. The printer was exhibited at various shows and has received several awards across the globe. Its users include local firm "Africa Tracing," who deploy it to make the plastic casting for its vehicle GPS technology. The lab has launched a 3D printing education initiative which aims to put a W.Afate into schools across Lome. Most technology incubation hubs across Africa are looking up to this new technology. The technology has shown potential for community-driven actions to take account of and reduce e-waste. WoeLab started its operation from what could be rightly called a fab lab (a small-sized workshop with an array of computer-controlled tools that could cover several different length scales and a variety of material). The main idea behind fab labs is to democratize the manufacturing technologies that were previously available only for expensive mass production (Gershfeld 2012). An important feature of these fab labs is enabling open and corroborative projects. It is also viewed as an avenue for affordable and non-expensive research and development. It promotes collaborative projects within the communities and a growing number of initiatives to exchange designs and experience the labs. As such, entire communities benefit from them rather than just individuals. It also enables the easier transfer of knowledge from developed to developing countries. WoeLab started with a 9-m^2 workspace as a fab lab in Lome but today has occupied two buildings and houses and involved in about ten community projects. WoeLab being an incubation and fabrication lab is reported to have a focus on creating other sustainable technologies in a local context by utilizing materials from the local environment.

Case 2: Wecyclers: a waste recycling service in Nigeria

Nigeria, standing as the most populous country and the largest emerging economy in Africa, has a gangling population estimated at over 200 million people in 2019. The former nation's capital, Lagos, is one of the busiest and populated cities in the world. Lagos has a population of over 20 million people concentrated in a localized land area of 3577 Km^2 (Ezeudu et al. 2021a) and, as such, has enormous waste management challenges. Reports have it that due to improper city planning and structures, the urban authorities are unable to optimally collect the generated waste for either recycling or disposal, which consequently results in indiscriminate waste disposal at the water bodies, water channels, and under the bridges (Suberu et al. 2012; Ezeudu et al. 2020). The waste collection services are limited to the visibility areas, while low-income areas such as slums and ghettos remain underserved (Ezeudu et al. 2020). Born and schooled earlier in Lagos, Mrs. Bilkiss Adebiyi Abiola while studying at MIT in the USA developed an interest in waste management as her specialist subject conceived an idea on how the quantity of waste collected from households can be optimized. In 2012 after graduation, she moved back to Nigeria and co-founded Wecyclers, a waste trading company in Lagos. Due to improper street networks in Lagos, Wecyclers would take out a specially designed tricycle to do waste collections in inaccessible areas of the city. They focus on the poor urban households where the waste management authorities are not able to access with standard waste collection trucks and other vehicular equipment due to poor street network (Ezeudu et al. 2021a). Wecyclers operate as a local innovation that collect recyclables from households, sort and weigh them, and reward the households with food items, cleaning products, and mobile phone air time according to the quantity. At the onset of the initiatives, the company visits households to register them as customers/partners, but over time more and more people are visiting the company to register on their own as they want to be part of the reward system (Guardian 2015). This could be vividly explained by the fact that the waste regulation of Lagos state requires the households to pay for their waste collection services while the Wecyclers offers a reverse model where the households get paid for their trash (Ezeudu et al. 2021a). By 2015, it has been reported that the company had collected over 500 tons of waste and has employed over 80 people (The Guardian 2015). Many MCs (such as Coca-Cola and GlaxoSmith-Kline), small and medium-scale industries, and the Lagos state government have found the services as a useful source of recyclables and recovered resources and have partnered

with them. As of January 2020, the company has serviced over 20,000 households, over 60,000 lives/ beneficiary has been reportedly touched, and about 6200 tons of recyclables have been collected (Wecyclers 2020). Among the recyclables' variants they collect include glass containers, aluminum cans, plastic and lid covers, PET containers, plastic buckets, used papers, used sachet water, cartons, plastic chairs, and bowls. Wecyclers has also issued franchises to local enterprises across the 36 states of Nigeria for recreation of the same waste recycling model.

Case 3: Agooday—company producing toothbrush with Moso bamboo in Taiwan

With 10% of global plastic ending up in the world's ocean each year (Fitzgerald 2011), the menace of plastic pollution has become a global environmental challenge. People are becoming more addicted to single-use and disposable plastics. Calculating with the recommended replacement of toothbrush for every 3 months, a person may use about 400 toothbrush throughout his or her lifetime (Kuo 2017). The use of plastic product is higher in Taiwan. In fact, Taiwan Environmental Information Association in 2014 reported that each person living in Taiwan uses 782 plastic bags in a year. This figure is 3.9 times higher than the quantity used in European Union countries. It is even more challenging considering the fact that Taiwan has a poor waste recycling rate for single-use plastics. Out of 16 billion disposable plastic bags used in Taiwan, less than 10% are recycled annually (Amcham Taiper 2020), while over 100 million plastic toothbrushes are disposed of in Taiwan per annum (Agooday 2020).

Motivated by the need to offer a replacement for a plastic toothbrush which constitutes about 99% of all the product in the market, a Taiwan company founded by a couple ventured into production of the biodegradable toothbrush from bamboo. They took advantage of the fact that bamboo is one of the fastest-growing plants on earth that needs neither fertilizer nor pesticides, and source wild bamboo to use for their products. How it is done is that after a stalk is cut for toothbrush production, it replaces itself in a short remarkable time of only 3 years (Kuo 2017). This practice was adopted to ensure that there would be no negative impacts on the environment. With the dimension of only $18 \times 1.4 \times 0.5$ cm, the utilization of bamboo is optimized while maintaining the ease of grip and flexibility of the toothbrush handle. The material for the bristle was the major challenge, because of the need for 100% biodegradable material. They first experimented with several materials such as palm fiber, horse hair before settling for pig hair. The bristle is made from pig hair, which is a by-product sourced from the Chinese meat industry. Faced with imminent lack of fund, they raised a start-up capital from Zeczec, a major crowdfunding platform in Taiwan. Their initial target was to raise NT$ 40,0000 (about $US12,500), but due to huge acceptance of their idea and products, they succeeded in raising NT$ 2.16 million ($US 67,500). Their product has been adjudged to have the same quality as the plastic type and can be 100% naturally decomposed in 90 days. In essence, it reduces the use of plastic and ensures environmental quality. The toothbrush is qualified by the total plate count test of the SGS test, thereby guaranteeing health safety and hygiene. By 2015, the products were reported to have sold over 25,000 and are poised for further growth in sales as it has been available in the most online shop in Taiwan and beyond.

Results and discussion

The evaluation of the three cases against the conceptual framework is shown in Fig. 2. The themes of the FGD were developed to coincide with the prior-constructed framework to create a common ground for the inquiry and discussed in what follows:

First, there are clear indications that the three cases studied are outcomes of considerations on resource constraints and/or optimal resource utilization. Though the CE is chiefly motivated by the need to protect the global environment against common global sustainability challenges such as climate change, global warming, greenhouse emissions, and resource depletion, hence it is advocating for caution and moderation on resource exploitations. FI in the studied cases was triggered by the fact that the said resources are not available or abundant (as in the case of Woelabs), the services are not available or efficient (Wecyclers), and environmental protection (Agooday). The Agooday case also revealed that the products designed under FI do emphasize the need for proactiveness to ensure the end-products' recoverability and recyclability as it is obtainable in the CE, while the other two cases of FI grossly focus on achieving core functionalities in a product/services by trimming down excesses or making use of what is available. The focus group interaction indicated agreement that both concepts are ardent crusaders of optimal resource utilization and environmental quality promotions and could play vital roles in solving the global resource constraint challenges. Hindocha et al. (2021) agree that having the ability to develop innovative solutions using limited resources for underserved consumers typically in low- and middle-income societies (known as frugal innovation) can contribute towards more sustainable and inclusive world by supporting a more circular economy. It has also been suggested that companies that want to be resource-efficient must foster a frugal culture in their organization which entails reinventing their value chain to operate in a circular way by adopting circular economy techniques (Radjou and Prabhu, 2014). Furthermore, in the CE context, the 4R are

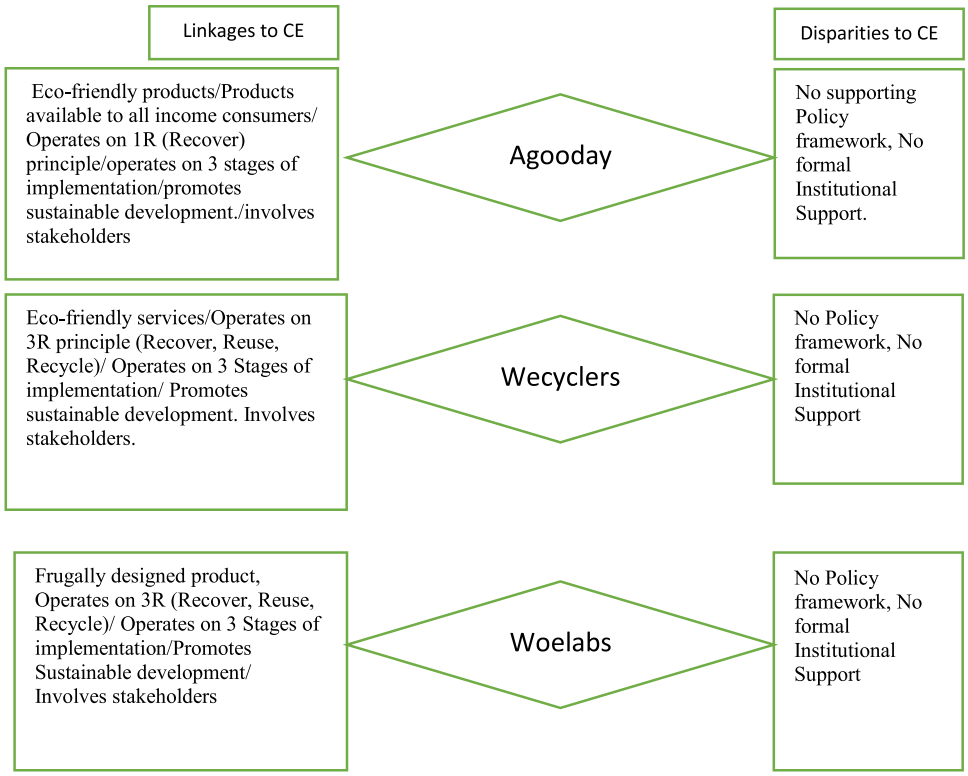

Fig. 2 The three cases evaluated against the conceptual framework

articulated under formal frameworks such as extended producer responsibilities and eco-industrial parks. But there is no such formal arrangement under FI as they are majorly emanating from the free-market economy system in the developing countries.

Second, all the studied cases recognize the levels of operation which is comparable to the stages of implementation in the CE model. In the group discussion, participant #4 posited that "levels of implementation are a common feature of the CE and FI' which is rightly in tune with sustainable development objectives that emphasize partnerships at all levels in solving the world's problem together." The Wecyclers, for instance, took off as frugal thinking/mindset and materialize first as a domestic innovation aimed at solving the community's problem but over time spread to enterprise level and further into formal partnerships with MCs.

Stakeholders' involvement is identified in the cases described. Participant #3 elaborated a weak connection in the stakeholders involved in the FI schemes since all the value chains are not expected to comply through formal policy proclamation as is the case for CE. Participants # 1, 2, 5, and 7 argued that though there might be no formal agreements gluing the stakeholders involved in FI, a kind of informal agreement framework would exist at some level. Informality has been reported as a critical enabler of FI in developing countries (Igwe et al. 2020). This is envisaged since FI is a peculiar practice that is necessitated by emerging economies' contextual conditions such as poor resource availability and a large market of low-income populations. The group discussion agreed that although stakeholders like the producers, consumers, enterprises, and businesses are involved in FI as it is with the CE, the stakeholders are not restricted to frugal products alone, secular products, and markets which also exist in parallel. A typical example is in the case of reverse innovation, which is an innovative product that though originated from the developing locations still found the market at the developed locations where secular innovation models exist.

CE implementation requires formal adoption of policies through formal institutions as stipulated in 5. For instance, the European Union is the major proponent of the CE in Europe through guidelines and action plans (Ferronato 2019; European Commission 2020). Also in China, the CE has been integrated into their socio-economic development through formal policies (Ogunmakinde 2019). Formal policies and institutions were found not to be associated with the FI cases described. Policies supporting FI is either still not available in most countries or at the minimum level in few countries like India (Hossain 2021b). Participants #4, 6, and 8 offered a perspective that considering the comparative benefits of FI in solving socio-economic problems in the emerging economies, there is a need for government support and adoptions through policies as it is the case for CE in many places. According to Prabhu (2017), in many sectors, competition from FI start-up firms might be too weak or slow to force MCs to change their existing resource-depleting

business models. In such cases, governments will have to play a role in introducing legislation or incentive that break the deadlock, increase competition, and hasten systemic changes.

Previous CE research by Ferronato et al. (2019) suggested a cost-effective mechanical biological treatment technology (a frugal technology) that can be adopted in the poor developing regions for pretreatment of waste before final disposal. The waste treatment technology is also said to improve environmental conditions in emergency circumstances (Trulli et al. 2018). It has other benefits such as waste stabilization, production of refuse-derived fuels, converting waste to energy as fuel, addressing the issue of energy demand, and ensuring sustainable waste management in a CE ideology (Munnich et al. 2006). This is comparable to the case of Wecyclers that instead of adopting the normal method of waste collection by the use of standard waste collection trucks constructed a specially designed tricycle to navigate the street for easier waste collection. This is a strong indication that FI can promote CE operationalization.

One of the main goals for the transitioning from linear to circular economy is to achieve sustainable development, which simply entails simultaneously creating environmental quality, economic prosperity, and social equity (Salmenpera et al. 2021; Morseletto 2020). Emerging literature on FI have also continued to point at sustainability as the key outcome of FI (Hossain 2020; Hossain et al. 2021a, b; Levanen et al. 2015).The three FI cases described show the ability to promote sustainable development through economic prosperity, social equity, and environmental quality promotions. They created employment opportunities while ensuring profitability for the enterprises. The biodegradable toothbrush produced by Agooday is eco-friendly and ensures environmental quality promotions; Wecyclers' services are based on recycling and resource recovery principles which are essential elements in waste valorization schemes recognized in the CE, while WoeLabs based their production on waste material, thereby ensuring multiple life spans for products at the end of its service life. WoeLabs produces a 3D printer from e-waste which is a cheap input resource. The frugally manufactured printer is available to the poor consumers in Togo which thereby avails the low-income/underserved customers' opportunity to use a product that they could not have afforded in its standard form. Khan (2016) explained that in the secular business context, secular MCs often fail to provide equal access to their products and services but innovate mainly for the top of the pyramid customers, but frugal innovators pull poor customers into the mainstream, innovate for them, and provide affordable and viable solutions to the needs, thereby contributing to social and economic goals of sustainable development simultaneously by adding value, producing solution cheaper than the alternatives, and turning non-consumers to consumers (Khan and Melkas 2020). These attributes are exemplified in the cases of Woelab and Wecyclers.

During the FGD, participant # 8 contributed that one of the major advantages of FI is that it is a flexible innovation method that factors in local conditions into its modalities. This attribute is in rhythm with the three cases studied. They all flexibly redesigned their products and services to the suitability of the targeted markets. Recent scholarships have also suggested that CE models can be flexibly applied to the suitability of the adopting locations according to political, economic, social, demographic, and even social peculiarities (Ferronato et al. 2019, Ezeudu and Ezeudu 2019, Oliviera et al. 2020).

Implications for theory and practice

Beyond just being an attempt to understand the connections between the FI and CE, this work has also tried to show how FI can promote CE objectives. Certain concerns have been raised in the previous literature as a possible hindrance to CE adoption in low- and middle-income countries such as poor financial standings, absence of state-of-the-art infrastructure, lack of knowledge, and absence of information (Su et al. 2013; Ngan et al. 2019). This work has shown a pre-existence of CE initiatives in these regions achieved through frugal processes and products. The only problem is that they have been studied in a different context and have not been linked to the current CE aims and objective both in theory and practice. Even a CE study that suggested a cost-effective technology for waste treatment in the developing regions has not viewed such innovation in the context of the FI (Ferronato et al. 2019). Consequently, our work would raise awareness that CE proposals and action plans for the developing regions have to make strong reference to indigenous FI and practices. Besides, our framework is flexible and non-prescriptive and therefore has achieved two purposes—(i) it can be applied across the range of FI cases to expand the knowledge on the nexus of the two concepts, and (ii) it is possible to expand the framework towards a comprehensive theoretical framework. Finally, this work would also partly respond to call on the enablers of sustainable development especially in the developing world's context.

In practice, the current work has thus raised an insight for the policymakers, governments, and businesses in developing countries on a credible route to pursue sustainable development goals through FI. We suggest, first, that adopting and implementing CE principles in these regions should be planned side by side with the indigenous frugal innovations. Second, since informality fosters FI and CE in the developing countries, this work has also brought awareness that the growing call for integration of informal activities (e.g., informal waste pickers) into the CE implementation plan in the low and middle-income countries should also extend to FI.

Conclusions

The current work aims to contribute to the previous literature on FI and CE by responding to calls on understanding the two concepts and the connections between them. By constructing a conceptual model and then exploring them in real-world cases, the study helps to clarify the linkages between the two concepts and further shows how FI can promote the CE. As the CE concept is gaining traction across the globe as a prospective method of achieving sustainable development, the FI which started in the emerging economies and has diffused to developed society with similar features with CE in terms of product design, stakeholders' involvement, and stages of implementation is more situated to be explored for possible integration in the CE agenda of the developing countries. It will be beneficial in helping the poor locations of the globe perceived to have socio-economic disadvantages in achieving sustainable development goals. However, future research should try to evaluate more in deep the activities of the case studies in a life cycle thinking perspective to widen the knowledge on their environmental impacts and benefits. We further believe that exploring the conceptual framework with more cases of FI would also bring out other perspectives on the conceptual nexus.

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Authors' contribution **OBE** conceptualized, investigated, curated the research data, formally analyzed the research data, and wrote the original draft of the manuscript. **TCO** participated in data curation. **UCU** and **JCA** supervised the project. All authors read and approved the final manuscript.

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