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# Digital Innovations for the Circular Economy

Phuc Hong Huynh Evertsen

NORD UNIVERSITY BUSINESS SCHOOL

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Phuc H. Huynh Evertsen

Stavanger, 30 December 2022

# Abstract

This dissertation explores the role of digital innovation in the circular economy (CE). The CE emerged to replace the "take-make-dispose" linear system with the "make-use-return" circular system and solve environmental issues (e.g., resource overexploitation and waste emissions). CE transitions require innovations to initiate sociotechnical changes at multiple levels, and reform consumer behaviours. Digital innovations based on the Internet of Things, big data, blockchain, sensors, artificial intelligence, and 3D printing technologies are vital to enable various new circular business models. While large firms are more likely to introduce incremental innovations and adopt marginal CE strategies (e.g., recycling and reuse), new entrants such as academic spin-off firms tend to have higher innovativeness to introduce more radical innovations and make substantial CE impacts.

Despite several initial works, the literature lacks a systematic investigation into how digital innovations can enable circular business models or how different types of CE-related firms can contribute to CE transitions. Whereas CE and innovation applications are highly context-dependent, little is known about how CE innovations can be applied in various sectoral and firm contexts. Most research on digital innovation in the CE is either conceptual or literature reviews but few empirical studies. These knowledge gaps may hinder a firm's incentives for CE transitions. Moreover, most taxonomies and investigations are related to large firms, while new firms, especially academic spin-offs, have received much less attention despite their potential CE impacts.

Drawing on the CE and innovation literature, my thesis aims to fill these gaps by answering the research question, "what is the role of digital innovation in the circular economy?" My thesis consists of four research papers that focus on three main aims: (1) the role of innovations in the CE; (2) the mechanisms of digital innovations that enable circular business models; (3) the actors that commercialize the CE innovations. I adopted a mixed methodology approach, using Multiple Correspondence Analysis, Qualitative Comparative Analysis, and Multiple-Case Study Analysis. Paper 1

systematically examines CE innovations and constructs a taxonomy of CE-related academic spin-offs. Paper 2 provides an in-depth understanding of CE-related academic spin-offs commercializing digital innovations and how these firms behave and create CE impacts. Paper 3 draws on the intercept of the resource-based view theory and digital entrepreneurship literature to examine which resource configurations are required for the success of digital academic spin-offs. Finally, Paper 4 investigates how digital technologies can enable circular business models in the fashion industry and identifies three types of digital circular business models. Three of my papers (Paper 1, Paper 2 and Paper 3) used Norwegian academic spin-off data, while Paper 4 used data from the fashion industry.

My thesis contributes to the innovation, CE, and academic entrepreneurship literature in several ways. First, my thesis adds a taxonomy of the CE-related ASOs to the literature on sustainability transitions, such as the circular economy. The thesis demonstrates the significant roles of start-ups and academic spin-offs in initiating radical circular innovations and creating circular values. Furthermore, my study makes the first step in defining and measuring CE innovations by CE and innovation attributes. Circular digital product innovation tends to be based on existing market knowledge, while circular digital process innovations seem more radical and more frequently patented. My study also shows the novelty degree of digital circular business model innovations. For example, the pull-demand model seems more radical and disruptive than the blockchain-based circular supply and service-based models. Digital innovations are crucial to enabling certain types of circular business models. Moreover, my study emphasizes the vital role of consumers in determining the success of circular digital innovations.

Second, my thesis adds new insights into the CE literature. My thesis finds that the ‘reduce’ strategy, the ‘optimize’ model and ‘narrowing the loop’ are the most prevailing CE practices among academic spin-offs. However, my study also draws cautious attention to the rebound effects of the ‘reduce’ and ‘narrowing the loop’ to not accelerate the loop speed. The 'narrowing the loop' concept should be understood not only as reducing resource consumption but also as reducing unnecessary new demands. To achieve this goal, radical business models such as the pull-demand model necessitate reforming consumer behaviours and shifting the fashion production-consumption paradigm. Finally, my thesis identifies five types of circular economy-related academic spin-offs in both the technical and biochemical cycles. The empirical evidence shows a predominance of academic spin-offs commercializing digital technologies. However, it also shows the importance of academic spin-offs implementing innovations related to circular bioeconomy. Industrial symbiosis holds a crucial role in several types of CE academic spin-offs.

Third, my thesis contributes to the academic entrepreneurship literature, which lacks empirical evidence on the social and environmental impacts of academic spin-offs. My study finds that academic spin-offs are more likely to act as technology suppliers for larger firms in the CE ecosystems. Not all are 'circular-born'; many academic spin-offs initiate CE innovations because of business incentives and market opportunities. Furthermore, my study integrates the resource-based view theory with digital entrepreneurship research to identify the resource configurations for the success of digital academic spin-offs. My thesis identifies two paths to firm success that are labelled 'market exploiters' and 'technology explorers'. For the market exploiters, a favourable market condition is a prerequisite to succeed when technical and commercial resources are lacking. For the technology explorers, combining different types of technical and commercial-related resources is the key to success in digital markets, which appear more open, dynamic, and fast changing.

Moreover, this thesis provides policy and managerial implications to reinforce the CE transitions of firms. My study is aligned with the EU's Circular Economy Action Plan 2020, highlighting the roles of digital innovation and start-ups in the CE transition. My study strongly suggests that policymakers should enact more effective policies on the demand side to incentivize sustainable consumption behaviours and increase market certainty to support circular start-ups and CE-related academic spin-offs. Besides digital academic spin-offs, more governmental support should be given to circular bioeconomy-related academic spin-offs to increase their CE impacts. Moreover, policy supports should not only give funding and grants but also provide start-ups with market knowledge through incubation programs and foster collaborations between actors in the system. Policymakers should also provide more solid CE guidance and procurements for firms to transform and prevent CE rebound effects. Finally, sustainable-related educational programs should be increased to stimulate the creation of sustainable academic entrepreneurship.

# Sammendrag

Denne avhandlingen undersøker rollen til digital innovasjon innen sirkulær økonomi. Sirkulær økonomi erstatter lineært forbruksmønster gjennom 'bruk og kast' med sirkulære systemer gjennom 'lag-bruk-returner' og løser dermed miljøproblemer relatert til for eksempel ressursoverforbruk, avfalls-, og klimagassutslipp. Skiftet mot en sirkulær økonomi krever innovasjoner som kan skape endringer i sosio-tekniske systemer og forbrukernes atferd på flere nivåer. Digitale innovasjoner basert på tingenes internett, store data, blokkjedeteknologi, sensorer, kunstig intelligens og 3d skriving er avgjørende for å muliggjøre nye sirkulære forretningsmodeller. Store bedrifter har større sannsynlighet for å introdusere inkrementelle innovasjoner og adoptere marginale sirkulærøkonomi strategier(F. Eks. resirkulering og gjenbruk), mens gründerbedrifter, slik som forskningsbaserte nyetableringer, har høyere innovasjonskompetanse som kan bidrat til å skape radikale innovasjoner og sirkulærøkonomiske verdier.

Til tross for flere tidlige studier mangler litteraturen en systematisk gjennomgang av hvordan digitale innovasjoner kan muliggjøre sirkulære forretningsmodeller og hvordan forskjellige typer sirkulærøkonomi-relaterte bedrifter kan bidra til økt bruk av sirkulærøkonomi i samfunnet. Sirkulære innovasjoner og anvendelser er høyst avhengig av konteksten, og det er begrenset med kunnskap om hvordan sirkulære innovasjoner kan implementeres i ulike sektorer og bedrifter. Mye av forskningen på digital innovasjon relatert til sirkulær økonomi er enten konseptuell eller litteraturgjennomganger, og det finnes relativt få empiriske studier. Disse kunnskapshullene kan hindre et bedriftene i å bidra til sirkulær økonomi. Mesteparten av forskningen er relatert til store bedrifter mens nye bedrifter, spesielt forskningsbaserte nyetableringer, har fått mindre oppmerksomhet til tross for deres potensielle bidrag til sirkulær økonomi.

Min avhandling sikter på å fylle disse kunnskapshullene innen sirkulærøkonomi- og innovasjons-litteraturen ved å svare på spørsmålet, hva er rollen til digital innovasjon

innen sirkulær økonomi? Avhandlingen består av fire forskingsartikler som fokuserer på tre hovedmål: (1) rollen til innovasjon i sirkulær økonomi; (2) mekanismene innen digitale innovasjoner som muliggjør sirkulære forretningsmodeller; (3) aktørene som kommersialiserer sirkulære innovasjoner. Jeg har brukt ‘kombinerte metoder’, en fremgangsmåte bestående av flere metoder slik som multippel korrespondanseanalyse (MCA), kvalitativ komparativ analyse (QCA), og multiple case studier. Artikkel 1 er en systematisk empirisk undersøkelse som utvikler en taksonomi av sirkulærøkonomi-relaterte forskningsbaserte nyetableringer. Artikkel 2 gir en dypere forståelse av sirkulærøkonomi-relaterte forskningsbaserte nyetableringer som kommersialiserer digitale innovasjoner. Denne artikkelen forklarer også hvordan disse bedriftene oppfører seg og bidrar til sirkulær økonomi. Artikkel 3 integrerer resursbasert teori og litteraturen om digital entreprenørskap for å studere hvilke konfigurasjoner som kreves for suksess i digitale forskningsbaserte nyetableringer. Til slutt, artikkel 4 studerer hvordan digitale teknologier kan muliggjøre tre typer av digitale sirkulære forretningsmodeller. Tre av mine artikler (artikkel 1, artikkel 2 og artikkel 3) bruker data om norske forskningsbaserte nyetableringer, mens artikkel 4 bruker data fra tekstilindustrien.

Min avhandling bidrar til litteraturen om innovasjon, sirkulær økonomi og forskningsbaserte nyetableringer på flere måter. Først, bidrar avhandlingen med en taksonomi av sirkulærøkonomi-relaterte forskningsbaserte nyetableringer. Denne studien viser betydningen av gründerbedrifter og forskningsbaserte nyetableringer for å skape radikale sirkulære innovasjoner og sirkulære verdier. Videre tar studien et første steg for å definere og måle sirkulære innovasjoner. Sirkulære digitale produktinnovasjoner pleier å være basert på eksisterende markedskunnskap, mens sirkulære digitale prosessinnovasjoner ser ut til å være mer radikale og hyppigere patentert. Studien viser også nyhetsgraden i digitalt baserte forretningsmodeller. For eksempel virker ‘etterspørselsdrevet modell’ mer radikal og forstyrrende enn ‘blokkjede-basert forsyningskjede modeller’ og ‘service-baserte modeller’. Digitale innovasjoner er kritiske for å muliggjøre enkelte typer av sirkulære forretningsmodeller.

Min studie vektlegger også den vitale rollen til forbrukeren for at digital sirkulær innovasjon skal lykkes.

Min studie bidrar også med ny innsikt i sirkulærøkonomi litteraturen. Den finner at 'redusere' strategien, 'optimalisere' modellen og 'innsnevre materialstrømmen' er de mest brukte sirkulære praksisene blant forskningsbaserte nyetableringer. Studien diskuterer også tilbakeslagseffekten til 'redusere' og 'innsnevre materialstrømmen' for å unngå å øke hastigheten på materialstrømmen. 'Innsnevre materialstrømmen' konseptet burde bli forstått ikke bare som et konsept om å redusere ressursforbruk men også som å redusere ny og unødvendig markedsetterspørsel. For å oppnå dette kreves radikale forretningsmodeller som etterspørselsdrevet modell for å endre forbrukernes adferd og skifte produksjon- og forbruksmønstre for eksempel i tekstil- og mote-industrien. Til slutt identifiserer min studie fem typer sirkulærøkonomi-relaterte forskningsbaserte nyetableringer i både tekniske og biokjemiske sykluser. Studien viser en større grad av forskningsbaserte nyetableringer som kommersialiserer digitale teknologier. Men den viser også viktigheten av forskningsbaserte nyetableringer for implementering av innovasjoner relatert til sirkulær bioøkonomi. Industriell symbiose har også en viktig rolle i flere typer av sirkulærøkonomi-relarterte forskningsbaserte nyetableringer.

I tillegg bidrar avhandlingen til litteraturen om akademisk entreprenørskap, som mangler empiriske eksempler på sosiale og miljøbidrag av forskningsbaserte nyetableringer. Min studie finner at forskningsbaserte nyetableringer kan bidra som teknologiutviklere til større bedrifter. Ikke alle bedriftene er født sirkulære, mange forskningsbaserte nyetableringer setter i gang med sirkulære innovasjoner på grunn av forretningsinsentiver og for å utnytte markedsmuligheter. Videre identifiserer studien ulike resurskonfigurasjoner for suksess av forskningsbaserte nyetableringer. Studien finner to veier til suksess for bedriftene, som er 'markedsutnyttere' og 'teknologiutforskere'. For 'markedsutnytterne' er et gunstig marked en forutsetning for suksess når tekniske og kommersielle resurser mangler. For 'teknologiutforskerne' er det å kombinere forskjellige typer tekniske og kommersielle resurser nøkkelen til suksess i de digitale markedene, som virker mer åpne, dynamiske og raskt skiftende.

Avhandlingen gir politisk- og  ledelses-messige implikasjoner som kan bidra til å forsterke overgangen til sirkulær økonomi hos bedrifter. Studien er på linje med EU's Circular Economy Action Plan 2020 som fremhever rollen av gründerbedrifter og digitale innovasjoner for sirkulær økonomi. Min studie foreslår at politikere burde innføre mer effektive reguleringer på forbrukersiden for å stimulere til bærekraftig forbruksatferd og øke markedssikkerheten, og derigjennom støtte sirkulære gründerbedrifter og sirkulærøkonomi-relaterte forskningsbaserte nyetableringer. I tillegg til digitale forskningsbaserte nyetableringer, bør det gis mer statlig støtte til sirkulære bioøkonomirelaterte forskningsbaserte nyetableringer for å øke deres sirkulære påvirkning. Dessuten bør politikkstøtte ikke bare gi midler og tilskudd, men også gi gründerbedrifter markedskunnskap gjennom inkubasjonsprogrammer og fremme partnerskap mellom ulike aktører. Politikere bør også gi mer solid sirkulærøkonomi-veiledning og tilgang til midler for bedrifter til å transformere og forebygge sirkulær økonomiske tilbakeslagseffekter. Til slutt, bærekraftrelaterte utdanningsprogrammer bør økes for å stimulere etableringen av bærekraftig akademisk entreprenørskap.

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# PART 1: COVER ESSAY

# 1 INTRODUCTION

Modern industrialization has given rise to resource depletion, environmental contamination, and economic unpredictability. These serious global issues have challenged business leaders, policy-makers, and academic scholars on whether traditional business models still fit or should better be replaced by more sustainable business models. The traditional model of 'take-make-dispose' which heavily relies on the availability of natural and energy resources has received intense criticism for its critical environmental harms (Stahel, 2016). Alternatively, the circular economy (CE) is proposed to replace the linear model in order to reduce resource extraction, minimise waste and emissions, and increase productivity (Andersen, 2007; Stahel, 2016; Geissdoerfer *et al.*, 2017). The debates about CE are taking place dynamically at multiple levels and among academia, policymakers, and practitioners. With its significant sustainable benefits, the CE transition is placed central in several national and international strategies, such as 'the EU's Circular Economy Action Plan 2020' and 'Norway's Circular Economy Strategic Plan 2021'.

Earlier research on CE and innovation has recognised innovation as a driving force for CE (de Jesus *et al.*, 2018). The CE transition requires different types of innovations (i.e., business model innovation, technological innovation, product innovation, service innovation, and process innovation) to unlock new circular business models, create new markets, and change consumer behaviours (De Jesus and Mendonça, 2018; Pieroni *et al.*, 2019; Ranta *et al.*, 2021). Notably, digital innovation is considered one of the most significant enablers for the CE (Ranta *et al.*, 2021). This notion was outlined in the EU's Circular Economy Action Plan 2020, stating that "building on the single market and the potential of digital technologies, the circular economy can strengthen the EU's industrial base and foster business creation and entrepreneurship among SMEs. Innovative models based on a closer relationship with customers, mass customisation, the sharing and collaborative economy, and powered by digital technologies, such as the Internet of Things (IoT), big data, blockchain, and artificial intelligence, will not only accelerate circularity but also the dematerialisation of our economy and make Europe less dependent on primary materials" (the EU's Circular Economy Action Plan, 2020, p.2). In Norway, the Norwegian government also emphasized the role of digital innovation for the CE, that "the government considers it increasingly important to make use of the potential of digitalisation in the shift to a circular economy. Digital solutions make it possible to collect and analyse large amounts of data and make this available for use by business, research and authorities" (Norway's Circular Economy Strategic Plan, 2021, p.5).

The advantages of digital technologies have opened up opportunities for firms to explore new market segments, gain competitive advantages over larger competitors, and create sustainability values (Chauhan *et al.*, 2022; Liu *et al.*, 2022). When it comes to CE, a wide range of digital technologies can be embedded in circular business models to provide customers with new products, enable recyclability, prolong product lifecycle, and improve production processes (de Sousa Jabbour *et al.*, 2018; Chauhan *et al.*, 2022; Liu *et al.*, 2022). For example, digital platforms and the Internet of Things technology can facilitate the 'reuse' services of virtual CE business models (Liu *et al.*, 2022). Blockchain technology can track and trace 'cradle-to-cradle' product activities to improve automatic sorting and recycling (Upadhyay *et al.*, 2021). Another example is the integration of sensors, real-time data, and digital platforms that provide more accurate analyses based on real-time market demand to optimize production, reduce resource consumption, and reduce waste (de Sousa Jabbour *et al.*, 2018).

At this stage, a dominant body of CE innovation research is focused on several perspectives: circular business model innovation, multi-level innovation collaboration, influential factors, firm dynamics and implementation, firm resources, biological cycles, and technologies (Suchek *et al.*, 2021). Despite these initial works, the literature lacks a systematic investigation into how digital innovations can enable circular business models or how different types of CE-related firms can contribute to CE differently. Several scholars pointed out that little attention has been drawn to the applications and impacts of digital innovation in the CE of various sectors (Lieder and Rashid, 2016; Suchek *et al.*, 2021). Furthermore, Pagoropoulos *et al.* (2017) stressed that most existing studies are either conceptual studies or literature reviews, but empirical investigations are considerably few. Ranta *et al.* (2021) and Rosa *et al.* (2019) underscored an essential need for more holistic, integrated, and empirical research to examine the applications of digital innovations in dissimilar CE contexts.

Moreover, most CE research examined the context of large incumbents, but few studies have been done on new market entrants with a higher ability to introduce radical CE innovations (Henry *et al.*, 2020). These knowledge voids could substantially hamper the CE adoption and transformation of firms. Previous studies showed that CE offers not only environmental impacts but also economic and social benefits (Lieder and Rashid, 2016). In practice, maybe not all firms are naturally 'sustainability-born' or 'circular-born' that aim for explicit social and environmental missions. Instead, traditional firms as profit seekers and market exploiters are more likely incentivized to create sustainability values if they can benefit from doing business sustainably. Therefore, proving the processes and benefits of digital innovation in CE may increase firm efforts for CE transitions. Finding this interdisciplinary research of digital innovation and CE significant and relevant to both pragmatic and theoretical stances, my PhD thesis is designed to address the following research question:

*"What is the role of digital innovation in the circular economy?"*

This research question entails three main components: digital innovation, CE, and the actors. Thus, the overarching research question is mapped on three research focuses:

1) The role of innovations in the CE.
2) The mechanism of digital innovations that enables circular business models.
3) The actors that commercialize the CE innovations.

My study includes four research papers exploring one or several of these focuses. Table 1 summarizes the theoretical gaps, research focuses, and specific research questions of the four papers in my thesis. The thesis adopts a mix-methodology approach and uses a diverse set of quantitative and qualitative analyses, including Multiple-Case studies, Multiple Correspondence Analysis, and Qualitative Comparative Analysis. I used two datasets, including a dataset of the Norwegian academic spin-offs established during 1999-2012 and a data sample of the Norwegian fashion firms. With these two datasets, this thesis is narrowed to two primary contexts: the academic spin-offs and the fashion industry. The relevance and significance of the contexts to this study are further discussed in the next section. Table 2 provides the updated status of the four papers.

**Table 1:** Summary of four research papers

| Paper titles | Research questions | Identified gaps | Methods | Main contributions |
|---|---|---|---|---|
| Paper 1: Commercialising circular economy innovations: a taxonomy of academic spin-offs. (Phuc Huynh, Einar Rasmussen, Oleg Nenadic) | What types of CE innovations are commercialised by academic spin-offs? | Systematic measurement and classification of CE innovations and the impacts of academic spin-offs in the CE | Multiple Correspondence Analysis and Clustering Analysis on 60 academic spin-offs in Norway. | • Consolidating the definition of CE innovations based on CE and innovation attributes.<br>• Systematic measurements of CE innovations.<br>• A taxonomy of the five types of CE-related ASOs (i.e., smart product-service provider, technical process enhancer, biochemical cycle extender, renewables provider, and biosphere regenerator).<br>• Policy recommendations for different types of CE-related ASOs |
| Paper 2: The circular economy impacts of digital academic spin-offs (Phuc Huynh, Einar Rasmussen) | How can academic spin-off firms commercialising digital innovations contribute to the CE? | The behaviours and impacts of digital-based academic spin-offs in the CE | Exploratory Multiple Case-study on 25 digital academic spin-offs | • Explaining the potentials of digital-based academic spin-offs as the forerunners in the transition toward the CE by narrowing the loop, orchestrating industrial symbiosis, optimising value creation, and increasing efficiency and productivity. |

| | | | | |
|---|---|---|---|---|
| | | | | • Emphasize the importance of contexts in investigating CE firms. Digital ASOs are more likely to involve the 'reduce' and 'optimize' models. |
| Paper 3: Resource configurations among digital academic spin-offs: Finding the technology-market fit (Phuc Huynh, Einar Rasmussen) | What are the resource configurations leading to success among digital academic spin-offs? | How resources should be combined to optimize values for firm success, particularly for digital start-ups. | Configuration approach, Qualitative Comparative Analysis on 49 digital-based academic spin-offs in Norway | • Two main paths to the success of digital ASOs: the market exploiters and the technology explorers.<br>• Funding is important but not sufficient if the only factor.<br>• Market exploiters are digital ASOs taking advantage of favourable market conditions when lacking technological resources and research collaboration resources.<br>• Technology explorers are digital ASOs combining various commercial- and technological-related resources to succeed. |
| Paper 4: Enabling circular business models in the fashion industry: the role of digital innovation (Phuc Huynh) | What are digital-based circular business models used by the fashion industry?.<br><br>How do fashion companies of different sizes (i.e. large, SMEs and startups) differently adopt those digital-based circular business models? | The mechanism of digital innovations for circular business models in the context of the fashion industry | Exploratory Multiple-Case Study on 10 fashion companies in Norway. | • Three archetypes of digital-based circular business models of the fashion industry: the blockchain-based supply chain model, the service-based model, and the pull demand-driven model.<br>• The radical pull demand-driven model may shift the fashion production-consumption paradigm<br>• Different strategies among large, SMEs and startup fashion firms. |

**Table 2:** Publication status of the four papers

| **Papers** | **Status** | **Publication** |
|---|---|---|
| Paper 1: Commercialising circular economy innovations: a taxonomy of academic spin-offs. (Phuc Huynh Evertsen, Einar Rasmussen, Oleg Nenadic) | • Published as a peer-reviewed research paper in the Technological Forecasting and Social Change journal | Huynh Evertsen, P., Rasmussen, E. and Nenadic, O. (2022) 'Commercializing circular economy innovations: A taxonomy of academic spin-offs', Technological Forecasting and Social Change, 185, pp. 122102. https://doi.org/10.1016/j.techfore.2022.122102 |
| Paper 2: The circular economy impacts of digital academic spin-offs (Phuc Huynh Evertsen, Einar Rasmussen) | • Published as a peer-reviewed book chapter in Research Handbook of Innovation for a Circular Economy, Edward Elgar Publishing. | Huynh, P. H. and Rasmussen, E. (2021) 'The circular economy impacts of digital academic spin-offs', in Siri Jakobsen, T.L., Francesco Quatraro, Einar Rasmussen, Marianne Steinmo (ed.) Research Handbook of Innovation for a Circular Economy. Cheltenham, UK: Edward Elgar Publishing. |
| Paper 3: Resource configurations among digital academic spin-offs: Finding the technology-market fit (Phuc Huynh Evertsen, Einar Rasmussen) | • Presented at the European Academy of Management Conference 2021.<br>• In the peer-review process of the International Journal of Entrepreneurial Behavior & Research.<br>• Revise and resubmit | In progress. |
| Paper 4: Enabling circular business models in the fashion industry: the role of digital innovation (Phuc Huynh Evertsen) | • Published as a peer-reviewed research paper in the International Journal of Productivity and Performance Management | Huynh, P.H. (2021). Enabling circular business models in the fashion industry: the role of digital innovation, International Journal of Productivity and Performance Management, Vol. 71 No. 3, pp. 870-895. https://doi.org/10.1108/IJPPM-12-2020-0683 |

# 2 THEORETICAL FRAMEWORK

This chapter presents the core concepts and literature related to the CE, innovation, digital innovation, and empirical contexts. Then, it reveals the research gaps and develops a conceptual framework for my thesis, which is positioned in the disciplinary literature of CE and innovation.

## 2.1 The circular economy

### 2.1.1 The circular economy concept

The first concept of the Circular Economy was early introduced in the 1970s, but only in recent years has it become more popular when natural resources and the environment were endangered. The causes of erosion, contamination, pollution, biodiversity loss and species extinction are believed to be the linear model's results (Geissdoerfer *et al.*, 2017). In the linear 'take-make-dispose' system, after being used, goods and materials are discarded into the environment before new processes are iterative (Korhonen *et al.*, 2018). The linear model assumes that natural resources are indefinite and can be incessantly extracted for unlimited production and consumption. This misperception has caused severe problems for the environment and society. European Commission [1] projected that by 2050, the consumption on the earth would be tripled, while the consumption of fossil fuels, metals, minerals would be doubled, and waste generation would be increased by 70%. Consequently, resource exploitation and pollution will continue to cause severe biodiversity loss and clean water issues.

These accelerating issues have given rise to a more sustainable alternative: 'the Circular Economy (CE)' that involves circular and restorative processes of 'make-use-return'. Bocken et al. (2016, p. 309) described CE as "design and business model strategies of slowing, closing, and narrowing resource loops". Geissdoerfer et al. (2017, p. 759) built on this definition to define CE as "a regenerative system in which resource input and waste, emission, and energy leakage are minimised by slowing, closing, and

[1] In the EU's Circular Economy Action Plan 2020

narrowing material and energy loops”. In 2015, the European Union introduced the first EU’s Circular Economy Action Plan, p.2 to promote a more competitive, greener and efficient Europe: “The transition to a more circular economy, where the value of products, materials and resources is maintained in the economy for as long as possible, and the generation of waste minimised, is an essential contribution to the EU's efforts to develop a sustainable, low carbon, resource efficient and competitive economy. Such transition is the opportunity to transform our economy and generate new and sustainable competitive advantages for Europe.” The efforts to transform economies into circularity have been expanded globally. In March 2020, European Commission established a Global Alliance on Circular Economy and Resource Efficiency, including many countries such as Norway, Germany, China, the United States, Canada, Nigeria, South Korea, Peru, and Kenya to promote stronger international CE partnerships.

### 2.1.2 A comparison between sustainability and CE

Scholars have questioned the similarities and differences between the ‘sustainability’ concept and the ‘CE’ concept. CE and sustainability have certain resemblances but also distinct differences (see Table 3). CE partially reflects the sustainability concept, as both have similar goals to advance sustainable environmental and social development beyond economic benefits. Both concepts adopt interdisciplinary, multidimensional approaches and view innovations and system designs as critical enablers to reaching the goals (Geissdoerfer *et al.*, 2017). Likewise, the roles of the private sector and stakeholder collaboration are considered central to enabling sustainable systems (Geissdoerfer *et al.*, 2017).

Besides similarities, distinctions between the two concepts exist. On the one hand, the main goal of sustainability is to integrate and balance the triple-bottom lines of the three performances: people (i.e., as social performance), profit (i.e., as economic performance), and planet (i.e., as environmental performance). “Instead of merely setting common goals, sustainability opens up the scope for multiple expectations about, for example, what should be developed and what is to be sustained, for how long, and for the benefit of whom” (Geissdoerfer *et al.*, 2017, p. 759). Sustainability seemingly aims for open, longer-term goals that integrate multiple aspects and expectations and seem “vague to be implementable” (Kirchherr *et al.*, 2017, p. 127) without specific targets. In contrast, CE provides more specific strategies (i.e., reduce, reuse, recycle) and business model frameworks.

On the other hand, the concept of CE originated from ecological economics with its environmental concerns, such as natural resource preservation and reduction of waste and emissions. In 1976, based on industrial economics, Stahel and Reday (1976) introduced a concept of a ‘closed-loop economy’ shifted from the traditional open-ended economic system in order to increase resource efficiency, reduce waste output, create jobs, and dematerialize the economy. From an economic perspective supported by Andersen in his later work (2007), the residuals discharged to the environment do not only cause harm to the amenity values and life support functions but also to the economic system. To some degree, the CE concept is related to several other concepts, such as ecological economics (Ayres, 1999; Jelinski *et al.*, 1992), cleaner production (Ghisellini *et al.*, 2016), sharing economy (Stahel, 1982; Henry *et al.*, 2021), regenerative design (Lyle, 1996), cradle-to-cradle (McDonough and Braungart, 2010; Braungart *et al.*, 2007), industrial symbiosis (Chertow and Ehrenfeld, 2012; Chertow, 2007), product-service system model (Tukker, 2004), and performance economy (Stahel, 2010). Since 2013, the concept of CE has gained traction when the Ellen MacArthur Foundation (2015, p. 7) promoted the CE as “an industrial system that is restorative or regenerative by intention and design”. In the EU’s Circular Economy Action Plan 2020, the European Commission has placed CE as an essential strategy to make Europe more competitive, greener, and sustainable. Environmental improvement and economic advantages are the primary goals of the CE (Lieder and Rashid, 2016), while social benefits are often the implicit results of economic and environmental improvements. These benefits may explain why CE appear more attractive to firms, as firms may gain cost savings and profitability while improving environmental performances. The divergence in CE and sustainability calls for further knowledge about CE to increase CE impacts at the firm level.

**Table 3:** Comparisons between the sustainability and circular economy concepts.

| | **Sustainability** | **Circular economy** |
|---|---|---|
| **Similarities** | • Benefit society and the environment beyond economic growth<br>• Interdisciplinary, interdimensional approaches<br>• Cooperation of multiple stakeholders<br>• Innovation and system design<br>• The central role of the private sectors | |
| **Dissimilarities** | • An older concept<br>• A broader concept depended on contexts<br>• Open-ended, multiple goals<br>• Balance equally the triple-bottom lines (economic, environmental, social performance)<br>• Benefits the society, environment, and economy at large | • First introduced in the 1970s and has gained traction since 2015<br>• A more specific concept<br>• More specific goals (i.e., closed-loop, reduce resource consumption and waste)<br>• More focused on environmental performances (e.g., reduce new extraction, prevent biodiversity loss, minimize environmental pollution). Resource efficiency, cost reduction, profits and social benefits are achieved through environmental improvements.<br>• Specific frameworks (i.e., the Rs)<br>• Incentivize the economic actors (e.g., firms) that implement the system. |

*Source: adapted from Geissdoerfer et al. (2017)*

### 2.1.3 CE strategies and principles

This section discusses the main CE principles and strategies frequently included in CE studies. CE is ascribed to two cycles (i.e., the biological and technical cycles). CE is most known for its three 'R strategies' as 'reduce', 'reuse', and 'recycle' (Kirchherr *et al.*, 2017). In the EU's action plan 2020, the European Union added 'recover' in the 4R framework (Kirchherr *et al.*, 2017). Some studies extend to the 6R or 9R framework adding 'repair', 'remanufacture', 'refurnish', 'refuse', 'rethink', and 'repurpose' (Morseletto, 2020). CE strategies can be categorized into three main principles 'narrowing the loop', 'slowing the loop', and 'closing the loop'. To some extent, 'narrowing the loop' which adopts the 'reduce' strategy is related to the resource efficiency of the linear system, as both terms indicate using fewer resources and material inputs to relieve the pressure of recurrent resource extraction on the ecological systems. Slowing the loop involves the 'repair', 'reuse', and 'extend the product lifecycle' to keep products and materials longer in the loop. Finally, 'closing the loop' through the 'recycle' and 'recover' strategies aim to restore values of post-use products or materials and create a circular loop (Bocken *et al.*, 2016).

### 2.1.4 CE on the multiple levels

This section describes the CE on multiple levels: micro-level (i.e., within firms), meso-level (i.e., between firms with other firms, organizations in networks), and macro-level (i.e., regions, countries). At the macro level (i.e., the city, region, and country level), CE integrates four systems: the industrial system, the infrastructure system, the cultural framework, and the social system (Ghisellini *et al.*, 2016). A common concept of CE at this level is eco-cities or collaborative consumption.

At the meso-level, CE involves by-product exchange and collaborative production processes between actors in the same system and industrial parks. CE activities at the meso-level are closely linked to industrial symbiosis which refers to "engaging traditionally separate industries in a collective approach to competitive advantage involving the physical exchange of materials, energy, water, and by-products. The keys to industrial symbiosis are the collaboration and synergistic possibilities offered by geographic proximity" (Chertow, 2000, p. 313). In an industrial symbiosis system, after being processed and regenerated, residuals of one firm or industry can become material or energy inputs for another firm or industry.

At the micro-level, the CE can improve a firm's production and logistic processes for cleaner production, resource efficiency, and eco-design (Ghisellini *et al.*, 2016) to reduce material and energy input and waste output per product unit (De Jesus and Mendonça, 2018). As economic actors, firms play a pivotal role in shifting the sociotechnical paradigm toward the CE (Geissdoerfer *et al.*, 2017). The adoption of CE strategies is distinguishable between large incumbents, SMEs and start-ups. These variations of CE strategies require more research efforts to distinguish CE frameworks in heterogeneous firm sizes and characteristics. My PhD thesis is focused at the micro level to examine CE-related innovations introduced by firms, especially by new ventures.

### 2.1.5 Circular business models

Circular business models are viewed as the core of the CE (Lieder and Rashid, 2016). Firms adopt CE strategies into their existing business models or design new circular business models. A circular business model is defined as "business models that are cycling, extending, intensifying, and/or dematerialising material and energy loops to reduce the resource inputs into and the waste and emission leakage out of an organisational system. This comprises recycling measures (cycling), use phase extensions (extending), a more intense use phase (intensifying), and the substitution of products by service and software solutions (dematerialising)" (Geissdoerfer *et al.*, 2017, p. 759). One circular business model can adopt several CE strategies, and firms can adopt one or several circular business models simultaneously. The circular business model framework commonly used for CE studies is the ReSOLVE framework proposed by the Ellen MacArthur Foundation (2015). This framework suggests six models: Regenerate, Sharing, Optimize, Loop, Virtual, and Exchange (see detailed explanations in Table 4). The adoption of circular business models depends on several influential factors, such as existing business models, product nature, competencies, resource availability and other external factors (Guldmann and Huulgaard, 2020). Table 4 summarises the three CE principles, four CE strategies, and the ReSOLVE models.

**Table 4:** Summary of the CE strategies, CE principles, and the ReSOLVE model framework.

| **Categories** | **Type** | **Description** |
|---|---|---|
| CE principles | Narrowing the loop | Narrowing the loop by using fewer resources and energy, making the production process cleaner, and increasing resource efficiency |
| | Slowing the loop | Slowing the loop by extending product lifetime by reusing products or increasing product quality and duration to maintain the products and materials longer in the loop. |
| | Closing the loop | Closing the loop by reusing materials and waste, or recycling materials and products |
| CE strategies | Reuse | Reuse second-hand products |
| | Recycle | Regenerate used materials or wastes for new materials or products with higher quality (upcycling) or lower quality (downcycling) |
| | Recover | Incinerate and convert non-recyclable materials into energy |
| | Reduce | Reduce resource consumption and waste emission during production and consumption processes |
| CE business models (ReSOLVE framework) | Regenerate | Shifting to renewable energy and bio/secondary materials.<br>Examples:<br>• Conversion of animal manure into biogas and fertilizer (Yazan *et al.*, 2018)<br>• Conversion of waste from almond and olive processing into technological nutrients to reduce greenhouse gas emissions, energy use and waste (Molina-Moreno *et al.*, 2016) |
| | Sharing | Sharing ownerships, products, and assets to increase product utility.<br>Example:<br>• Shared mobility (Uber, Nabobil), shared accommodation (Airbnb) and shared clothing (Nuuly) (David *et al.*, 2016; Annarelli *et al.*, 2016) |
| | Optimize | Increasing production performance and resource efficiency to reduce resource use and waste emissions.<br>Example:<br>• Reduction of unnecessary energy and materials spent by using cyber-physical systems data that can predict and correct operational failures (Nascimento *et al.*, 2019) |
| | Loop | Reusing and recycling organic and technical materials, extending product lifetime.<br>Example:<br>• Closing the loop through the actions of repair and reuse at the end-stage of products such as refrigerators and washing machines (Lieder *et al.*, 2017)<br>• Extending the product lifespan by predictive maintenance and material tracking, thanks to radio frequency identification and the Internet of Things technology (Bressanelli *et al.*, 2018) |
| | Virtualize | Dematerializing and virtualizing products and services<br>Example:<br>• Virtualized models used as the stimulation for the reserve logistics (Dev *et al.*, 2020) |
| | Exchange | Shifting the entire production and consumption paradigm (e.g., real-demand-based production replaces mass production).<br>Example: |

| | | |
|---|---|---|
| | | • Shifting to a new production and consumption paradigm to generate less waste by enabling customized production, increasing the use of dismantled composting and recycling products. 3D Printing or additive manufacturing makes it possible to print functional components while generating minimal prototype waste. (Nascimento *et al.*, 2019). |

*Source: Adapted from Morseletto (2020), Geissdoerfer et al. (2020), Bocken and Ritala (2021)*

Circular business models, CE principles, and CE strategies are interconnected and influential on each other. I have developed a figure to synthesise the complex links between the CE principles, CE strategies, and circular business models (see Figure 1). The elements of CE principles, CE strategies and circular business models can overlap, meaning that one CE principle or CE strategy can be achieved by several types of circular business models. For example, 'narrowing the loop' linked closely to the 'reduce' strategy can be performed by the 'optimize', 'virtual', and 'exchange' models. More specifically, resource consumption and waste emission can be reduced when a company improves its production (i.e., optimize model), when consumers use virtual products such as digital books instead of physical products (i.e., virtual model), or when a new radical business model changes the entire production-consumption paradigm (i.e., exchange model).

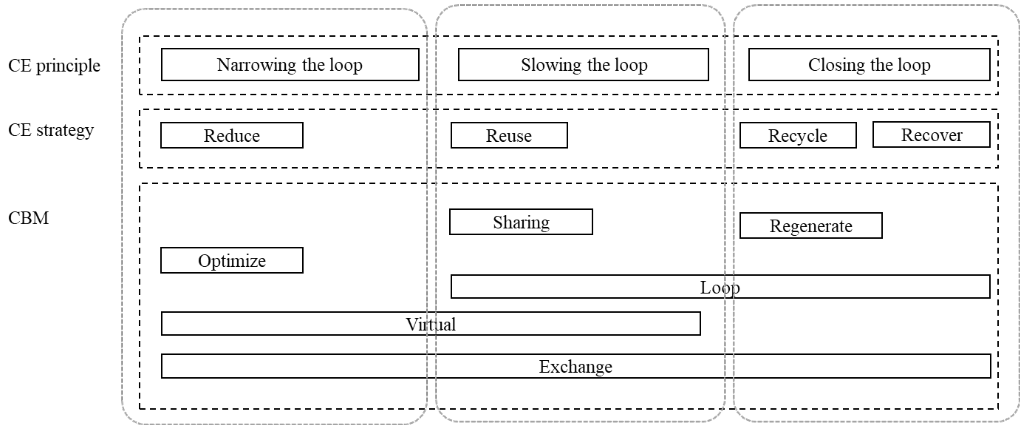


**Figure 1:** CE principles, CE strategies, and circular business models

## 2.2 Innovation in the circular economy

The CE transition as a sociotechnical paradigm shift necessitates innovation as a critical driver. This section discusses the role of innovation in economic and sustainable development, the concepts of eco-innovation and CE-related innovations, and digital innovations in the CE.

### 2.2.1 The role of innovation in the economic and sustainable development

Schumpeter (1942, p. 83) conceptualized innovation as "the process of industrial mutation, that incessantly revolutionizes the economic structure from within, incessantly destroying the old one, and creating a new one." Schumpeter highlighted the role of innovation as a catalyst for economic dynamics and firm innovativeness to maintain competitive advantages. Path dependency theory suggests that a lock-in situation and path dependency may weaken an organization's ability to respond to market competition and fluctuation over time (Boschma and Frenken, 2018). Innovation help firms avoid this situation by enabling technological trajectory changes, generating new market opportunities, and promoting economic growth. The positive effect of innovation on firm economics is demonstrated in the Cobb-Douglas production model: $Q = A*K^{\alpha}*L^{\beta}$, where A is the innovation/technological input; K and L are capital and labour inputs, respectively. The output performance is multiplied by technological input (A), which is a critical factor for production productivity and cost reduction. This economic model outlines the significance of innovation and technology on productivity and economic performance.

However, more importantly, innovation contributes to not only economic growth but also sustainability. "The challenge for innovation no longer rests solely in economic potential, but also the societal changes induced by innovative activity and the consequences of this for environmental and social sustainability" (Smith *et al.*, 2010, p. 437). The benefits of innovation on environmental challenges can be traced back to the early 1990s in the Handbook of Industrial Innovation, Chapter 34: Environmental Issues and Innovation by Skea (1995) (De Jesus and Mendonça, 2018). Over the past few years, innovation has become increasingly important for sustainable development under high industrialisation pressures. Deteriorating environmental and societal conditions such as resource degradation, biodiversity loss, and environmental contamination have triggered serious concerns about ecological modernisation on "how innovation can redirect production towards environmental goals, and decouple economic growth from environmental degradation" (Smith *et al.*, 2010, p. 436). In sustainability transitions, innovation is believed necessary to make cleaner production, minimize the risks of harmful substances and materials, shift to renewable and sustainable materials and energy, and reduce pollution and waste emission (de Jesus *et al.*, 2018; Carrillo-Hermosilla *et al.*, 2010; Seebode *et al.*, 2012).

### 2.2.2 Eco-innovation and CE-related innovation

"Transition is an inherently innovation-intensive process of reconfiguration and adaptation" (De Jesus and Mendonça, 2018, p. 76). CE transitions require innovation as a crucial enabler to facilitate technological shifting to circularity and align users and providers toward new societal paradigms (De Jesus *et al.*, 2019). Despite its vital role, the nascent research on CE innovation still lacks a clear, solid concept of CE innovation. Due to this absent concept, CE scholars tend to borrow the concepts of 'eco-innovation' or 'sustainable innovation' when examining and measuring CE innovations.

Sustainable innovation is defined as innovation that aims to improve sustainable performances, including ecological, economic, and social values (Carrillo-Hermosilla *et al.*, 2010; Boons *et al.*, 2013). Eco-innovation is "innovation with ecological and social concerns and effects" (De Jesus and Mendonça, 2018, p. 76). Compared to eco-innovation, sustainable innovation seems to be a broader concept that goes beyond eco-innovation, is closely linked to holistic and long-term sustainability, and includes all environmental, social, and economic objectives (Boons, Montalvo, Quist, & Wagner, 2013). By contrast, the focus of eco-innovation is ecological performance. Both concepts may relate to CE innovation to some extent. For example, eco-innovation and CE innovation have similar goals to improve environmental performances (e.g., mitigating waste issues, reducing pollution, and using natural resources responsibly). Sustainable innovation and CE innovation can also be partly related; for example, by improving environmental issues, CE innovation can directly or indirectly create economic and social values. However, because the concepts of sustainability or ecological economics are distinctive from the CE concept, neither sustainable innovation nor eco-innovation can mirror the circularity principles of CE innovation. Using these two concepts to indicate CE innovation may lead to unconsolidated and fallible measurements of CE innovation. Therefore, it requires a more explicit and solid definition of CE innovation in which CE principles are fully embedded.

At the current stage, research on innovation for the CE is primarily centred on aspects such as business model innovation, multilevel approach and collaboration for CE innovation, influential factors of eco-innovation in the CE, firm capabilities and dynamics, technologies and waste management, bio-CE innovation, and cluster's competitiveness (Suchek *et al.*, 2021). A large body of research on CE innovation seemed to favour circular business model innovations, whereas the role of technological innovation gains less attention. Moreover, prior studies showed heterogeneities of CE strategies and CE innovations among large, small & medium firms and entrepreneurial firms (Henry *et al.*, 2020). Nevertheless, there have been few empirical investigations into CE innovations among entrepreneurial firms. The review of Suchek *et al.* (2021) calls for more research on CE-related startups to expand the understanding of how these firms capture and deliver the values of CE innovations.

### 2.2.3 Digital innovations for the CE

Recent research on digital innovation for the CE has gained substantial academic attention. Digital innovation is considered an emergent facilitator for a number of circular business models such as servitization, product-service systems (PSS), and optimisation models (Tukker, 2004; Chauhan *et al.*, 2022; de Sousa Jabbour *et al.*, 2018; Ranta *et al.*, 2021; Bressanelli *et al.*, 2018). Digital innovation is defined as "product or business process innovations that contain ICT, as well as innovations that rely to a significant degree on information and communication technologies (ICTs) for their development or implementation" (OECD, 2019, p. 38). Digital innovation is built on diverse digital technologies such as big data, the Internet of Things, blockchain, automation, artificial intelligence, and 3D printing. The unique attributes (e.g., more open, reprogrammable, and less predefined) of digital technologies have substantially changed the processes and outcomes of innovation and entrepreneurship (Nambisan, 2017) and determine how firms may adopt circular business models (Chauhan *et al.*, 2022). The digitalization and CE transition phenomena are jointly and rapidly occurring in many low-tech and high-tech sectors.

Digital technologies contribute to narrowing, slowing, and closing the loop by, for example, optimizing the material flows and enabling reverse material flows (Pagoropoulos *et al.*, 2017), integrating value chains through data collection and sharing (de Sousa Jabbour *et al.*, 2018), and improving traceability of product activities (Upadhyay *et al.*, 2021). Moreover, digital technologies can also improve information about product location, condition, and availability and offer higher possibilities for predictive maintenance (Liu *et al.*, 2022). Table 5 provides an overview of the core digital technologies having been implemented in the CE.

Despite innovation's significant roles, most present studies about digital innovations for the CE are either conceptual or literature reviews, but few empirical studies show the mechanism and impacts of digital innovations for the CE (Chauhan et al., 2022). Furthermore, digital applications on circular business models are highly firm-heterogeneous and contextual-dependant. No 'one-size-fits-all' digital circular business model can fit all firm types and sectors. In this respect, Suchek *et al.* (2021) observed that the literature needs more empirical research on the applications of digital innovations in various sectoral and firm contexts.

**Table 5:** Brief descriptions of digital technologies used in the circular economy

| **Types of digital technologies** | **Brief descriptions** |
|---|---|
| Cyber-physical systems | The interaction of physical objects, cyberspaces and data enables autonomous operation, monitoring, and control of processes and objects in real-time (Ahmadov and Helo, 2018; de Sousa Jabbour *et al.*, 2018) |
| Big data | The storage to store and analyse a high variety, volume, and velocity of data (Rajput and Singh, 2019) |
| Internet of things | The connectivity of physical objects facilitated by the Internet, sensors, barcodes, and radio-frequency identification technology (de Sousa Jabbour *et al.*, 2018) |
| 3D printing/ additive manufacturing | The layer-by-layer printing of physical objects directly from 3D models to shorten production lead-time and enables customization (Beltagui *et al.*, 2020; de Sousa Jabbour *et al.*, 2018) |
| Blockchain | Distributed digital ledgers that record and digitally encrypt transactions as immutable, stamped chains to enable transparent traceability (Kouhizadeh *et al.*, 2020; Rajput and Singh, 2019) |
| Digital platform | The digital interface hosting activities and interactions of multiple users via the Internet (OECD, 2019) |

## 2.3 The empirical contexts

This section illuminates the contexts in my thesis. Paper 1, Paper 2, and Paper 3 are developed in the settings of academic spin-off firms and Paper 4 of the fashion industry. With their innovative capability, ASOs hold a high potential for CE impacts. However, only a few studies have examined ASOs in the CE (Henry *et al.*, 2020; De Angelis and Feola, 2020). In addition, the fashion industry is also selected as a context for my paper. This industry, one of the world's most polluting industries, is an excellent example to examine and demonstrate how digital innovation can help enable fashion circular business models and contribute to the CE. Sections 2.3.1 and 2.3.2 further explain the relevance of ASOs and the fashion industry to my study.

### 2.3.1 Academic spin-offs

Academic spin-offs (ASOs) are science-based new ventures originating from academic organizations (i.e., universities or research institutes) to commercialize advanced technologies and scientific knowledge (Colombo and Piva, 2012). The founders of ASOs are often the academics such as professors, PhD students, and scientists at their host academic institutions (e.g., universities or research institutes). With high innovativeness, ASOs are more likely to perform and survive better than other traditional start-ups (Mathisen and Rasmussen, 2019). Through their technology transfer and commercialization, ASOs can generate not only economic values but also sustainability values. The initiatives of ASOs possibly drive technological changes, embed circularity into production-consumption systems, and reinforce collaborations in the innovation ecosystem (Henry *et al.*, 2020).

Concerning CE, earlier research showed that start-ups are more likely to introduce radical innovation and technological advances than incumbent firms (Kennedy *et al.*, 2017; Schaltegger *et al.*, 2016; Hockerts and Wüstenhagen, 2010). Moreover, entrepreneurial firms often adopt radical CE strategies and design holistic new business models. By contrast, incumbent firms are more inclined to marginal CE strategies (e.g., recycling and reduce) or improve existing business models gradually (Bocken *et al.*, 2017; Henry *et al.*, 2020). The roles of entrepreneurial firms and ASOs are essential for the CE transition in which shifting in technological trajectories and consumer behaviours may be required (Henry *et al.*, 2020). However, most CE taxonomies and investigations are built on well-established and large firms due to their stronger influence on their markets (Henry *et al.*, 2020), while much less is known about start-ups and academic spin-offs concerning CE impacts (Suchek *et al.*, 2022; Henry *et al.*, 2020). Moreover, Zahra (2021, p. 1843) emphasized that "while acknowledging the heterogeneity of entrepreneurs and resources, prior studies often overlook the heterogeneity of entrepreneurial firms themselves". CE-related ASOs may be distinguished from each other in terms of types of technologies, innovations, and CE strategies. Therefore, a further understanding of how ASOs innovate to contribute to the CE should be added. My research papers provide more theoretical insights in this regard.

### 2.3.2 The fashion industry

The fashion industry is widely known for its environmental pollution. In the EU's Circular Economy Action Plan 2020, European Commission places the fashion industry as a high-impact sector that urgently needs a CE shift. The linear fast fashion model consumes a large amount of hazardous chemical, fertiliser and non-renewable energy (i.e., oil). Despite the polluting production process, garment products have been used irresponsibly with low utility and frequency. The number of garments using times has decreased significantly by 36% compared to 15 years ago due to the growing fast fashion trend in consumer behaviours (Ellen MacArthur Foundation, 2017). According to Statistics Norway, in 2018, each Norwegian discarded an average of 23 kilos of garment annually, and at the same time, Norwegian fashion retailers shipped 277-ton kilos of unsold inventories out of the country. Up to 60% of garment materials contained plastic (UNEP, 2019), and 85% of all textiles were thrown away yearly (UCENE, 2018). The polluting process of fashion production accounted for 1.2 billion tonnes of $CO_2$ in 2015 globally, 10% of carbon emissions in 2018 and is projected to reach 26% of carbon emissions by 2050 (Ellen MacArthur Foundation, 2017). Approximately 500,000 tonnes of microfiber, equivalent to 50 billion plastic bottles, are released into the ocean during the washing process of fashion production (Ellen MacArthur Foundation, 2017). Because of low sorting and lack of recycling technology, less than 1% of garments are recycled into new clothing. Additionally, the recycling process contaminates and pollutes the ecological system with many harmful chemicals used to decolourise and deodorise garments.

This accelerating pace of fast fashion can significantly destroy the entire ecological system in the foreseeable future. The issues are rooted in the fact that consumers prefer buying fast, cheap garments and using them only a few times before throwing them away. Moreover, the current linear mass-production model of fast fashion is based on a six to nine-month market forecast with high risks of unexpected events or changing consumer preferences. Garment wastes from households and retailers altogether have continued worsening waste problems. While fashion companies and authorities are still struggling to handle garment waste, new cycles of polluting production repeat incessantly. The EU's Circular Economy Action Plan 2020 strongly outlined that the fashion industry needs to be transformed into the CE by empowering sustainable fashion businesses and consumption, incentivizing circular business models (e.g., products as services, circular production, and supply chain), and enhancing sorting and recycling processes. Digitalization appears critical to achieving a circular fashion, as emerging digital technologies such as blockchain, 3D printing, and the Internet of Things might make a circular fashion possible by altering the whole paradigm of garment production and consumption (Luoma *et al.*, 2022; Piller, 2022).

## 2.4 The research gaps and conceptual framework

The previous literature review section revealed several theoretical and empirical gaps. Section 2.4 sums up these research gaps and develops a conceptual framework for this study. As depicted in Figure 2, the four research papers address three main issues: (1) the role of innovations in the CE, (2) the mechanism of digital innovations in enabling circular business models, and (3) the actors that commercialize the CE innovations.

Paper 1 is conducted to fill the gap of lacking a solid definition and systematic measurements of circular economy innovation by CE and innovation attributes. Due to this missing concept, no prior study has constructed an empirical taxonomy of ASOs based on their CE innovations. Paper 1 is focused on two research topics: the role of CE innovations and the actors that commercialize the CE innovations (i.e., CE-related ASOs). Paper 2 identified that the literature still lacks an understanding of how science-based ASOs may commercialize digital innovations to create CE impacts. Therefore, this paper focuses on the role of CE innovations and the actors in the CE. (i.e., digital CE-related ASOs).

Paper 3 addresses the literature void on which resource configurations may lead to the success of digital ASOs. The integration of resource-based perspectives and digital academic entrepreneurship remains absent in the research. Thus, Paper 3 is focused on the actors (i.e., digital ASOs). Finally, Paper 4 recognized limited knowledge of how digital technologies can be adopted into circular business models, given the heterogeneities of digital applications and CE practices concerning firm types and sectors. This paper addresses this gap by exploring the mechanism of digital innovations in circular business models and the role of the actors commercializing CE innovations (i.e., fashion firms with various firm sizes).

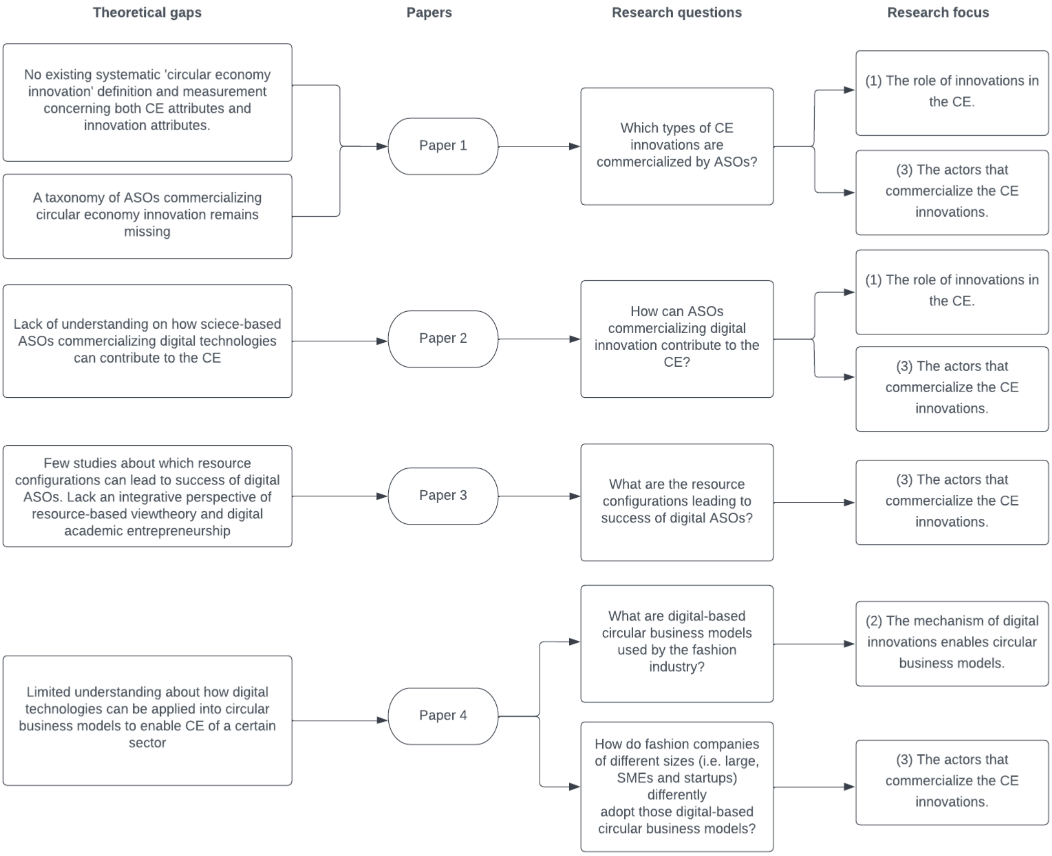


**Figure 2:** Research gaps, research papers, and research questions

The research gaps in the preceding section give reasons for my conceptual framework (see Figure 3). Overall, my study incorporates three main components: innovation with a focus on digital innovation, circular economy, and actors carrying out CE innovations. Paper 1 has a broader focus on different innovation types to provide an overview of CE innovations and CE-related ASO clusters. Paper 2 focuses more specifically on particular digital innovations and how these digital ASOs contribute to the CE. Paper 3 explores the success recipes of digital ASOs by integrating the resource-based view theory. These papers use the same dataset and have the same firm context. Finally, Paper 4 has a slightly different angle and context but maintains its focus on digital innovations and the circular economy. This paper is based on the fashion industry data.

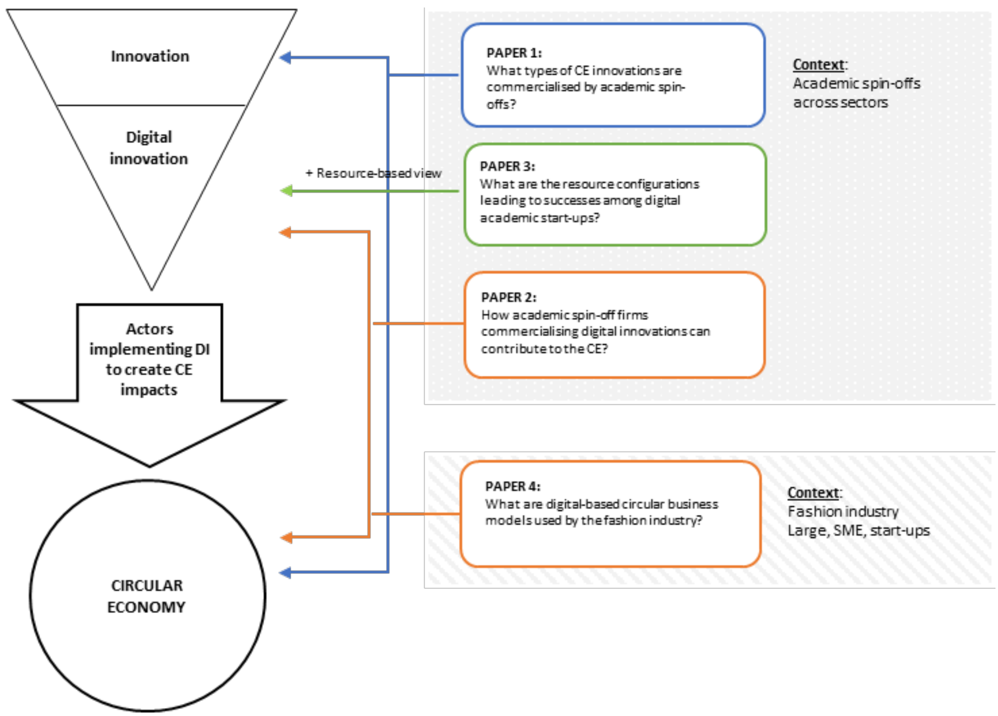


**Figure 3:** Conceptual framework of the dissertation

# 3 METHODOLOGY

This chapter describes the philosophical standpoints guiding my research, then introduces my methodological choices, and finally discusses several ethical considerations of my thesis[2].

## 3.1 Philosophical standpoints

Ontology as a metaphysical concept relates to the nature of reality on which entities exist and relate to each other. Ontology "raises basic questions about the nature of reality and the nature of the human being in the world" (Denzin and Lincoln, 2011, p. 183). Ontology matters whether reality exists independently or within the human mind (Crotty, 1998) and is often presented in realism and relativism (Levers, 2013). Realism considers that reality exists independently from the human mind regardless of human experiences or consciousness and that the world of reality cannot be accessed as an entirety but only partial fragments (Levers, 2013). In realism ontology, science seeks to identify phenomena and develop agreements about the entirety or partial agreements. Also, the truth can be obtained through reasoning rather than pure observations (Levers, 2013). By contrast, relativism argues that reality is constructed subjectively by the human mind and cannot be separated from experiences (Denzin and Lincoln, 2011). In relativism ontology, the interpretations of multiple experiences shape realities in multiple forms, and science is meant to explain subjective experiences of multiple realities (Denzin and Lincoln, 2011; Lincoln *et al.*, 2011).

Another important philosophical concept is epistemology, defined as "a way of understanding and explaining how I know what I know" (Crotty, 1998, p. 3) (i.e., how reality will be known and how knowledge about reality is created ). Epistemology is often presented in two opposing stances: objectivism and subjectivism (Levers, 2013).

[2] Some of the text in Sections 3.1, 3.2, and 3.3 is based on my term paper for the 'philosophy of sciences' PhD course, University of Stavanger, 2022.

Objectivism epistemology argues that the truth of an object is derived within itself and independently of human subjectivity and biases. In this stance, the actual understanding of an object can only be acquired by observations distant from human biases and contextual factors (Crotty, 1998). The observer and the observed are two independent entities and do not influence each other. From the objectivism epistemology standpoint, sciences aim to discover universally applicable knowledge because the truth does not change regardless of who observes and studies the object (Crotty, 1998). By contrast, subjectivism epistemology is a contrary belief that knowledge is 'value-laden' (Levers, 2013) and "always filtered through the lenses of language, gender, social class, race, and ethnicity" (Denzin and Lincoln, 2011, p. 21). Subjectivism epistemology argues that the understanding of an object is influenced by local observations and subjective perspectives, and the observer and the observed have influences on each other (Denzin and Lincoln, 2011).

A philosophical paradigm is defined as "a basic set of beliefs that guides action" (Guba, 1990, p. 17) or "general philosophical orientation about the world and the nature of research that a researcher brings to a study" (Creswell and Creswell, 2017, p. 5). Self-philosophical beliefs, research interests and purposes will determine a researcher's philosophical paradigm that provides directions for further development of research problems, research questions, and data. For example, a cause-effect question may require more different formulated hypotheses and methods than an exploratory research question which explores an emerging phenomenon (Huff, 2008). Philosophical paradigms can be distinguished with respect to distinctive ontologies, epistemologies, and methodologies.

Different philosophical paradigms have different and somewhat contrary views. Positivism and constructionism are among the most-known philosophical paradigms in the history of sciences. Classical positivism holds an extreme view of strict causality. Postpositivism arrives later with a more moderate and less extreme view in this respect. Compared to classic positivism, which argues for absolute reality and universal knowledge, post-positivism accepts that causal relationships may or may not occur under certain probabilities, and no absolute knowledge can be claimed about human behaviours and actions (Creswell and Creswell, 2017). Postpositivism believe that knowledge can be influenced by contextual factors (McEvoy and Richards, 2003) but should still be achieved by objective investigation, logical reasoning, and evidence-based (Crossan, 2003). Postpositivists often ask the 'what' questions to determine probable causalities between objects and quantify these causal relationships into numeric measures (Creswell and Creswell, 2017). They tend to adopt deductive, objective, and quantitative approaches, using numeric data and computer programs to prove existing theories (Phillips and Burbules, 2000).

Interpretivism, which seems more prevalent in sociology, has an opposing worldview to postpositivism. Interpretivists believe in multiple realities through subjective interpretations influenced by feelings, experiences, and beliefs (Denzin and Lincoln, 2011). They seek an understanding of the world they live in and tend to question 'how' or 'why' about a social phenomenon (Crotty, 1998). This philosophical paradigm is shaped by relativism ontology and subjectivism epistemology. In interpretivism, knowledge is formed by historical, temporal, cultural, and subjective contexts (Benoliel, 1996). This paradigm deals with the complexity of reality by searching for varied, multiple, and imperfect meanings rather than narrowing understanding into categories or numbers (Creswell and Creswell, 2017). Interpretivists often design research with open-ended questions to observe and listen to what participants can share based on their backgrounds, cultures and experiences and explore the interactive processes of individuals or objects (Creswell and Creswell, 2017). Table 6 provides a summary of the philosophical paradigms and their standpoints.

**Table 6:** Summary of philosophical paradigms concerning ontology, epistemology and methodology.

| | Positivism | Interpretivism | Pragmatism |
|---|---|---|---|
| **Ontology** | **Realism**<br>Universal knowledge and reality exist independently from the human mind and experiences.<br>Logical reasoning, evidence-based | **Relativism**<br>Multiple realities are constructed by subjective experiences and influenced by contexts.<br>Observing, explaining, and interpreting a reality based on subjective experiences and within contexts. | **Dualism**<br>Accept multiple realities (i.e. subjective, objective, intersubjective).<br>Rejects traditional dualisms (e.g. subjectivism vs. objectivism; facts vs. values).<br>Recognized human inner in actions; truth, meaning and knowledge are tentative and changing over time. |
| **Epistemology** | **Objectivism**<br>Knowledge is objective, value-free, and universally applicable.<br>Knowledge of an object is derived within an object and not influenced by human subjectivity and biases.<br>The observer and the object being observed do not influence each other. | **Subjectivism**<br>Knowledge is subjective, value-laden, and contextual-bounded.<br>Knowledge of an object is perceived and interpreted by observers and influenced by the observer's experiences, beliefs and feelings. The observer and the object being observed can influence each other. | **Intersubjectivity**<br>Knowledge is based on both the existing reality of the world we live in and also constructed by our experiences. |
| **Methodology** | **Mainly quantitative-oriented**<br>To identify causal relationships of the 'what' question.<br>Deductive approach.<br>Theory-testing.<br>Variance-oriented analyses.<br>Hypothesis testing, statistics, quantification, numeric. | **Mainly qualitative-oriented**<br>To explain the situation and mechanism of 'how' and 'why' questions<br>Inductive approach.<br>Theory-building.<br>Case-oriented analyses.<br>Hermeneutical, narrative, case study, grounded theory, ethnographic, history | **Mixed-methodology**<br>Endorse methodological pluralism and eclecticism in methods and perspectives to find what works and solve individual and social-level problems.<br>Deductive, inductive, and abductive approaches.<br>Variance and case-oriented.<br>Quantitative and qualitative methods. |

*Source: Adapted from Onwuegbuzie et al. (2009) and Levers (2013). The table was referred to my term paper for the Philosophy of Science course.*

## 3.2 My philosophical paradigm as a pragmatist researcher

Social sciences research is "a collaborative human activity in which social reality is studied objectively to gain a valid understanding of it" (Mouton and Marais, 1988, p.

7). The traditional view of social sciences seemingly directs objectivity of social sciences to natural sciences, whose objects such as gases, molecules, and temperature supposedly exist before sciences and are independent of human consciousness. This traditional view faces some criticisms because social sciences are more challenged to determine whether several social objects (e.g., marriage, crime, and culture) may co-exist with human interactions instead. Moreover, whether 'brute facts' (i.e., facts that exist regardless of human existence) can be obtained utterly independently of contextual factors and individual interpretations. Unlike natural phenomena, social phenomena might be partly man-made (Montuschi, 2014). For example, in my research topic, the transition of a circular economy may not exist without the problems caused by human behaviours and, subsequently, human solutions to 'fix' the system.

The second challenge of objectivity in social sciences concerns how social sciences may obtain value-free scientific knowledge, while social sciences are often considered value-laden. Montuschi (2014, p. 142) pointed out that "value-ladenness is an aspect of factual information and cannot simply be set aside". The third challenge relates to the methodological objectivity of social sciences. Montuschi (2014) emphasized the importance of mixed-methodology and phenomenal contexts to achieve methodology objectivity in social sciences. "There are no best/better methods in principle in view of achieving objective results. Methodological objectivity is often the consequence of how a method responds to the questions posed by a specific investigated context. Besides, the best answers often come from a combination of methodologies rather than expecting one single method to have all the answers or all the tools required in the circumstances. There is no 'golden rule', no 'one-size-fits-all' strategy able to offer 'the most objective' assessment and confidently guide us in making decisions on what works and what does not in real situations." (Montuschi, 2014, p. 140).

My belief rests on the assumptions that emerging social phenomena and objects may co-exist with human existence, and knowledge of social sciences cannot be purely value-free and contextual-free. The methodology should not be restricted to a single philosophical paradigm. Even though relying on the robustness and objectivity of quantitative methods, I believe that quantitative analysis's result should still be interpreted carefully in specific contexts and circumstances because today's complex and dynamic society requires interdisciplinary knowledge, manifold theoretical lenses, and understanding of the contexts (Johnson and Onwuegbuzie, 2004). Hence, social phenomena might not be fully explained by only numbers or statistics but also by local observations and interpretations. Consequently, flexible combinations in method use may be needed to discover complex social realities.

Based on these beliefs, my philosophical paradigm is led by pragmatism, which "arises out of actions, situations, and consequences rather than antecedent conditions"(Creswell and Creswell, 2017, p. 10). Pragmatism has been developed from the viewpoints of C. S. Peirce, William James, George Herbert Mead, and John Dewey (Cherryholmes, 1992) to find 'what works' and solutions for real-world problems (Johnson and Onwuegbuzie, 2004). Pragmatism underlines pluralism in philosophical beliefs and method choices and is considered a philosophical paradigm for the mixed-methodology approach (Johnson and Onwuegbuzie, 2004). This paradigm reflects that quantitative and qualitative methods are compatible and complementary (Mitchell and Education, 2018).

Pragmatists do not perceive reality as an absolute entity but rather as "what is useful, practical and works" (Creswell & Poth, 2017). They tend to consider multiple alternatives for collecting and analysing data rather than committing to one method or philosophical system. Pragmatists are open to different worldviews, assumptions, forms of data and analysis (Creswell and Creswell, 2017; Cherryholmes, 1992; Rossman and Wilson, 1985). Hence, they focus on research problems and consider all approach possibilities to understand and address social issues (Rossman and Wilson, 1985). The research approach of pragmatists can be both inductive and deductive, as well as objective and subjective evidence, and use a mixed methodology with all possibilities of quantitative and qualitative techniques and data (Luck *et al.*, 2006; Onwuegbuzie *et* *al.*, 2009). Johnson and Onwuegbuzie (2004, p. 18) have outlined several core attributes of pragmatism:

- Pragmatism rejects traditional philosophical dualism (e.g., subjectivism vs objectivism, facts vs values, realism vs relativism) and prefers more moderate and common-sense philosophical standpoints to find what works and solutions.
- Recognize the importance of the natural world but also acknowledge the emergent psychological and social world, which involve human co-existence and subjective values. Recognize the importance of the human inner world in human actions and tentative, changing knowledge over time.
- Believe that knowledge is constructed and based on the reality of the world we experience.
- Accept fallibilism in knowledge instead of perfect, absolute, certain knowledge.
- Believe in eclecticism and pluralism (e.g., accepting different and conflicting methods and philosophical standpoints).
- Endorse practical theory (i.e., a theory that informs practices)

My philosophy of science reflects a pragmatist's philosophical standpoint. My research question is to explore not only 'what' are the relationships between digital innovation and the CE but also the process of 'how' digital innovation should be integrated into circular business models. The occurrence and development of the CE and digital transformation are complex, contextual-dependent, and might not be understood in a narrow view of one philosophical paradigm or method. Therefore, multiple worldviews, forms of data, or methods may better address my research problems. Both quantitative and qualitative methods are essential to exploring the relationship between digital innovation and circular economy and how these two elements impact each other. The previous table 6 shows the ontology, epistemology, and methodology of pragmatism.

## 3.3 Research approach: Mixed-methodology

Based on my philosophical worldview and research purposes, I employed a mixed-methodology approach combining qualitative and quantitative methods. Pragmatism is viewed as a philosophical paradigm of the mixed-methodology approach (Johnson and Onwuegbuzie, 2004). Johnson *et al.* (2007, p. 125) explained that "many (or most) mixed methods writers have argued for some version of pragmatism as the most useful philosophy to support mixed methods research. We agree that pragmatism is a well-developed and attractive philosophy for integrating perspectives and approaches. Pragmatism offers an epistemological justification (i.e., via pragmatic epistemic values or standards) and logic (i.e., use the combination of methods and ideas that helps one best frame, address, and provide tentative answers to one's research question[s]) for mixing approaches and methods."

Mixed methods research is defined as "an intellectual and practical synthesis based on qualitative and quantitative research; it is the third methodological or research paradigm (along with qualitative and quantitative research). Mixed research is the research paradigm that (a) partners with the philosophy of pragmatism in one of its forms (left, right, middle); (b) follows the logic of mixed methods research (including the logic of fundamental principle and any other useful logics imported from qualitative or quantitative research that are helpful for producing defensible and useable research findings); (c) relies on qualitative and quantitative viewpoints, data collection, analysis, and inference techniques combined according to the logic of mixed methods research to address one's research question(s); and (d) is cognizant, appreciative, and inclusive of local and broader socio-political realities, resources, and needs" (Johnson *et al.*, 2007, p. 129).

The mixed-methodology approach has been developed to compromise quantitative and qualitative limitations. Quantitative methods can find the relationships between variables but can barely explain how and why these relationships may exist. By contrast, qualitative methods can observe and find emerging patterns of a phenomenon but can barely be certain to which extent these generalized patterns are the truth. In this regard, Sieber (1973) illustrated the advantages of combining quantitative and qualitative approaches in research design, data collection, and data analysis. For instance, in research design, quantitative data can help identify representative cases and samples for qualitative methods, and qualitative data can complement quantitative components with conceptual frameworks or instrumental development. In data analysis, quantitative data can assist in validating generalizations of qualitative data, while qualitative analysis can help interpret, clarify, and explain quantitative research results (Sieber, 1973; Johnson *et al.*, 2007). For that reason, the mixed-methodology approach is essential in combining various data types and methods to serve different research purposes.

In my thesis, the mixed-methodology approach is used to solve my research problems requiring complex data and method combinations. The quantified data and quantitative methods were used in Paper 1 to build a taxonomy of CE ASOs and characterize types of CE innovations. After that, qualitative methods were used in Paper 2, Paper 3, and Paper 4 to further understand digital innovations and digital CE ASOs. Qualitative methods are more inclined to inductive, exploratory, and theory-building attributes, while quantitative methods are more likely to have deductive, explanatory, and theory-testing attributes. However, several quantitative methods (e.g., correspondence analysis, factor analysis, or clustering analysis) can have inductive, exploratory, and theory-building natures. Also, several qualitative techniques (e.g., qualitative comparative analysis and case studies) can have deductive, explanatory, and theory-testing natures. Even though using both quantitative and qualitative methods, my thesis is inclined to theory-building and inductive rather than theory-testing and deductive due to research purposes, data, and theory availability. Both CE and digital innovation are emerging phenomena with limited theory and empirical evidence and therefore need more theories, data, and frameworks to establish hypotheses before theory validation. Thus, an inductive, exploratory mixed-methodology approach is suitable for my research to contribute more theoretical insights into the CE innovation literature.

## 3.4 Data

This section describes the datasets in my thesis, including FORNY data (Paper 1, Paper 2, and Paper 3) and the fashion industry data (Paper 4). Moreover, this section explains the coding processes (see Table 10).

### 3.4.1 The FORNY data

My first dataset is based on a research project compiling a longitudinal dataset of Norwegian ASOs. This dataset contains data about ASOs reported to the FORNY-program operated by the Research Council of Norway as a governmental policy to research and stimulate the commercialization of scientific research (Mathisen, 2017; Fini *et al.*, 2017). The unit of analysis in this database is the Norwegian ASOs. Two-thirds of the ASOs were established by universities (e.g., NTNU, University of Oslo, University of Stavanger, University of Bergen) and one-third by research institutes (e.g., IRIS, and SINTEF) (Mathisen and Rasmussen, 2022). The FORNY-program was operated during 1995-2012 and renewed until 2019 as 'FORNY2020' (Mathisen, 2017). In FORNY, the 'commercialization of science' is referred to when the licensing agreements of new industries or new ventures are established (Mathisen, 2017). The FORNY dataset consists of 373 ASOs founded from 1999 to 2011, and their business activities were tracked until 2019. This longitudinal database includes intensive data from various sources, including annual firm reports (i.e., firm registration, firm events, published financial statements, and corporate announcements) from the National Register of Business Enterprises in Norway, patent registration from the Norwegian Industrial Property Office, market surveys, and newspaper articles archived by A-teskt/Retriever and internet search engines.

The ASOs belong to diverse sectors such as oil& gas, aquaculture, energy, environment, and pharmaceutical. Previous research outlined the importance of distinguishing ASOs by their technologies (Mathisen, 2017). Thus, the ASOs are reported with various technology types, such as digital, biochemical, environmental, nanotechnology, material, biomedicine, or maritime technology. Similar to the common context of academic entrepreneurship, a majority of the ASOs in Norway are based on biomedicine and digital technology (Mathisen, 2017). The survival and growth rates of the ASOs are relatively high compared to other traditional start-ups. Statistics of the first tracking period during 1999 - 2012 showed that one-third of the ASOs survived independently after fifteen years, and only about 30% of the ASOs were expected to fail (Mathisen, 2017).

Based on 374 Norwegian ASOs, I conducted the coding processes and obtained three datasets: CE-related ASOs, digital CE-related ASOs, and digital ASOs. The CE-related ASOs dataset (for Paper 1) includes 60 ASOs commercializing CE-related innovations based on digital technology, nanotechnology, biotechnology, energy and environmental technology, material technology, and maritime technology. The biomedicine technology and pharmaceutical sectors had no CE-related ASOs. The digital CE-related ASOs dataset (for Paper 2) is a subset of the CE-related ASOs dataset, consisting of 25 firms obtained by segregating the CE-related ASOs based on digital technologies (e.g., the Internet of Things, big data, blockchain, 3D printing, sensors, automation, and digital platform). The digital ASOs dataset (for Paper 3) obtained from the entire database of 373 ASOs includes 49 digital ASOs (among them are those with CE impacts).

### 3.4.2 The fashion industry data

In addition to the ASO data, I collected another dataset in the fashion industry context. The cases were selected from the Norwegian fashion industry. Compared to other country's fashion industries, the Norwegian fashion industry is relatively minor in scale (i.e., turnover NOK67 billion and 42,000 workers[3], but rather rich in resources

[3] According to the Norwegian Fashion Hub organization.

and fast adopting emerging advanced technologies. Besides several large fashion incumbents, most Norwegian fashion companies are small and medium-sized. The Norwegian fashion industry was started in the 18th century and is long-known for the high-quality production of wool products, pattern knitting, and outdoor sportswear. In recent years, small and medium-sized Norwegian fashion companies have promoted “made in Norway” products and aim to re-shore parts of their value chain to Norway, so that fashion production can be less dependent on outsourcing suppliers and be more resilient over global shocks such as the COVID-19 pandemic. Given advantages in research and technology, Norway has aimed to digitalize the fashion industry and transform it into circularity. Similar to some European and other countries, the textile sector in Norway has received substantial governmental attention and is considered an impactful sector in sustainability policies.

Moreover, the Norwegian government provide considerable monetary and non-monetary supports for the fashion industry’s circular economy transitions. The Norwegian fashion industry is driven simultaneously by digital transformation and CE transition. The policymakers have highlighted that digitalization is an important strategy to achieve the Norwegian fashion industry's triple bottom line of environmental, social, and economic sustainability. Several joint research and training projects of Norway with other European countries were initiated to enhance digitalization and sustainability competencies. Given its significant context, the fashion industry in Norway should be a valuable case to examine how digital advances can be applied in fashion business models to achieve CE values.

This dataset includes 10 Norwegian fashion companies belonging to distinct fashion segments (e.g., high-end fashion, casual fashion, and sportswear) and in various sizes (e.g., large, SMEs, and start-up companies). These firms also hold several roles in the value chain (manufacturers, technology suppliers, and service providers). Most large firms in the dataset have factories abroad, while smaller firms manufacture in Norway. By selecting diverse types of fashion firms, my study can compare the similarities and differences between the firm types to differentiate their CE and digital innovation strategies in this regard.

## 3.5 Research methods

This section describes three research methods in my thesis (see the overall view in Table 7). First, by using *Multiple Correspondence Analysis (MCA) and Agglomerative Hierarchical Analysis*, Paper 1 provides a systematic, quantitative examination of the CE innovations and constructs a taxonomy of CE-related ASOs. Correspondence analysis is "a descriptive method for examining relationships among categorical variables. The general goal of correspondence analysis is to closely reproduce the similarities among the rows and the columns of the table in a space of low dimension…" (Le Roux and Rouanet, 2010, p. viii). This multivariate unsupervised method is frequently used to explore emerging patterns in the data rather than hypothesis testing. MCA is analogous to Principle Component Analysis but uses same-scaled categorical variables instead of continuous ones. Based on prior literature, I developed two sets of variables describing CE and innovation attributes. By using MCA and Clustering Analysis, I measured proximities between the variables. Then, I grouped similar variables and ASO firms along the two primary dimensions: CE attributes (as CE principles) and innovation attributes (as product versus process innovation) and classified the CE-related ASO clusters.

After exploring the ASOs and their CE innovations, empirical evidence from the data showed a predominant subset of CE-related ASOs relying heavily on digital technologies. Therefore, I used the *Multiple-Case Study* method for Paper 2 and Paper 4 to add in-depth insights on digital-based CE ASOs. The Multiple-Case Study method is recommended when a study's purpose is to examine the "how" and "why" questions and when the behaviours of research subjects cannot be controlled (Baxter & Jack, 2008; Yin, 2003). Baxter and Jack (2008) differentiated a variety of case studies: explanatory, exploratory, descriptive, intrinsic, instrumental, collective, and multiple-case studies. A case study is useful for the preliminary investigation of empirical insights prior to hypothesis testing (Stake, 2013). A Multiple-Case Study approach generates a literal replication (a similar result) or a theoretical replication (a contrasting result for a predictable reason) (Yin, 2003; Baxter and Jack, 2008). This method is relevant for Paper 2 and Paper 4, which examined and compared several empirical cases to investigate similarities or differences between digital ASOs and between fashion firms.

The *Qualitative Comparative Analysis (QCA)* method was applied in Paper 3 to examine resource configurations for the successful performance of the digital ASOs. QCA is a set-theoretic method based on Boolean algebra and counterfactual analysis to assess whether an individual factor suffices the outcome. This method also systematically recognizes all logical configurations (Rihoux and Ragin, 2008; Schneider and Wagemann, 2012). QCA combines the strengths of both variable-oriented and case-oriented nature to overcome the shortcomings of marginal effect analyses, which neglect complex reality and variable interactions (Ragin, 2014). QCA rests on the logic that factors can interact with each other and be combined in multiple ways to result in the same outcomes. This situation is termed "equifinality" that means "the persistence of a variety of design choices that can all lead to the desired outcome" (Fiss, 2011, p. 394). As a case-based method, QCA is not restricted by small and medium-sized samples and is applicable for exploratory, inductive, theory-building research (Fiss, 2011). Concerning my research, it matters not only that resources are essential to firm performance but also how resources should be effectively combined for firm success (Borch *et al.*, 1999; Chitsaz *et al.*, 2017). Thus, QCA is a suitable method to explore these interactive terms (e.g., resource configurations) leading to firm success.

**Table 7:** Summary of the four papers' methods

| Paper | Method | Approach | Data | Analysis unit |
|---|---|---|---|---|
| Paper 1:<br>Commercialising circular economy innovations: a taxonomy of academic spin-offs. | Multiple Correspondence Analysis and Agglomerative Hierarchical Clustering | Quantitative, exploratory/ inductive | 60 academic spin-offs commercializing CE innovations | ASOs |
| Paper 2:<br>The circular economy impacts of digital academic spin-offs | Content analysis, Multiple-Case Study | Qualitative, exploratory/ inductive | 29 academic spin-offs commercializing digital innovation for CE | ASOs |
| Paper 3:<br>Resource configurations among digital academic spin-offs: Finding the technology-market fit | Qualitative Comparative Analysis | Qualitative, exploratory/ inductive | 49 academic spin-offs based on digital technologies | ASOs |
| Paper 4:<br>Enabling circular business models in the fashion industry: the role of digital innovation | Multiple-Case Study | Qualitative, exploratory/ inductive | 10 large, SMEs and start-up fashion companies. | Fashion firms |

## 3.6 Research quality criteria

Multiple Correspondence Analysis, Qualitative Comparative Analysis, and Multiple-Case Study methods have strengths and weaknesses (see Table 8). Overall, the advantage of Multiple Correspondence Analysis and Qualitative Comparative Analysis is using the algorithm to systematically examine, explore new data patterns, and reduce personal biases. Moreover, these methods are not restricted to medium-small datasets often entailed in emergent research fields such as CE. Furthermore, the Multiple-Case Study method is a complementary match for Multiple Correspondence Analysis and Qualitative Comparative Analysis. This qualitative method helps deepen insights into the CE phenomenon and compares cases to identify differences and similarities between settings.

However, all three methods have also disadvantages. Overall, all these three methods have an exploratory and inductive nature; thus, they can reveal emergent correlated patterns in data but cannot test to confirm the significance of these correlations. Other quantitative analyses can complement the hypothesis testing of these relationships. Furthermore, Qualitative Comparative Analysis's results are sensitive to how its conditions are calibrated. Thus, this calibration process in the Qualitative Comparative Analysis needs to be done thoroughly.

My research follows four parallel quality criteria in quantitative and qualitative methods to address methodological shortcomings and enhance research quality. Table 9 provides general definitions of the four quality criteria, and the next sections discuss my study's development following these criteria.

**Table 8:** Pros and cons of the methods

| **Methods** | **Pros** | **Cons** |
|---|---|---|
| Multiple Correspondence Analysis (MCA) & Clustering Analysis | • Provide a systematic examination of proximity-based variable correlations to find emergent patterns in the data.<br>• Visualize plots to showcase the clusters of variables and cases.<br>• Useful to construct taxonomy by measuring and grouping similar cases.<br>• Can also be applied to categorical variables, not restricted to continuous variables like Principal Component Analysis.<br>• Not restricted by sample sizes. | • Do not provide testing; thus, cannot confirm the significance of variable relationships |
| Qualitative Comparative Analysis (QCA) | • Useful to systematically examine the interactions and correlatedness of conditions leading to the outcome.<br>• Provide necessary condition analysis and sufficient condition analysis.<br>• Not restricted by sample sizes. | • The results are prone to change by the calibration of conditions. Thus, the calibration process should be done carefully and rationally.<br>• Does not provide testing; thus, cannot confirm the significance of relationships. |
| Multiple-Case Study | • Provide in-depth insights into the process and the mechanism of the phenomenon.<br>• Allow case comparisons to find similarities and differences between cases. | • Need to interpret the findings in careful consideration of research contexts to avoid false generalization. |

### 3.6.1 Internal validity/ credibility

The first criterion refers to the true value of the evidence indicated as internal validity in quantitative methods and credibility in qualitative methods (Guba and Lincoln, 1989; Sandelowski, 1986). Internal validity concerns that the variables can explain the true outcomes by generating the correct sets of independent variables, formulating correct hypotheses, and considering control variables (Frambach *et al.*, 2013; Fraenkel *et al.*, 2012). Credibility concerns that the study's findings should be trustworthy and sensible to readers through data triangulation (i.e., using a variety of data sources), investigator triangulation (i.e., involving different researchers in data collection and coding), and theory triangulation (i.e., using multiple theories to interpret the findings) (Guba and Lincoln, 1989; Miles *et al.*, 2018; Healy and Perry, 2000).

Using multiple methods, my study attempts to accord with these criteria. The sets of variables used in my research were generated based on both theoretical stances (i.e., recognizing them in prior investigations and linking them to prior theories of CE, innovation, and resource-based view) and empirical stances (i.e., considering new variables/ evidence patterns that emerged from data). The results of Qualitative Comparative Analysis are prone to vary according to how the conditions are measured and calibrated. Therefore, I thoughtfully conducted the calibration process and applied a calibration technique using three thresholds of fully-in (i.e., maximum value), fully-out (i.e., minimum value), and cross-over point (i.e., mean value) to transform continuous variables into accurate membership scores.

Furthermore, I attempted to conduct data, investigator and theory triangulation for the Multiples- Case Study in Paper 2 and Paper 4. A variety of data sources were used, including interview data, survey data, financial data, corporate announcements, project descriptions, and news articles. Multiple data types might help reduce missing information and misperception of the cases. Moreover, two or three persons with full training were involved in the coding process to attain mutual agreement and reduce personal biases in coded terms. The cases were selected in multiple types to achieve more diverse views of the phenomena. Multiple theoretical lenses (e.g., innovation, entrepreneurship, CE, resource-based theory) were helpful in interpreting the findings more holistically.

### 3.6.2 External validity/Transferability

External validity in quantitative research and transferability in qualitative research are related to the applicability of the evidence (Sandelowski, 1986). External validity concerns the extent to which results presented by the data can be true to the population (Sandelowski, 1986), and transferability is the extent to which the findings can be relevant and applied in similar settings (Guba and Lincoln, 1989; Merriam, 1995). My quantitative data is extracted and quantified from a population of Norwegian ASOs. The data samples are collected with all relevant cases of CE-related ASOs and digital ASOs from the population of the Norwegian ASOs. Only cases with severe missing information were excluded from the data samples. The Norwegian context of the ASOs is relatively presentative and relevant to the context of other developed countries. For instance, the creation of ASOs is stimulated by governmental schemes and research efforts to increase the commercialization value and technology transfer of scientific knowledge. Therefore, the Norwegian ASOs receive generally similar governmental support as ASOs in other similar contexts.

Regarding my second dataset, the context of the Norwegian fashion industry is smaller in scale compared with other fashion exporters such as Turkey and China. However, with high innovativeness, advanced technologies, and concrete goals for sustainability, the Norwegian fashion industry should be a relevant context to examine how digital innovations can contribute to sustainability and CE. Besides, many fashion industries in the world are facing the same environmental and social problems of overproduction and overconsumption. The case of the Norwegian fashion industry appears appropriate and relatable to many, especially developed countries, for example, the United States which also aims to harness technological advances and re-shore its fashion manufacturing chain back home to become more sustainable and profitable.

Furthermore, the applications of CE, innovation and entrepreneurship are highly contextual-dependant and influenced. Existing studies outlined that the applications of these concepts should be distinguished in various contextual settings and theoretical lenses. Therefore, my papers' results were compared with other prior studies to evaluate the similarities and differences in the same and different contexts. My study showed consistency and relevance with most studies examining the same contexts (e.g., small new firms and fashion firms) and some minor contradictions with studies in other contexts (e.g., larger firms). These points will be further illuminated in the conclusion section.

### 3.6.3 Reliability/confirmability

The third criterion affirms the consistency of the evidence, defined as reliability in quantitative research and confirmability in qualitative research (Sandelowski, 1986; Guba and Lincoln, 1989). These criteria determine to which extent the study's results are consistent and still be held if the study is replicated by other researchers and methods (Guba and Lincoln, 1989; Golafshani, 2003). Using matrix algebra calculation, Multiple Correspondence Analysis is a robust unsupervised exploratory, descriptive method to systematically examine and visualize potential correlations between variables or cases based on their proximity. Qualitative Comparative Analysis also uses Boolean algebra and counterfactual analysis to systematically identify logically possible configurations of conditions leading to the outcome. These methods are appropriate to deal with within-case complexity, specifically in social science disciplines such as the CE and entrepreneurship. With their systematic, logical nature, these methods should be able to provide consistent results if the study is replicated in similar contexts, variable sets, and procedures. Likewise, the sets of variables in my research were developed consistent with prior theories and might provide a groundwork for further studies to replicate and investigate in other contexts. Regarding the Multiple-Case

Study method, my study's interviews and coding were conducted in line with a protocol of guidelines and training to ensure standard quality regardless of who was involved in data collection and coding processes.

### 3.6.4 Objectivity/ reliability

Objectivity in quantitative research and confirmability in qualitative research refer to the neutrality of the evidence (Sandelowski, 1986). These criteria determine bias-free research and that personal biases must be transparent and explicit if existing (Frambach *et al.*, 2013). To obtain these criteria during the data collection processes, I built the clear and transparent coding protocols regarding how variables were coded and quantified and how the interviews were conducted. Interviews were fully transcribed, and direct quotes from the company's informants were shown in the papers to ensure interpretations based on the provided evidence rather than my assumptions. The findings were thoroughly discussed with co-authors to ensure unbiased interpretations. Moreover, Multiple Correspondence Analysis and Qualitative Comparative Analysis provide algorithm calculations that help segregate the results from personal misassumptions, increase accuracy in measurement and clustering, and reduce individual biases. One of the strengths of the mixed-method study is that it combines different quantitative and qualitative methods to provide more dimensional and less biased views of the phenomena. Finally, I also described in detail and transparency how this thesis was developed, its methods and limitations.

**Table 9:** Quality criteria of quantitative and qualitative methods

| | **Quantitative methods** | **Qualitative methods** |
|---|---|---|
| **The true value of evidence** | **Internal validity**<br>**Definition:**<br>The extent to which the independent variables can measure and explain the observed outcomes/ effects. | **Credibility**<br>**Definition:**<br>The extent to which the study's findings are trustworthy and sensible to readers. |
| **The applicability of evidence** | **External validity**<br>The extent to which the results of the data sample can be generalized to the population. | **Transferability**<br>The extent to which the findings can be understood and applied in other context settings. |

| | | |
|---|---|---|
| **The consistency of evidence** | **Reliability**<br>The extent to which the study's results are consistent if replicated. | **Dependability**<br>The extent to which the findings are consistent across researchers and methods. |
| **The neutrality of evidence** | **Objectivity**<br>The extent to which personal biases are eliminated and value-free results are obtained. | **Confirmability**<br>The extent to which the findings are generated based on the study's participants and context rather than the researcher's biases. |

*Source: Adapted from Guba and Lincoln (1989) and Frambach et al. (2013)*

## 3.7 The coding processes

This section presents the coding processes to obtain the datasets, coded terms and variables. Overall, the coding process of Paper 1 includes four stages. First, 4252 news articles written about 295 ASOs were archived by A-teskt/ retriever and internet research engines. About 70 companies which early bankrupted or exited were not reported in the news articles and therefore excluded from the coding. Next, the CE impacts of these ASOs were coded to obtain a sample of 60 ASOs with CE impacts. After that, the news articles about 60 ASOs were reread to qualitatively code relevant information about the variables before these variables were quantified as binary values. As a subset of Paper 1's dataset, the coding process of Paper 2 repeats the same stage 1, stage 2, and stage 3 as Paper 1. Paper 2 added an extra step to sort out the CE-related ASOs by their technologies and obtained a dataset of 25 CE-related ASOs based on digital technologies.

Paper 3 has the same stage 1 of Paper 1. However, this paper first sorted out the ASOs by technologies to obtain a dataset of 49 digital ASOs. Then, relevant information related to the conditions was coded and quantified into numeric values. Next, the calibration process of the conditions was conducted for the Qualitative Comparative Analysis.

My coding process for Paper 4 is relatively common in qualitative methods. First, interviews with the cluster organization and the companies were conducted to collect pertinent information. In addition, project descriptions and company website information were also gathered for the coding. Next, the interviews were transcribed with relevant phrases and terms coded to identify emerging patterns in the qualitative data.

To sum up, one of the core coding techniques in my thesis (e.g., Paper 1, Paper 2, and Paper 3) is to code relevant information from the news articles and then quantify these qualitative terms into numeric values for quantitative analyses.

**Table 10:** The coding processes of the four papers

| Paper | Data sample | Coding process |
|---|---|---|
| Paper 1 | 60 CE-related ASOS | • Stage 1: downloaded 4252 news articles written about 295 of the ASOs in the population of 373 firms by using newspaper archive (i.e., A-tekst/Retriever) and internet search engine.<br>• Stage 2: coded the CE impacts of the ASOs equalling '1' if the firm's innovation has CE impacts, '0' otherwise. Descriptions of the CE impacts were noted. Obtained a dataset of 60 ASOs with CE impacts.<br>• Stage 3: coded the variables. First, re-read the newspaper articles and qualitatively code with relevant information about the variables. Then, quantitatively code the variables as binary values equalling '1' if the certain attribute is present, '0' otherwise. |
| Paper 2 | 25 digital CE-related ASOs | • The same process of stage 1, stage 2, and stage 3 as Paper 1<br>• Stage 4: sorted the CE-related ASOs by their technologies to obtain the data sample of 25 CE-related ASOs using digital technologies.<br>• Stage 5: content analysis |
| Paper 3 | 49 digital ASOs | • Stage 1: the same process of stage 1 as Paper 1<br>• Stage 2: sorted the ASOs by the technologies of the firms. Selected the firms using digital technologies.<br>• Stage 3: read the newspaper articles written about the ASOs with digital technologies. Qualitatively coded the variables with relevant information.<br>• Stage 4: quantitatively code/ calibrate the variables. |
| Paper 4 | 10 Norwegian fashion companies | • Stage 1: collected primary data by interviewing the companies' project leaders, managers, and CEOs. Collected secondary data of companies' project descriptions and website information.<br>• Stage 2: transcribed the interviews and coded the data to identify relevant information and the data patterns for theory building. |

## 3.8 Ethical considerations

My PhD study is conducted following Nord University's research ethics guidelines. In principle, the research should be of high quality, transparency, and responsibility. According to the guideline, the research should be conducted with freedom of topics, methodologies, and data. The research should be conducted under the protection of data privacy and confidentiality and only use data under the permissions and consents of research participants (e.g., companies and individual interviewees), and the research consent must be informed, explicit, voluntary and documentable. The researcher must prevent the use and dissemination of information that violate private privacy or cause harm to research participants, society and the environment, and the research should be conducted with professional manners, honesty, trustfulness, transparency and integrity. The process of collecting and coding data needs to be transparent and ethical and must not create or add false information to the data while ensuring transparency in using, changing, and adapting data sources. In that sense, the researcher must not fabricate data and withhold unwanted results. Furthermore, the relevant roles and authorships in which the researcher is involved must be transparent and clarified to colleagues, research participants, funding sources, and other relevant actors. Researchers and their co-authors should be responsible, fair, and transparent in collaborating on the joint research. Data copyright must be clarified before data collection takes place in research projects. Research cannot be plagiarised or published with another person's research work & data. The methodologies should be scientifically justified and avoid errors and deficiencies.

# 4 PAPER SUMMARY

This chapter summarises the main ideas of my four research papers, including the introduction, theory, method, and key findings. These papers were written in a standard format of peer-review research articles. Each paper addresses different research questions interconnected to the main research question. The updated status of the four papers is previously presented in Table 2.

## Paper 1: Commercializing circular economy innovations: a taxonomy of academic spin-offs

### Introduction

Technological innovation and scientific commercialization may drive circular systems and consumer behaviours for CE transitions. New market entrants with a more open-minded mindset are more likely than incumbents to pursue sustainability-related opportunities and radical innovations (Hockerts and Wüstenhagen, 2010). As innovative science-based start-ups, ASOs can potentially commercialize CE innovations based on advanced technologies. Although some research has been carried out on innovations for the CE, no studies have systematically examined CE innovations and CE ASOs. The research area has still borrowed the concept of 'eco-innovation' or 'sustainable innovation' to denote CE innovations. However, the substantial differences in the attributes of ecology and sustainability compared to CE may weaken the reliability of 'eco-innovation' and 'sustainable innovation' terms used to indicate 'CE innovation'. Furthermore, a taxonomy of various ASOs commercializing CE innovations is still lacking. Based on this gap, Paper 1 addresses the research question, "what types of CE innovations are commercialized by ASOs?". Paper 1 takes the first step in my thesis to provide an overview of CE innovations and the types of CE-related ASOs.

**Theory**

The paper's framework was constructed in the interdisciplinary literature of CE and innovation. The assessment of CE innovations includes conventional indicators of innovation characteristics such as product versus process orientation, technology domains, knowledge domains, industry collaboration, and patent (Pavitt, 1984; De Jong and Marsili, 2006; Carayol, 2003; Souitaris, 2002; Evangelista, 2000). Additionally, contextual factors such as environmental, market, and social issues have been important determinants of innovation taxonomies (Autio *et al.*, 2014; Dziallas and Blind, 2019; Souitaris, 2002). Therefore, the paper proposes a novel way to examine CE innovations by including CE characteristics as contextual factors. The interconnection between CE and innovation has been somewhat recognized in early studies that innovation is an essential enabler for the CE (de Jesus *et al.*, 2018); vice versa, CE also determines the innovation process (Blomsma *et al.*, 2019). This paper also constructs a taxonomy of CE ASOs, which rest on existing assumptions that technology is a significant source for new, technology-based firms (Autio, 1997) and technological heterogeneities differentiate the types of sectoral firms (Pavitt, 1984).

**Method**

The Multiple Correspondence Analysis and Agglomerative Hierarchical Clustering were used to assess the CE innovations and construct the taxonomy. MCA generated a low-dimensional plot and evaluated proximities between the variables and ASOs. Each variable and each case is displayed as a coordinated point on the MCA plot. The first property of MCA concerns the proximity of variables to the centre point. Variables in the remote areas of the plot and far from the centre point demonstrate more distinct, unique characteristics than their counterparts. MCA also concerns the proximity between the variables or between the cases. The proximity of the variables or cases indicates some potential associations between them. In other words, these variables may have similar characteristics to each other. Using Agglomerative Hierarchical Clustering embedded with the MCA, I contoured the cases and identified the firm clusters.

### Key findings

Paper 1 provides a systematic understanding of ASOs commercializing CE innovations. Five clusters of CE-related ASOs are identified, including Cluster 1 'virtual product- service providers', Cluster 2 'technical process enhancers', Cluster 3 'biochemical cycle enhancers', Cluster 4 'renewables providers', and Cluster 5 'biosphere regenerators'. Each of the five CE-related ASOs holds different roles in enabling their CE. All five clusters operate in both the technical cycle and the biochemical cycle. A majority of ASOs are engaged in the 'reduce' strategy to narrow the loop of CE. Industrial symbiosis is vital to certain types of CE-related ASOs, such as the biosphere regenerators which regenerate waste outputs of one industry to material inputs for another. Moreover, the predominance of Cluster 1 and Cluster 2, which rely heavily on digital technologies, shows an importance of digital technologies to CE. This empirical finding is a theoretical motivation for Paper 2 to explore how these ASOs with such digital technologies can contribute to the CE.

## Paper 2: The circular economy impacts of digital academic spin-offs.

### Introduction

Digital technologies are characterized by unique attributes such as open, reprogrammable, flexible, less predefined, and less bounded (Nambisan, 2017). These attributes have drastically changed academic entrepreneurship's process and outcome, which may hold an important position in sustainability transitions. As a high-technology firm, ASOs may exploit new digital competencies, lead technological changes, explore unaddressed market demands, create new markets, and make sustainable impacts. Although digital technologies and ASOs are the essential enablers for CE, this link between digital technologies and CE-related ASOs remains unclear in the CE research. Little is known about how many ASOs may harness digital advances to create CE impacts. Considering this aspect, Paper 2 answers the research question, "how do ASOs commercializing digital innovations contribute to the CE?". Adding to Paper 1's findings about the predominance of digital technologies among CE ASOs, Paper 2 provides deeper insights into how and in which ways these digital-based ASOs can contribute to the CE.

**Theory**

Digital academic entrepreneurship literature highlighted the role of academic entrepreneurial firms that promote economic growth and enable technological changes and sustainability shifts (Rippa and Secundo, 2019). The CE as a sustainability transition may entail technological changes and market reforms. Digital innovations commercialized by ASOs can be important sources for such transitions. Digital technologies are classified into three main groups: digital artefacts, digital platforms, and digital infrastructure (Nambisan, 2017). Entrepreneurial firms can select and adopt various digital technologies into business models to tackle sustainability issues (George *et al.*, 2020). In the CE, digital technologies can activate and facilitate different CE strategies. For example, blockchain can enable automatic tracking and tracing to enhance recycling processes. Artificial intelligence and virtual models can optimize productivity and decrease resource consumption and prototype waste. Digital platforms and the Internet of Things can improve information on locations, availability, and conditions of products for premaintenance, reuse, refurbishment, and recycling. Most previous studies of digital technologies for CE are either conceptual research or literature reviews. Empirical evidence on how digital academic entrepreneurship can contribute to the CE remains underexplored.

**Method**

Paper 2 adopts an exploratory, inductive approach and a Multiple-Case Study method. The content coding and analysis technique was used to define the sample from 195 newspaper articles written about digital ASO firms. On the first-order coding, I coded direct quotes from the articles concerning CE impacts, digital technologies, and innovation types (e.g., product versus process, novelty). On the second-order coding, the first-order coded terms are reduced as keywords such as 'sensors' and 'robots, and assigned to relevant categories. The categories include the types of innovations (i.e., incremental, radical product, and process innovation), the types of digital technologies (i.e., sensor, artificial intelligence, real-time data, and software), the subcategories of digital technologies (i.e., digital artefact, infrastructure, platform), CE impacts (i.e., resource efficiency and waste minimization), and firm performances (i.e., commercialization and survival). Finally, crossed-case comparisons were conducted to identify similarities and differences in the data patterns.

**Key Findings**

The first type of digital CE ASOs relies on digital platforms and digital artefacts to introduce digital product innovations such as learning portals, virtual interfaces, or digital laboratories. These new products and services offer multiple stakeholders novel communication and interaction methods without being spatially bounded. Moreover, virtual products such as virtual laboratories and digital books can replace physical objects to reduce waste emissions and material consumption. Digital platforms and digital artefacts are closely connected. The second type of digital CE ASOs introduces process innovations relying on digital infrastructures (e.g., sensors, robotics, big data, and the Internet of Things). These digital innovations optimize and increase production productivity by coordinating physical and virtual objects with real-time data, self-operating and decision-making to minimize failed prototypes and resource inputs. Digital process innovations commercialized ASOs seemed more radical with unique market solutions than digital product innovations that were more incremental and built upon existing applications. Furthermore, digital process innovations were patented, whereas non of these digital product innovations were patented. ASOs have a pivotal role in coordinating with other incumbents in their ecosystems to supply new digital technologies for CE transitions. Cost cutting, product optimization, and new market demand are among the most significant incentives for sustainable initiatives of digital ASOs. A combined effect of ‘technology-push’ and ‘demand-pull’ has led to technological shifting and CE transitions in the digital ecosystem of ASOs.

## Paper 3: Resource configurations among digital academic spin-offs: finding the technology-market fit.

### Introduction

Digital attributes have created new challenges and opportunities for digital entrepreneurship. Many ASOs commercialize research knowledge based on various digital technologies. Because digital technologies are less predefined, more open, more editable, and more collaborative than other technologies, digital ASOs may develop ventures in different paths and face higher market uncertainty compared to traditional start-ups. Thus, digital ASOs might have to mobilize and orchestrate their resources in different ways to maintain their competitive advantages and survive in digital markets. The resource-based view theory has emphasized how resources should be configured for firm success. It proved that firms which fail to combine and align multiple resources could be outcompeted in markets (Wiklund and Shepherd, 2005). Although the significance of resources in firm performances is known, research still has not identified which recipes of resource configurations can lead to successful outcomes for digital start-ups. Paper 3 answers the research question, "what resource configurations lead to success among digital academic start-ups?"

### Theory

Paper 3 draws on digital entrepreneurship literature and resource-based perspectives to examine the resource configurations for digital ASOs' success. Tangible and intangible resources are vital for firms, especially start-up firms with resource restraints. The liability of newness requires start-ups to secure various resources such as technological resources, financial resources, knowledge resources, alliance resources, and market resources. In addition to internal resources, external factors such as market conditions and the environment are also decisive determinants. Resource-based view theory stresses the mutual interactions between resources and their external environment. It concerns how resources should be configured to maximize a firm's competitive advantages for firm survival and growth. The literature lacks research on the resource management of start-ups (Zahra, 2021). Moreover, although the causal-effect relationship between resources and firm performance is acknowledged, little is known about resource configurations or which type of resources should be bundled for optimal resource values. For that reason, this paper aims to explore the resource configurations for the success of digital ASOs. Assuming digital technologies affect the process and outcome of academic entrepreneurship differently, I focused on the context of digital ASOs. The investigation of resource configurations is framed on the four resources (e.g., technological resources, research knowledge resources, strategic alliance resources, funding resources) and a contextual factor (e.g., market condition). The paper concludes the technology-market fit for digital ASOs through the empirical evidence of resource configurations.

**Method**

Paper 3 adopted a configurational approach and applied the Qualitative Comparative Analysis (QCA) on the longitudinal dataset of 49 digital ASOs. "The configurational approach has been developed to overcome the shortcomings of contingency theory, which focuses primarily on the unidirectional influences of (situational) diversified environments on organizations" (Korunka *et al.*, 2003, p. 25). Combining both variance and case orientation, QCA is viewed as a middle path to overcome the shortages of techniques examining only individual effects rather than the interactive effects of variables on outcomes. QCA provides the truth table and identifies all possible logical configurations, and conducts necessary analysis and sufficient analysis. The method is appropriate for my research context of digital academic entrepreneurship which is characterized by social complexity and resource heterogeneities and thus requires multiple combined resources for firm performance.

**Key findings**

The results of QCA showed that no single resource but the necessary combinations of resources could suffice digital ASOs' successes. QCA identified five distinct resource configurations that may lead to the same successful outcome of digital ASOs. Of these five resource configurations, two prominent development paths of digital ASOs can be recognized. The first group of digital ASOs are termed 'market exploiters' as those commercializing in favourable market conditions when lacking technological resources or research collaboration resources. The second group of digital ASOs termed 'technology explorers' are firms that need different combinations of various resources (i.e., combining research collaboration resources with strategic alliance resources; strategic alliance resources with technological resources; and financial resources with research collaboration resources if lacking technological resources).

## Paper 4: Enabling circular business models in the fashion industry: the role of digital innovation

### Introduction

Digital technologies and circular business models are the key drivers behind the CE transition. Digital technologies (e.g., the Internet of Things, big data, 3D printing, blockchain, and artificial intelligence) can be adopted into various circular business models. Both digital technologies and circular business models are heterogeneous and divergent in terms of types and applications in sectoral contexts. There is no one-size-fits-all circular business model for all firm types. Different firm types adopt different digital circular business models. Paper 4 examines how digital technologies can empower circular business models in the fashion industry. The fast fashion industry releases enormous waste and contaminates the environment. The fashion issue stems from both sides: producers overproduce, and consumers underuse garments. Paper 4 addresses the research questions, (1) which digital-based circular business models are used by the fashion industry?; and (2) how do fashion companies of different sizes (i.e. large, SMEs and startups) differently adopt those digital-based circular business models? The paper also compared the differences in strategies of adopting digital-based circular business models among the different-sized fashion companies.

### Theory

The paper is framed on two main literature streams: digital technology and circular business model. Circular business models as "how an organisation creates, delivers, and captures value in a circular economic system" (Den Hollander and Bakker, 2016, p. 2) can be classified as downstream circular adoption, upstream circular adoption and full circular adoption (Urbinati *et al.*, 2017). Circular business model innovation refers to the shift from linear business models to circular business models. Geissdoerfer *et al.* (2020) distinguished the four types of circular business model innovation as circular business model transformation (i.e. modification of an existing business model), circular startups (i.e. the creation of new business models that entail CE strategies), circular business model diversification (i.e. the addition of the circular business model into the existing business model) and circular business model acquisition (i.e. the merger, acquisition and integration of the circular business models into the organisation). Different-sized firms may adopt circular business model innovations differently. Emergent digital technologies include the Internet of Things, big data, 3D printing, blockchain, cyber-physical system, and platforms. Digital technologies can be implemented in various circular business models to generate multiple CE impacts such as reduce, reuse, recycle (Liu *et al.*, 2022). Most current research about digital innovations in circular business models is either theoretical or conceptual and focuses on one technology type or one company (Rosa *et al.*, 2019). It lacks empirical evidence considering multiple types of digital technologies in one sector and comparing different-sized firms in the same industry. In this paper, I investigated the context of the fashion industry as a consumer-based industry facing significant waste and contamination issues. The reason is that fast fashion production model is based on a six to nine-month market forecast that highly fluctuates with high uncertainty. This situation results in large amounts of unsold inventories. In addition, the fact that modern consumers tend to buy cheap clothes and throw them fast also contributes to enormous household waste.

**Method**

Paper 4 examines ten Norwegian fashion companies by applying the Multiple-Case Study method. This paper seeks to understand how digital technologies should be integrated into fashion circular business models and how different-sized fashion firms selected and implemented their digital circular business models for a more circular fashion. The case study method is useful for investigating the "why" and "how" questions to "illuminate a decision or a set of decisions: why they were taken, how they were implemented, and with what result" (Schramm, 1971, p. 6). This method can compare cases to find similar and dissimilar patterns in firm strategies when adopting innovations. I interviewed the fashion cluster organization's and companies' managers and founders to collect data. In addition to interview materials, the project descriptions and information on company websites were used to provide a more comprehensive understanding of digital innovation and sustainable projects. The four-ordered coding was conducted. First, the interviews were fully transcripted. Next, written phrases and sentences relevant to the research interests were highlighted as coded terms. Then, the related coded terms were grouped into more overall themes and categories. Finally, the main themes and categories were labelled and compared for interpretation.

**Key findings**

Three archetypes of digital-based circular fashion business models are identified: the blockchain-based supply chain model, the service-based model (with two subtypes: the clothing renting/ subscription-based model and the repair/second-hand sale model) and the pull demand-driven model. The blockchain-based supply chain model uses blockchain technology and big data to improve garment sorting and recycling automation. The service-based model focuses on downstream businesses and end-users to provide clothing services such as renting, subscription, and repairing. This service-based model relies on digital platform technology, the Internet of Things, and big data. The pull demand-driven model which combines diverse digital technologies such as 3D models, 3D printing, big data, and the Internet of Things entails upstream and downstream businesses. This model aims to radically shift the consumer and producer paradigm from fast fashion to tailored-made fashion, from the economy of scale to the economy of scope, and from six to nine-month market forecast production to real-time demand production. The pull demand-driven model may help to reduce overproduced waste from producers and underutilized waste from consumers. These digital advances are critical to balance the supply-demand equilibrium of fashion markets to decrease waste amounts. However, the pressure of new garment production can only be relieved when unnecessary new demands of consumers are minimized. Heavily dependent on consumers' behaviours, the fashion industry necessitates radical business model innovations such as the pull demand-driven model to shift the entire unsustainable consumption-production paradigm into circularity. My empirical evidence found that large fashion firms are more likely to adopt incremental innovations and add additional functions (e.g., repairing services) into their existing business models. By contrast, fashion start-up firms are more likely to introduce radical innovations and disruptive business models such as the pull demand-driven model.

# 5 CONCLUSION

The final chapter concludes the thesis with the main contributions and policy implications. Overall, this thesis contributes to the CE, innovation, and academic entrepreneurship literature and provides empirical evidence on the role of digital innovations in CE. The research question "what is the role of digital innovation in the circular economy?" can be dissected into three main focuses (see Table 11):

(1) The role of innovations in the CE.

(2) The mechanism of digital innovations enables circular business models.

(3) The actors that commercialize the CE innovations.

**Table 11:** Synthesized findings of the four articles

| Research focuses | Key findings |
|---|---|
| (1) The role of innovations in the CE. | • Optimize circular production (i.e., technical process enhancer firms).<br>• Reinforce and reform circular consumer behaviours (i.e., in service-based models, pull-demand models, and product-service provider firms).<br>• Extend bioproduct life (i.e., biochemical cycle extender).<br>• Facilitate industrial symbiosis and material/ product exchanges among firms in the network (i.e., renewable provider, biosphere regenerator).<br>• Enable radical circular business models (e.g., the pull demand-driven model).<br>• Enable service-based activities (e.g., the service-based model)<br>• Deliver the reduce, reuse, recycle strategy.<br>• CE innovations can be assessed along two dimensions of innovation attributes (e.g., technology domain, product versus process, basic versus applied research, academic institution, industry partnership, patent) and CE attributes (e.g., CE strategy, circular business models). |
| (2) The mechanism of digital innovations enables circular business models. | • Digital technologies help facilitate functions of circular business models (e.g., fashion models) to increase recyclability and reuse to reduce unnecessary new demand.<br>• Blockchain-based supply chain models use blockchain, the Internet of Things, and QR codes to provide information on tracking transactions of garment products, provide sustainability metrics, and increase reusing, repairing and recycling capabilities.<br>• Service-based models use digital platforms, the Internet of Things, and blockchain technologies to prolong the lifecycle of garments, increase garment uses, and offer consumers clothes renting, repairing, and second-hand selling.<br>• The pull demand-driven models use 3D design, 3D avatar model, digital platform, 3D printing, AI and automation to shift mass production to on-demand, dematerialize physical prototypes, provide customization, |

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| | enable interactive communication between stakeholders, and automate productions. |
| (3) The actors that commercialize the CE innovations. | • Convert scientific knowledge into market practices, initiate sociotechnical changes in 'circular ecosystems', and introduce circular economy innovations.<br>• More likely to be technology suppliers for larger firms in the system to optimize production processes.<br>• Economic incentives are essential for most CE innovations, especially those CE innovations aiming at the 'reduce' strategy and the 'optimize' model.<br>• Digital ASOs may need different resources to grow and survive under the unique influences of digital attributes. Two paths to the success of digital ASOs as the market exploiters and the technology explorers. Market exploiters take advantage of favourable market conditions when other technological and research knowledge resources are lacking. Technology explorers need to combine various technical and commercial-related resources to succeed. |

## 5.1 Theoretical contributions

### 5.1.1 Contributions to the innovation literature

My study contributes to the rapidly expanding field of innovation for firm-level sustainability transitions by investigating the impacts of innovations in general and digital innovations in particular for sustainable CE production and consumption. My study adds a taxonomy of CE-related ASOs as high-technology start-ups to the prevailing innovation taxonomies (e.g., Castellacci (2008), Pavitt (1984)) which were mostly built on large firms. Research on sustainability transitions should not overlook the significant role of entrepreneurial firms in initiating technological changes and developing radical CE innovations. Building upon the arguments of Autio *et al.* (2014) and Zahra (2021) about the importance of contextual factors to innovation measurements and heterogeneities in entrepreneurial firms, I added CE variables as the contextual variables to conceptualize and measure CE innovations. My study is one of the first attempts in the field to define and classify CE innovations and lays the groundwork for future research on the role of innovation in CE transitions. My co-authors and I identified CE innovation as *'incremental or radical improvements of products, services, production processes, or business models that minimise the use of* *resource inputs and the generation of waste through the principles of narrowing, slowing, and closing the production-consumption loop.'* The CE innovations commercialized by the ASOs can be assessed along two dimensions of innovation characteristics (e.g., technology domain, product versus process, basic versus applied research, academic institution, industry partnership, and patent) and CE characteristics (e.g., CE strategy and circular business models).

Digital innovation and circular business model innovation can be incorporated to achieve the CE goals of improving environmental performance and increasing efficiency. Paper 2 provides empirical insights into circular digital product innovation and circular digital process innovation. Digital process innovations pertain to emergent digital infrastructure technologies (e.g., sensors, the Internet of Things, big data, and blockchains), while digital product innovations are more related to digital artefacts such as apps and new virtual features. The digital platform is an effective medium that can be embedded in both digital process and product innovations to benefit the CE. When developed by ASOs, digital product innovations are often built upon existing market knowledge, whereas digital process innovations seem more radical and more likely to be patented. These innovations foster CE strategies such as 'reduce' (e.g., by automation, 3D model, and 3D printing), 'reuse' (e.g., by the Internet of Things and platform), and 'recycle' (e.g., by blockchain and automation). Circular process digital innovations can disruptively change and incrementally improve the production and supply chain processes. In contrast, circular product digital innovations appear as new products and services for end users, such as digital music and streaming service (e.g., Netflix and Spotify) or sharing mobilities and assets (e.g., Airbnb and Uber).

Furthermore, by showing how digital technologies can be integrated into and facilitate circular business models in a specific sectoral context, my thesis extends the existing research of George *et al.* (2021) and Nambisan *et al.* (2019) about the applications of digital innovations in sustainability transitions. The digital-led circular business models (e.g., blockchain-based circular supply chain models, service-based models, the pull-demand models) have contributed to the CE transition of the fashion industry. The degree of innovation novelty is also varied among the types of digital-led circular business models. For example, I found that the blockchain-based circular supply model relies on blockchain technologies to increase the automated sorting and recycling of the CE. The service-based model depends on the Internet of Things, big data, and digital platform to enable the reuse, repair, clothes renting, and subscription services to maintain garment products longer in the loop. These two models, which focus on upstream and downstream business, seem incremental innovations and act as additional features in existing business models. By contrast, I also found that the pull-demand model is more radical and disruptive than the others. This model is expected to disrupt the linear mass-fashion production process based on long market forecasts, transform the fashion production-consumption paradigm, and shift the economy of scale to the economy of scope. The pull demand-driven model replaces the old system with a more circular, collaborative, tailored-made fashion production following real-time demands to reduce excessive inventory waste and unnecessary new demand waste. The combination of digital technologies (e.g., sensors, AI, automation, digital platform, the Internet of Things, and big data) facilitates this model.

Moreover, my study has also provided some empirical insights into how digital innovations may change the methods of communication and collaboration among stakeholders. Digital innovations allow more interactive, integrative, and multi-dimensional communications and partnerships among multiple actors, shorten the lead-time and forecast more accurately market demands based on a real-time basis. Furthermore, digital technologies engage stakeholders in the value chain (e.g., consumers, designers, and suppliers) in more early stages to reap the combinatory effects on both the demand and supply sides. The role of consumers is significant to the adoption of circular economy-related digital innovations, as several digital-led circular business models insist on consumer behaviour changes to succeed. Therefore, the role of innovation policies for such sustainability transitions is vital to reinforce desirable consumer behaviours or even force necessary changes.

Another empirical finding of my study differentiates the adoption strategies of CE innovations among firm types. Given distinct resources, organisation structures, capabilities, and liabilities, firms are incentivized and plan their adoptions of CE innovations differently. The result is consistent with earlier studies that large firms tend to adopt incremental innovations rather than disruptive, radical innovations. Large firms often add CE strategies (i.e., reuse or repair) as additional functions in their existing business models gradually. These firms prefer to wait for higher market certainty instead of investing too early in radical, disruptive innovations. Prior studies also outlined that start-ups and small firms with restrained resources but more open mindsets often introduce radical technologies and adopt disruptive business models to explore new niche markets (Henry *et al.*, 2020). In line with these early findings, I found that fashion start-ups and ASOs are more likely to introduce radical CE innovations and adopt more novel business models (e.g., the pull demand-driven model).

### 5.1.2 Contributions to CE literature

My thesis also contributes to the CE literature in several ways. My finding somewhat contradicts the early findings of Ghisellini *et al.* (2016) and Merli *et al.* (2018) that the 'closing the loop' principle, the 'loop' model, and the 'recycle' strategy are among the most common CE practices documented in research. Instead, I found that, given the context of ASOs, the 'optimize' model, the 'reduce' strategy and 'narrowing the loop' are more predominant. The differences in findings can probably be explained by the heterogeneities in firm types (i.e., large, SMEs, and start-ups), technology types, and sectors. My empirical evidence showed that CE innovations introduced by new entrants appear as technical solutions and are mainly related to the 'reduce' strategy to optimize resource efficiency and minimize waste residues. This finding is a complementary match with recent studies of Henry *et al.* (2020) and Parchomenko *et al.* (2019). The discordant results in CE research emphasize contexts' influence in measuring CE innovations and CE firms.

Following the preceding discussion, I found that among the three principles (i.e., narrowing, slowing, and closing the loop), 'narrowing the loop' appears to be the dominant principle among the ASOs. This CE principle does not directly influence the speed or cyclability of the resource flows but makes production processes cleaner, increases resource efficiency, and narrows the use of resources. However, Hofmann (2019, p.369) criticized that 'slowing the loop' is irreconcilable and incoherent to our current economy based on "consumerism", "permanent economic growth", and "ceaseless technological progress". Adding to this point of view, I suggest that narrowing the loop by boosting resource efficiency may subsequently accelerate the recurrence of new loops. Perhaps, solving the CE issues matters more about "what is truly required to reduce environmental impacts is less production and less consumption" (Zink and Geyer 2017, p. 600). A condition to prevent this 'circular economy rebound' effect is to increase efficiency but simultaneously not lead to a further increase in production and consumption. In that case, narrowing the loop should not only be understood as increasing efficiency and reducing resource consumption but also reducing unnecessary new demands. For example, in the fashion context, the overconsumption issues may be only addressed by minimizing new fast fashion demands rather than recycling clothes (with only 1% recyclability rate). However, reducing new market demand may subsequently lead to unsolicited revenue declines. To avoid conflicting economic and environmental interests, radical business model innovations such as the pull-demand model may necessitate transforming consumer behaviours from 'fast fashion' to 'more personally-made clothes' and introduce new business practices such as 'tailored-made' to shift the economy of scale to the economy of scope and enable on-demand production.

Furthermore, my study has contributed a CE taxonomy to the CE literature by identifying the five CE ASO clusters in terms of CE innovation types. CE innovations developed by ASO clusters are ascribed to both technical (i.e., the technical process enhancers, the smart product service providers) and biochemical cycles (i.e., the biochemical cycle extenders, the renewable providers, and the biosphere regenerators). The empirical evidence has shown a dominance of ASO clusters related to the technical cycle. The two largest CE ASO clusters adopt the 'narrowing the loop' principle and use diverse emerging digital technologies to optimize production processes (i.e., the technical process enhancers) or offer virtual products and services (i.e., the smart product-service providers).

Alongside ASOs pertaining to digital technologies and the technical cycle, another large subset of ASOs introduce innovations for the circular bioeconomy. The biogeochemical cycle and CE are intertwined (D'Amato *et al.*, 2020; D'amato and Korhonen, 2021). These firms contribute to the circular bioeconomy differently by extending the biochemical life of products (i.e., the biochemical cycle extender), providing renewable materials (i.e., the renewables provider), and regenerating materials from wastes (i.e., the biosphere regenerator). Furthermore, my study confirms the crucial role of industrial symbiosis for certain types of CE ASOs (e.g., the renewable provider and the biosphere regenerator) in facilitating by-product and resource exchange to retain the values of post-used products and materials. Close collaborations among actors in the network are vital to enable the convertion of waste flows into materials.

### 5.1.3 Contributions to the academic entrepreneurship literature

The third contribution of my thesis is to the academic entrepreneurship literature, which has paid considerable attention to the economic performances but much less to the environmental and social impacts of ASOs. The differences in CE innovation strategies between large firms and start-ups requested additional taxonomies specified for different firm types (Henry *et al.*, 2020). My research papers added an important dimension to the growing body of sustainable academic entrepreneurship research by examining the supplier roles of ASOs in CE transitions. With their high innovativeness, ASOs can commercialize scientific knowledge, introduce radical innovations, transfer new technologies, defuse knowledge spillover, and create significant changes in technical systems. Such sustainable transitions need a higher level of stakeholder engagement, radical technological shifts, and market changes, and ASOs can initiate more disruptive and radical changes in the CE loop than larger companies. ASOs tend to be technology suppliers for larger firms to facilitate horizontal and vertical integrations of the value chains rather than introduce their new products and services. Not all ASOs may be ‘circular-born’ firms or ‘social start-ups’ that aim at explicit CE goals. Instead, many ASOs contribute to sustainable impacts indirectly through their original business purposes. In return, the circular initiatives of ASOs could also result in economic gains by restoring the values of post-used products, minimising resource scarcity, and opening new markets.

In addition to showing the role of ASOs in the CE and sustainability transitions, my study provides an integrative view of the resource-based perspective with digital entrepreneurship research by defining resource configurations for digital ASOs’ successes. My study found that the external environment is decisive for how new digital-based ventures allocate and combine resources. If digital ASOs commercialize in a favourable market, fewer specific resources seem required for their success. In addition, in line with Zahra (2021)’s finding, my research showed that financial resources seem important but, per se, do not suffice the success of digital ASOs. By using QCA, I could distinguish two main paths leading to the success of digital ASOs. The first path to success involves a type of digital ASOs termed “the market exploiters”, which take advantage of good market conditions when technological or research knowledge resources are absent. This finding is aligned with prior studies that ASOs perform better when operating in less concentrated industries (Nerkar and Robert, 2014) and using the market exploitation strategy (Soetanto and Jack, 2016).

The second path to success entails “technology explorers” ASOs, which need to combine various technological and commercial-related resources (i.e., research knowledge resources and strategic alliance resources; strategic alliance resources and technological resources; financial resources and research knowledge resources when in shortage of technological resources). This second path shows the crucial links between scientific and commercial knowledge that many ASOs often struggle to acquire. My study also contributes to the growing stream of digital entrepreneurship research by unveiling the success recipes for ASOs in the particular context of digital markets. The digital entrepreneurship literature underscored the need to understand how start-ups are created, developed, and grown under the influence of digital attributes. The combinations of both commercial-related resources and technological resources are significant for start-up firms to gain competitiveness and thrive in digital markets, which seem more open, dynamic, and rapidly evolving. Because digital product lifecycles have become shorter and more liable to change, digital ASOs need to quickly adapt new resources and competencies.

## 5.2 Managerial and policy implications

My thesis provides a premise for managerial and policy strategy development. My empirical evidence shows agreements with the EU's Circular Economy Plan 2020, highlighting the role of digital transformation and entrepreneurial firms as the critical drivers for CE transitions. The EU's Circular Economy Action Plan, p.2 states that "building on the single market and the potential of digital technologies, the circular economy can strengthen the EU's industrial base and foster business creation and entrepreneurship among SMEs". This strategy is aligned with my study explaining how digital technologies help transform industries such as the fashion industry to be more circular and sustainable.

Furthermore, my study is consistent with Linder and Williander (2017)'s research stressing the significant challenges of market patterns and consumers to the success of circular business models. Because the digital CE transition is driven by both demand pull and supply push, the fact that whether consumers accept and have the adequate technical knowledge to use circular products and services will ultimately determine the success of several digital-based circular business models. This situation is proven in the cases of the pull demand model and the rental and subscription models. Therefore, demand-supply balanced policies are required for the success of digital CE transitions.

Despite the consumer roles in digital CE transitions, little attention is devoted to this topic in research and policies. My study urges policymakers to enact more effective demand-side policies to raise awareness, increase technological knowledge, incentivize sustainable consumption, and reinforce market certainty. One-sided policies may fail the firms' sustainable efforts.

Regarding managerial implications, digitalization and sustainability transition are expected to rapidly and drastically impact the fashion industry. Multinational fashion incumbents such as H&M, Zara, and Adidas have introduced various sustainable and circular programs using recyclable materials, 3D models, or blockchain track and trace. At the local level, many fashion start-ups also introduced innovations such as clothes renting and 3D knitting production. Therefore, fashion companies should prepare business capacities, technological competencies, and sustainable strategies for this sociotechnical transition. My study informs business leaders on how to prepare for this transition and how digital innovations can be applied in circular business models. While fashion start-ups are introducing radical and disruptive innovations to fashion markets, my study provides advice for large fashion companies. Large companies should be prepared for the emergence of start-ups with the potential to disrupt traditional markets, create new markets, and weaken large incumbents' market competitiveness. In addition to recycling and reuse strategies, large firms should collaborate with start-ups for joint innovation development projects to create more substantial CE impacts. A combination of competition and collaboration strategies should be considered. Collaborative innovation empowered by digital technologies can also enhance the innovation ecosystem of large firms, SMEs, and start-ups.

Moreover, my study also emphasizes the role of ASOs for the CE not only at the firm level but also at the ecosystem level as an actor carrying out and transferring scientific knowledge. Hence, supports for ASOs should be a part of the policy mix. Policymakers should collaborate with higher education institutions to introduce more education programs for sustainable entrepreneurship to increase sustainable academic entrepreneurship's value creation. My study provides empirical insights into how market conditions determine ASOs' development and success. Therefore, the policy support should not only be about giving more funding and grants but also creating favourable market conditions for start-ups. For example, incubation programs can help increase market knowledge for ASOs or incentivizing market demands may generate positive market effects. Moreover, several policy programs can be enacted to foster collaborative synergies and build ASOs' market capabilities.

Another important implication stresses that the CE implementation should be considered carefully to prevent rebound effects and speeding loops. Although 'narrowing the loop' through optimizing production processes, reducing resource inputs, and increasing efficiency remain an essential CE strategy, several other factors, such as the time-dimension, should be concerned when using 'narrowing the loop' to avoid loop speeding. Policymakers should consider providing more procurements and guidance for firms to control the rebound effects of CE resource efficiency by narrowing the loop. Thinking out of the box, narrowing the loop should be interpreted not only narrowly as reducing energy and resource consumption but also, more importantly, as reducing unnecessary new demand and overconsumption, as in the fashion industry case. Therefore, policies could emphasize this point by incentivising radical innovations which help decrease excessive new demand. In addition, 'narrowing the loop' can be combined with other CE strategies such as 'reuse' and 'recycle'. Another policy implication is about the role of the firms. Technical cycle-related firms such as 'product-service providers' and 'technical process enhancers' are significant contributors to CE impacts. However, better governmental incentives should also be equally given to circular bioeconomy firms such as 'biochemical cycle extenders' (to slow the rate of waste emission), 'renewable providers' (to replace with more sustainable materials), and 'biosphere regenerators' (to reduce waste amounts). Policymakers should strengthen industrial symbiosis and collaborative activities among ecosystem actors.

## 5.3 Limitations and future research agenda

My thesis is conducted under an awareness of data and methodological limitations. Data used in this thesis relies primarily on news articles to identify relevant information about ASOs, their CE impacts and technologies. The qualitative data coded from news articles were quantified for the Multiple Correspondence Analysis, Clustering Analysis and Qualitative Comparative Analysis. Using news article data may expect some activities and events that are likely underreported in the media, resulting in missing information. To minimize these underreported cases, I combined the newspaper article data with other supplementary data sources, including website information, patent data, publicly published financial statements, firm registrations, and firm announcements.

Besides, one caution for generalization is due to method approaches. With the inductive nature, Multiple Correspondence Analysis, Qualitative Comparative Analysis, and Multiple-Case Study are helpful in identifying emergent patterns from the data and their relatedness. For example, QCA reveals potential relationships of factors or conditions that may lead to the outcomes, or MCA shows distance-based similarities of variables and cases. Multiple-Case Study provides in-depth insights into the cases to explain the 'why' and 'how'. However, these methods are often used on generally small datasets that may not fully represent the entire population. Also, these methods do not provide significance tests, so they cannot confirm the existence of these relationships. Under these circumstances, generalizations should be made thoughtfully and carefully when applying these methods. The empirical results of these methods can form a basis for further large-scale variance-based analyses to validate propositions generated by the Multiple-Case Study and related patterns found by the MCA and QCA.

Another caution for generalization is given to context boundaries. In my thesis, the multiple-case study is applied to ten fashion company cases in Norway which appear as a more resourceful economy than many other countries. Similarly, although most

ASOs are established by international-oriented academic institutions and commercialize global technologies, ASOs in Norway may involve more substantial institutional support and incubation programs than other counterparts. Differences in these contextual factors (e.g., sectors, markets, technologies, or institutions) may significantly diversify the empirical results of CE and entrepreneurship research. Therefore, given the limited scope of data and peculiar contexts, the thesis does not attempt to generalize but provides further explanation of a significant, emerging phenomenon under specific contextual settings. Since CE and entrepreneurship are conditioned by contexts such as those of the fashion industry or academic spin-offs in which firms operate CE innovations practices and entrepreneurship processes, the empirical findings of CE and entrepreneurship research are naturally understood under the boundaries of these reality complexities.

Based on empirical findings from this study, my thesis opens several interesting avenues for future research (see Table 12).

**Table 12:** The future research agenda

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| (1) The role of innovations in the CE. | a. Combining different types of innovations and their radicalness to create CE impacts.<br>b. The challenges associated with adopting digital innovations on the consumer-side of the CE.<br>c. The possible rebound effects of digital technologies on the CE. |
| (2) The mechanism of digital innovations enables circular business models. | a. The sporadic or systematic mechanism of digital technology in enabling, developing and modifying circular business models and vice versa.<br>b. The influence of digital-based circular business models on the macro-level (e.g., how sectors of some countries will change their global value chain, reallocate resources, and consequently lose or gain economic benefits when applying new digital-based circular business models)<br>c. The economic, environmental and social performances of digital-based circular business models compared to traditional business models. |
| (3) The actors that commercialize the CE innovations. | a. A comparison of the developing path and performances of the five CE-related ASO clusters ‘product-service providers’, ‘technical process enhancers’, ‘product lifecycle extenders’, ‘renewable providers’ and ‘biosphere regenerators’.<br>b. A comparison of resource configurations that CE and non-CE start-ups need. |

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| | c. The significance and magnitude of resource configurations on the performance of CE-related firms.<br>d. The importance of other contextual factors in addition to market factors on the implementation and development of ASOs commercializing digital CE innovations.<br>e. The effects of other types of technology-related and business-related resources on technology-based CE firms and non-technology-based CE firms |

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# Commercializing circular economy innovations: A taxonomy of academic spin-offs

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ABSTRACT

Innovation and the commercialization of new technologies are seen as important drivers of the transition to a more sustainable development. An actionable strategy to achieve such a transition is outlined in the European Union strategy on resource efficiency and the development of a circular economy (CE). Academic spin-offs (ASOs) are new ventures based on scientific research that play an important role in commercializing technological innovations. However, the potential role of ASOs in the CE transition has not been systematically examined. We build on a unique dataset covering the population of ASOs in Norway and coded newspaper articles to identify potential CE-related innovations being commercialized by these firms. Using multiple correspondence analysis and clustering analysis, the ASOs were empirically classified along two dimensions related to the types of innovation (i.e., product or process) and the types of CE principle (i.e., narrow, slow, or close the production-consumption loop). Five clusters of CE-related ASOs were identified (i.e., smart product-service providers, technical process enhancers, biochemical cycle extenders, renewables providers, and biosphere regenerators), each having specific roles in the CE transition. This taxonomy can serve as a basis for more systematic comparisons of CE-related innovations across different firms and contexts. We conclude by outlining an agenda for further research and implications for how policies can harness the potential of ASOs to foster CE innovations.

## 1. Introduction

Science, technology, and innovation play a key role in addressing societal challenges, such as the excessive extraction and use of natural resources and associated challenges with pollution and waste (Schot and Steinmueller, 2018). With its main aim of addressing natural, environmental, and societal issues, the circular economy (CE) has emerged as a significant concept for transforming economies from the linear 'take-make-dispose' system to the circular 'make-use-return' system (Geissdoerfer et al., 2017). In the European Union's (EU's) Circular Economy Action Plan 2020, the European Commission has set ambitious goals for transitioning to a stronger CE, in which obsolete materials and goods are regenerated and restored to narrow, slow, and close the production-consumption loop.

Technological innovation is essential in such a transition towards a CE because numerous initiatives rest on the implementation of new technology to create a circular system (Cainelli et al., 2020). Hence, the rapid commercialization of scientific knowledge and technology to improve the circularity of physical resource flows will likely be a key enabler for the CE transition to succeed. Radical and sustainability-related innovations are more likely to be commercialized by entrepreneurial ventures, such as spin-offs and start-ups, than by large firms already established in the market (Hockerts and Wüstenhagen, 2010; Schaltegger et al., 2016; Kennedy et al., 2017; Homfeldt et al., 2019). With fewer asset liabilities, flexible organisational structures, and open technological mindsets, entrepreneurial firms often take the pioneering role as opportunity explorers and pursue sustainability goals (Homfeldt et al., 2019). Conversely, large firms with organisational inertia and locked-in paths, but better R&D financing, tend to take follower positions to exploit market opportunities that occur when technological trajectories are changing, when new policies are enacted, or when consumers become increasingly concerned about environmental and social issues (Schaltegger et al., 2016; Hockerts and Wüstenhagen, 2010). Large firms are inclined to adopt marginal CE strategies, such as recycling, but rarely shift their whole organisational paradigms (Bocken et al., 2017; Henry et al., 2020). By contrast, innovative spin-offs and start-ups can introduce disruptive innovations, design holistic circular business models, and thereby create substantial CE impacts (Henry

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et al., 2020).

The existing CE literature predominantly focuses on large established firms, while the important role of innovative start-ups remains only marginally studied (Henry et al., 2020). This is unfortunate because the CE frameworks and strategies used by large established firms may not be applicable for small spin-offs and start-ups (Henry et al., 2020; De Jong and Marsili, 2006). By commercializing scientific research developed at academic institutions, academic spin-offs (ASOs) are highly innovative start-ups with the potential of creating high economic (Vincett, 2010) and societal impacts (Fini et al., 2018). ASOs are potential forerunners by facilitating knowledge spillovers from the research base (Audretsch and Keilbach, 2008) and developing innovations (Shane, 2004). In the CE transition, ASOs may be essential innovators by commercializing new technologies and contributing to radical product and process CE innovations in other firms (Pavitt, 1984; Autio, 1997). However, the potential role that different types of ASOs can play in commercializing CE innovations is not well understood. Furthermore, there are no clear definition and systematic measurement of CE innovations considering both CE attributes and innovation attributes. At this current stage, CE studies mostly borrow the concepts of eco-innovation or sustainable innovation to indicate CE innovation, but eco-innovation and sustainable innovation may not be able to fully reflect all CE characteristics and CE principles.

This paper addresses these gaps by examining the potential role of ASOs in introducing innovations that improve the circularity of the economy. This study explores the following question: *What types of CE innovations are commercialized by ASOs?* To answer this question, we analysed a comprehensive dataset covering the population of 373 ASOs established between 1999 and 2011 on the basis of academic research at universities and research institutes in Norway. By searching media archives, we identified 60 ASOs commercializing CE innovations. We used Multiple Correspondence Analysis (MCA) and Clustering Analysis to define types of CE innovations and identify five clusters of CE-related ASOs according to the types of innovations they commercialized. This taxonomy provides empirical evidence about the different types of CE innovations commercialized by ASOs, which enhances the understanding of the roles of ASOs in the CE transition. Our taxonomy forms the basis for discussing implications for policy and future research.

## 2. Literature review

### 2.1. CE and the role of innovation

CE is defined as “a regenerative system in which resource input and waste, emission, and energy leakage are minimised by slowing, closing, and narrowing material and energy loops” (Geissdoerfer et al., 2017, p. 759). At the firm level, firms can adopt CE strategies in their businesses to enable circularity in their systems. CE strategies act as “how-to” guidelines and are often operationalized as the ‘R’ strategies (Kirchherr et al., 2017). The most widely used is the ‘3R framework’ which refers to the reduce, reuse, and recycle strategies (Morseletto, 2020; Lieder and Rashid, 2016; Kirchherr et al., 2017). The EU introduced the ‘4R framework’ for the official EU's Circular Economy Action Plan, including reduce, reuse, recycle, and recover. Additionally, the CE strategy of extending product longevity is also often included and involves designing for durability, quality, and reliability to maintain longer product utilities (Bocken et al., 2016). Some scholars proposed an extended ‘6R framework’ or even ‘9R framework’ entailing further CE strategies such as repair, remanufacture, refurnish, and rethink (Morseletto, 2020; Kirchherr et al., 2017). The selection of CE strategies in firms or research depends on business strategies and research cases. In this study, we focus on the five strategies reduce, reuse, recover, recycle, and extend product longevity.

These five strategies correspond to the general principles of narrowing, slowing, and closing the production-consumption loop (Bocken et al., 2016; Konietzko et al., 2020). *Narrowing the loop* involves the reduce strategy and resource efficiency to decrease resource consumption, make production cleaner and generate less waste. To some extent, the *narrowing the loop* CE principle relates to the resource efficiency of the linear economy because they both aim for higher efficiency and cost-saving by introducing new technologies into production processes (Bocken and Ritala, 2022). However, *narrowing the loop* is a crucial principle of the CE and this point of view is reflected in several national and regional plans. The EU's Circular Economy Action Plan 2020 highlights the ultimate goals of CE to keep “its resource consumption within planetary boundaries, and therefore strive to reduce its consumption footprint and double its circular material use rate in the coming decade” (European Commission, 2020, p.2).

The *slowing the loop* CE principle focuses on increasing product lifetime and maintaining products in use. This strategy can be achieved by enhancing product quality, maintaining and repairing products (Bocken and Ritala, 2022) through the reuse of products and extending product longevity. This principle is necessary to solve the issues that “many products break down too quickly, cannot be easily reused, repaired or recycled, and many are made for single use only” (European Commission, 2022, p.3). Finally, the *closing the loop* CE principle focuses on reusing and recycling materials and products post-usage through downcycling activities (i.e., burning and converting organic wastes into fuels) or upcycling activities (i.e., recycling materials to produce new forms of products) (Bocken and Ritala, 2022).

The CE is characterised by two main cycles: the technical cycle and the biological cycle of products and materials (Murray et al., 2017; Jabbour et al., 2019; Bocken et al., 2016). CE improves the technical cycle by increasing the technical life of the products to maintain products and technical components longer in the production-consumption loop, maximising product utility by ownership sharing, minimising value loss of products, and enhancing the technical production and consumption processes by advanced technologies such as digital technologies (Huynh and Rasmussen, 2021). Regarding the biological life of products and materials, CE aims to retain values of biomass through the activities of recycling or by-product exchanges, shift to renewable biomass, biofuels, and biomaterials, as well as to increase the lifespan of bioproducts in the loop to reduce wastes.

Innovation plays a crucial role in the CE transition (Smol et al., 2017; Konietzko et al., 2020) by creating necessary changes in products, services, and production systems, which enable more circular resource flows (Cainelli et al., 2020). Shifting towards a new CE paradigm of the technical and biological cycles requires innovation on multiple levels of the economy (de Jesus et al., 2018). At the macro level, CE innovation concerns the implementation of policies and regulations on an international, national, or regional scale. CE innovation at the *meso* level involves inter-actor collaboration, such as industrial symbiosis (de Jesus et al., 2018). Industrial symbiosis is a system to enhance integration and collaboration among actors in the same industrial system or different sectors to exchange by-products (i.e. residuals of one industry as resource inputs of another industry), optimize resource efficiency, increase material utility, and reduce greenhouse gas emissions (Domenech et al., 2019; Sun et al., 2017; Provin and de Aguiar Dutra, 2021). Micro-level CE innovation depends on the activities of individual firms (de Jesus et al., 2018) that implement circular business model innovations and technological innovations based on relevant CE strategies (Ghisellini et al., 2016).

Diverse types of innovation are required to transform the linear economy into a CE (de Jesus et al., 2018). Most CE-related innovation studies have focused on four main aspects: circular business model innovations, technology and digital technology, external and internal influences, and multiple levels and multiple actors. Research on circular business model innovation, one of the dominant literature streams, explored how firms may apply CE strategies and shift production processes from linear to new circular business models. Circular business model innovation is referred to as “a shift from a linear to a circular business model” (Linder and Williander, 2017, p. 194) or as “the conceptualisation and implementation of circular business models, which comprises the creation of circular start-ups, the diversification into circular business models, the acquisition of circular business models, or the transformation of a business model into a circular one" (Geissdoerfer et al., 2020, p. 8).

Circular business model innovation research has moved from a traditional view of the business canvas framework to more heterogenous, interdisciplinary perspectives of business model innovation and CE (Pieroni et al., 2019). Henry et al. (2020) examined circular start-ups and identified six types of circular business models in response to CE strategies, relating to design-based (i.e., reduce or reuse), waste-based (i.e., recycle or recover), platform-based (i.e., various CE strategies), service-based (i.e., various CE strategies), nature-based (i.e., regenerate), and other types (i.e., reduce, reuse, or recycle). Linder and Williander (2017) revealed that some circular business models relating to the reuse and remanufacturing strategies may induce some challenges (e.g., innovation uncertainty) for the entrepreneurs.

Several studies relating to innovation for the CE focus on specific technologies, for example, the emergence of digital technologies and automation in the CE transition (Chauhan et al., 2022; Despeisse et al., 2017; Suchek et al., 2021). Ranta et al. (2021) investigated how digital technologies (i.e., data collection, data integration, data analysis) may enable radical and incremental circular business model innovations. Another stream of research explored the drivers and barriers of CE innovation. Cainelli et al. (2020) found that environmental policy and demand-side factors were significant drivers for CE-related innovations. De Jesus and Mendonça (2018) emphasized that hard factors (e.g., technical, economic, financial, or market) and soft factors (e.g., institutional, regulatory, social, or cultural) contribute to the pathways of CE-related innovations to the CE 'transformation turn'.

The significant role of innovation for the CE is widely recognised but the research about CE-related innovations is still relatively generic and fragmented, leaving the relationships and mutual effects between CE and innovation yet to be fully explored (de Jesus et al., 2018). A more holistic view that integrates both innovation and CE attributes is lacking. De Jesus and Mendonça (2018) highlighted the significant need for better integrated, systematic views of innovation and CE research to provide a clearer understanding of how the CE transition can be facilitated. Hence, we consider CE innovation by combining both CE and innovation perspectives (Murray et al., 2017).

### 2.2. Towards a definition of CE innovation

A consolidated definition of CE innovation is lacking (Cainelli et al., 2020). To examine innovation for the CE, scholars tend to borrow the 'eco-innovation' concept (De Jesus and Mendonça, 2018). Eco-innovation is defined as innovation that contributes to improving environmental and ecological issues and to progressing sustainable development (OECD, 2009; Carrillo-Hermosilla et al., 2010; Rennings, 2000). Eco-innovation and CE innovation are related in several ways, such as their similar goals of decreasing environmental impacts, reducing pollution, and using natural resources and energy responsibly (Carrillo-Hermosilla et al., 2010; de Jesus et al., 2018). However, eco-innovation refers to sustainability as a generic, holistic concept aiming to benefit the environment, economy, and society at large without prescribing how to achieve it (Elkington, 1998; Geissdoerfer et al., 2017). CE innovation provides more explicit, pragmatic, and applicable guidance of specific strategies (e.g., reduce, reuse, recycle, or recover) for implementation at the firm level (Geissdoerfer et al., 2017). Hence, not all eco-innovation may reflect CE principles and the research field needs a more specific definition of CE innovation (de Jesus et al., 2018).

Because CE includes a variety of distinct strategies, different types of innovations are likely to vary in their potential to generate CE impacts. Hence, to develop a more systematic understanding of CE innovation types, innovation variables should be taken into account. We build on the defining attributes of innovation and the key CE principles to propose the following definition of CE innovation: *incremental or radical improvements of products, services, production processes, or business models that minimise the use of resource inputs and the generation of waste through the principles of narrowing, slowing, and closing the production-consumption loop*.

### 2.3. Towards indicators to measure CE innovations

Several indicators are used to measure the characteristics of innovations, such as product versus process, knowledge domains, and patent (see Table 1). Contexts such as market competitiveness, environmental issues, and social issues can determine firm-level innovation characteristics to a great extent (Autio et al., 2014; Dziallas and Blind, 2019; Souitaris, 2002). Hence, contextual variables are important for measuring and constructing the taxonomies of innovation (Dziallas and Blind, 2019). CE strategies may also be the significant contextual determinants for innovation given their potential influences on innovation strategies at micro, *meso*, and macro levels. This linkage between CE and innovation is closely intertwined because innovation is essential to CE (de Jesus et al., 2018). At the same time, CE strategies can also impact the management of innovation, particularly at the firm level (Blomsma et al., 2019).

Measures and taxonomies of CE-related innovations tend to be centred on CE attributes, such as circular business models and CE strategies (Smol et al., 2017; Blomsma et al., 2019; Henry et al., 2020; de Jesus et al., 2018) but less on innovation attributes. For example, to build a typology of circular start-ups, Henry et al. (2020) used determinants such as CE strategies (i.e., regenerate, reduce, reuse, recycle, or recover), downstream (i.e., product-service system or consumers' involvement) versus upstream activities (i.e., industrial symbiosis or circularity standards), and core and enabling technologies. However, conventional innovation variables such as technology domain, product versus process orientation, knowledge domain, research organisation, and collaboration have typically not been included in the investigations of CE-related innovations.

In our classification, CE innovations demonstrate inherent attributes of innovation, for example, process-oriented, product-oriented, or business model innovation; radical or incremental innovation; innovation based on basic or applied research; innovation based on patented or non-patented technology; and based on different technologies. Thus, we propose a novel approach to examining CE innovations by considering both conventional innovation attributes and CE attributes (see Table 1).

Identifying CE innovation attributes is crucial to constructing a taxonomy of CE-related firms. Classifications of innovative firms rest on the assumptions that the nature of the technology at hand shapes firm behaviour and that innovative firms have distinguishable innovation

**Table 1**
Elements and indicators of innovation constructs.

| Determinants | Indicators | Example studies |
|---|---|---|
| Nature of innovation | Product and process | Pavitt (1984), De Jong and Marsili (2006), Evangelista (2000), Tether and Tajar (2008), Peneder (2010) |
| | Sectors and technology domains | Pavitt (1984), Evangelista (2000), Autio et al. (2014), Souitaris (2002) |
| Knowledge & research | Basic and applied research | Carayol (2003), Grinstein and Goldman (2006) |
| Means of innovation | Patents | Carayol (2003), Peneder (2010) |
| Network | Collaboration with industry partners | Evangelista (2000), Souitaris (2002), De Jong and Marsili (2006) |
| | Collaboration with academic partners | Carayol (2003), Tether and Tajar (2008), Souitaris (2002), Evangelista (2000), Dziallas and Blind (2019) |
| Contextual factors | Societal, environmental, and CE influences | Smol et al. (2017), Autio et al. (2014), Luz et al. (2015) |

patterns (De Jong and Marsili, 2006; Audretsch et al., 2020). Pavitt (1984)'s seminal taxonomy of innovation modes illustrates how firms can be differentiated with regard to sectoral technologies, institutional sources and nature of technology, and characteristics of innovating firms. The author's taxonomy distinguished four types of firms (i.e., supplier-dominated firms, large-scale producers, specialised suppliers, and science-based firms). In particular, science-based firms can play an important role in the CE transition because of their role in providing knowledge and technology to other firms (Autio, 1997; Pavitt, 1984).

ASOs are set up to commercialize scientific research and are characterised as highly innovative firms (Colombo and Piva, 2012) with the potential of transforming industries (Colombo and Piva, 2012) and local economies (Pisano, 2010; Aaboen et al., 2016). However, ASOs are relatively heterogeneous in their potential of generating impacts depending on their technological and institutional backgrounds (Garnsey and Heffernan, 2005). Therefore, the characteristics of ASOs may have important implications for their impacts on the economy and society, but empirical studies on these relationships are missing (Fini et al., 2018). Hence, a taxonomy of CE-related ASOs is important for understanding whether and how different firm types are commercializing different types of CE innovations.

To explore our research question related to the types of CE innovations commercialized by ASOs, we develop two sub-questions: (1) *what are the characteristics of CE innovations commercialized by ASOs?*; and (2) *what are the clusters of CE-related ASOs?* The study is focused on the context of ASOs and classifies ASOs according to their various CE innovations. Fig. 1 illustrates the conceptual framework for this study including the selected innovation and CE variables used (see more details in Section 3.2).

## 3. Method

### 3.1. Data

We obtained our sample from a database compiled by the Research Council of Norway comprising the population of 373 Norwegian ASOs established between 1999 and 2011. The ASOs were new ventures established to commercialize research results from publicly funded research organisations and were reported annually to the database. About two-thirds of the ASOs originated from universities and one-third from research institutes (Mathisen and Rasmussen, 2022). Similarly to other developed countries, the creation of ASOs has been stimulated by the Norwegian government and research organisations in an effort to increase research-based value creation (Fini et al., 2017).

Our data collection and coding process entails three main stages as shown in Fig. 2. In the first stage, we relied on collected data for the whole population of 373 ASOs. This data included the firms' annual reports that are mandatory for all firms in Norway (including the statement by the board of directors, detailed financial statements approved by a registered public accountant, and notes), all corporate announcements registered on the firms, obtained from the National Register of Business Enterprises in Norway, and patent data collected from the Norwegian Industrial Property Office. This extensive longitudinal data from 1999 until 2019 allowed us to map the firms' financial activities (e.g., sales, revenues, and assets) and operational events (e.g., survival, patent, and technology transfer) from their establishment until 2019 or exit. By using a comprehensive newspaper archive (i.e., A-tekst/Retriever) and internet search engines, we identified and downloaded 4252 articles written about 295 of the ASOs in the population of 373 firms. We excluded the remaining 79 ASOs that were early failures with no media coverage.

In the second stage, we selected our sample of ASOs with CE potential impacts. To identify CE-related ASOs and be able to code CE innovation variables, we primarily used media-coverage data. However, we also consulted other sources, such as company websites, annual reports, and financial statements to complement the news articles and achieve a more detailed understanding of the ASOs' CE innovations. We coded ASOs with CE potential as ‘1’ and ‘0’ otherwise. Notes were written down to justify the decisions. For example, one ASO developed a new chemical gel to reduce water consumption by 35 % and increase oil recovery by 30 % during oil drilling. This ASO's innovation was coded as the reduce strategy. Another ASO developed a technology to convert lignocellulosic biomass and organic residues to transportation fuels. The CE innovation of this ASO was coded as the recover strategy. After this round, a sample of 60 ASOs that commercialized CE-related innovations was obtained. The CE-related ASOs introduced different advanced technologies (e.g., digital technology, nanotechnology, biotech, energy and environmental technology, and material technology) and were involved in various sectors (e.g., oil and gas, processing, aquaculture, marine, energy, and environment). The medical technology and pharmacy sectors had no CE-related ASOs. A majority of CE-related ASOs in the sample (about 43 %) introduced digital technologies (e.g., sensors, digital platforms, software, application, and 3D models) and about two-thirds of the firms introduced process innovations. The reduce strategy and the optimize model were the most used ones by the ASOs.

In the third stage, we coded the remaining CE and innovation variables. This stage entails qualitative coding followed by quantitative coding. In the qualitative coding, we re-read the data for the 60 CE-

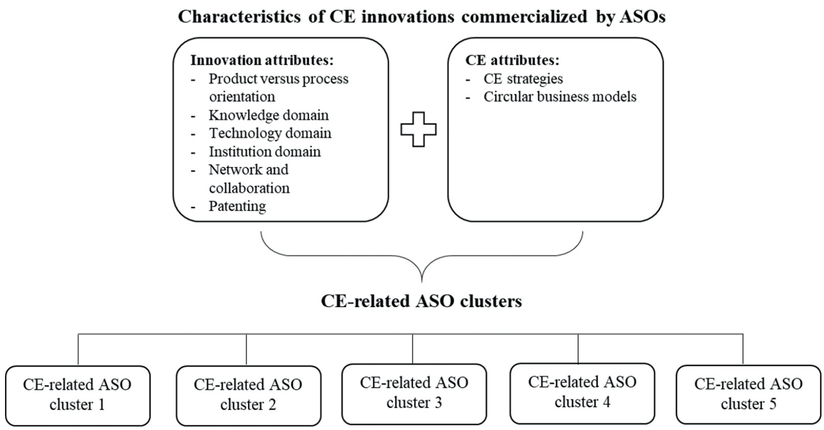


**Fig. 1.** The conceptual framework.

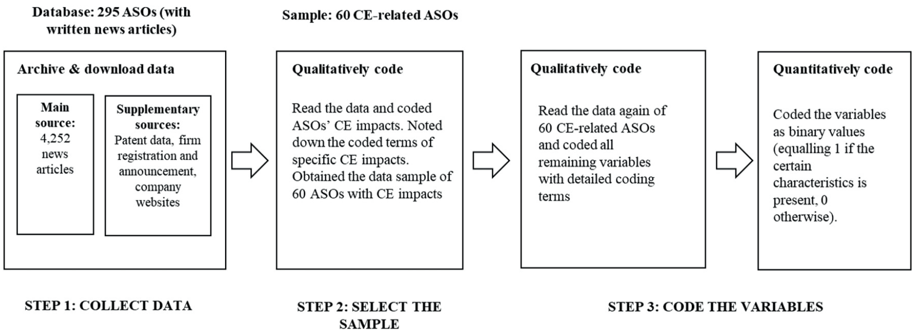


**Fig. 2.** The process of data collection and coding.

related ASOs, identified relevant article contents, and assigned them to variable categories that reflected key innovation attributes and CE attributes. Then, we quantified these qualitatively coded terms and coded twenty-one variables as binary values equalling '1' if the ASO exhibited the given attribute and '0' otherwise.

To improve coding reliability and reduce perception bias, the first author of this article and a research assistant independently coded the data. Before coding, the coders were trained to fully understand the

**Table 2**
Innovation and CE-related variables used in this study.

| | Category | Variable | Label | Description |
|---|---|---|---|---|
| Innovation characteristics | Technology domain | Digital technology | Dig | =1 if the CE innovation is involved in digital technology<br>=0 otherwise |
| | | Material technology/ nanotechnology | Mat. nano | =1 if the CE innovation is involved in material technology/ nanotechnology<br>= 0 otherwise |
| | | Biotechnology/chemical | Bio.che | =1 if the CE innovation is involved in Biotechnology/chemical technology<br>= 0 otherwise |
| | | Energy/environmental technology | Eng | =1 if the CE innovation is involved energy or environmental technology<br>= 0 otherwise |
| | | Maritime technology | Mar | =1 if the CE innovation is involved maritime technology<br>= 0 otherwise |
| | Product versus process | Product innovation | Prod | =1 if CE innovation of the firm is product oriented<br>=0, otherwise |
| | | Process innovation | Proc | =1 if CE innovation of the firm is process oriented<br>=0, otherwise |
| | Basic versus applied research | Basic research | SB-gen | =1 if the CE innovation of the firm is based on basic research<br>=0, otherwise |
| | | Applied research | SB-sac | =1 if the CE innovation of the firm is based on applied research<br>=0, otherwise |
| | Academic institution | Research institute | RI | =1 if the firm is originated from the research institute<br>=0, otherwise |
| | | University | Uni | =1 if the firm is originated from the university<br>=0, otherwise |
| | Industry partnership | Industry partnership | Ind | =1 if the CE innovation involves in a industry partnership<br>=0, otherwise |
| | Patent | Patent | Pat | =1 if the CE innovation is patented<br>= 0, otherwise |
| Circular economy characteristics | CE strategy | Reduce | Red | =1 if the CE innovation involves the reduce strategy<br>=0, otherwise |
| | | Recover | Rec | =1 if the CE innovation involves the recover strategy<br>=0, otherwise |
| | | Extend product longevity | Ext | =1 if the CE innovation involves the extend product longevity strategy<br>=0, otherwise |
| | | Recycle/reuse | Rec.Reu | =1 if the CE innovation involves the recycle or reuse strategy<br>= 0, otherwise |
| | Circular business model | Regenerate | Reg | =1 if the CE innovation is related to the 'regenerate' business model<br>=0, otherwise |
| | | Optimize | Opt | =1 if the CE innovation is related to the 'optimize' model<br>=0, otherwise |
| | | Virtual | Vir | =1 if the CE innovation is related to the 'virtual' model<br>=0, otherwise |
| | | Loop | Loop | =1 if the CE innovation is related to the 'loop' model<br>=0, otherwise |

coding framework and terminologies. In the case of coding disagreement, the two coders compared and discussed their coding, and a third coder was consulted to serve as the judge.

### 3.2. Innovation and CE-related variables

The quality and reliability of classifications are dependent on the selection of variables, which should be based on both theoretical and empirical considerations (De Jong and Marsili, 2006). We were able to include key innovation and CE variables as shown in Table 2 and outlined below.

#### 3.2.1. Innovation variables

*Technology domain* refers to the type of technology the innovation is related to, which is found to impact firm growth and innovation strategies (Autio et al., 2014). The heterogeneity of sectoral technologies distinguishes the types of sectoral firms and innovation strategies. The ASOs in this study are specialised in five technology domains (i.e., digital, material technology/nanotechnology, biotechnology/chemical, energy/environmental, and maritime).

*Product* versus *process innovation* is frequently used to measure innovation in prior studies (De Jong and Marsili, 2006; Tether and Tajar, 2008; Peneder, 2010; Pavitt, 1984). Process innovation refers to direct or indirect new or substantially improved methods and inputs (i.e. equipment, software, and techniques) for the production and delivery processes within or between firms (OECD, 2005). Product innovation refers to new or significantly improved goods and services offered to end-users (OECD, 2005).

*Basic* versus *applied research* reflects the nature of research inputs for the innovation. Scientific research in academic institutions is the main source of knowledge input for ASOs in high-tech industries, such as ICT, biotechnology, nanotechnology, chemicals, and energy (Pavitt, 1984). Basic research seeks to understand a phenomenon or theory without considering particular applications, whereas applied research produces scientific knowledge for specific practical objectives or applications (Lim, 2004; OECD, 2015).

*Academic institution* indicates the parent organisation of an ASO. ASOs are usually originating from a university, but a significant share of academic research is performed by public research institutes. The latter institutes have no teaching obligations and are often conducting more applied research in collaboration with industry (Gulbrandsen, 2011). The types of CE innovations commercialized by ASOs may depend on the type of academic institution it comes from (i.e. university or public research institute).

*Industry partnership* relates to whether an ASO was set up in collaboration with an industrial partner. ASOs established as joint ventures with industry are regarded as being better in overcoming major development milestones (Munari and Toschi, 2011; Wright et al., 2004). This is because they are better at recognizing market opportunities, building legitimacy, and accessing critical resources and capabilities. Some CE strategies, particularly at the *meso* level, require higher between-firm collaborations to facilitate reuse of materials and by-product exchanges (de Jesus et al., 2018).

*Patent* is an indirect indicator of innovation that represents new technologies (Dziallas and Blind, 2019). Patents are considered a relatively reliable measurement of innovation activity (Acs et al., 2002), despite some limitations. For example, not all innovations are patented; patenting propensity depends on firms' innovation orientation such as product versus process, sector, and firm size; and inventions or radical innovations are more likely to be patented (Arundel and Kabla, 1998). Technology-based firms, such as ASOs, generally have a high patenting rate (Audretsch, 2002; Rydehell et al., 2019). Patenting among ASOs may also be associated with institutional, regional and organisational factors at the research organisation (Ar et al, 2021; Temel et al., 2021).

#### 3.2.2. CE variables

*CE strategies* reflect the main strategies to enable a CE. The reduce strategy is used to minimise energy consumption, resource use, and waste emissions. The recover strategy means incinerating and converting residuals of unrecyclable waste into energy. The extend product longevity strategy through product designs and biochemical effects is often not explicitly mentioned in the four R framework but it is an essential CE strategy, especially for the biogeochemical cycle (Bocken et al., 2016). The recycle strategy involves the processing to extract secondary material from used waste materials or goods. The reuse strategy involves the second or further use of waste materials or products. This strategy can be grouped with the recycle strategy in the *closing the loop* principle (Bocken et al., 2016) when it indicates the reuse of waste materials from one process or one industry to another one. Moreover, the reuse strategy can be grouped with the extend product longevity strategy in *slowing the loop* principle (Bocken and Ritala, 2022) when it indicates the reuse of second-hand products. We grouped recycle and reuse into one variable category (recycle/reuse) because only a few companies belonged to the reuse and recycle categories. Moreover, the ASOs are engaged in reusing of waste materials, not second-hand products. Hence, in our context, the reuse strategy has closer meaning with the recycle strategy than the extend product longevity strategy.

*Circular business models* relate to the models that ASOs can adopt to commercialize CE innovations. Circular business models define how firms structure, innovate, and create value by narrowing, slowing, and closing the production-consumption loop. To measure different types of circular business models, we relied on the ReSOLVE framework proposed by the Ellen MacArthur Foundation (2015). Rosa et al. (2019) highlighted the simplicity but comprehensiveness of the ReSOLVE framework, which has become widely used to classify circular business models (Mendoza et al., 2017; De Angelis and Feola, 2020; Jabbour et al., 2019). This framework relates to six distinct circular business models (i.e., regenerate, share, optimize, loop, virtual, and exchange) (see Table 3). It is important to note that some firms may combine several circular business models simultaneously (Henry et al., 2020). During the coding, we found only the regenerate, optimize, loop, and virtual models among the ASOs. Therefore, the share and exchange models are not included in our analysis.

### 3.3. Multiple correspondence analysis

MCA with agglomerative hierarchical clustering was employed to generate a classification of CE-related ASOs based on CE innovations. MCA is a multivariate unsupervised learning method commonly used for exploratory, inductive research to explore new patterns in data, as well as to conduct quantitative predictions and construct taxonomies rather than deductive research and hypothesis testing (Greenacre and Blasius, 2006; Hoffman and De Leeuw, 1992; Clausen, 1998). MCA is not restricted by small samples and qualitative survey data and is

**Table 3**
The ReSOLVE framework.

| CE business models | Objectives |
|---|---|
| Regenerate | Shifting to renewable energy and materials, restoring the ecosystem, or returning recovered biological resources back to the biosphere. |
| Share | Sharing ownership and asset. |
| Optimize | Increasing production efficiency to reduce waste and reduce resource consumption. |
| Virtual | Dematerialising physical objects and offering virtual products or services. |
| Loop | Circulating the resource flow by extending product longevity, recycling, and reusing materials and products. |
| Exchange | Radically shifting the production-consumption paradigm through disruptive technologies, such as 3D printing. |

Source: Ellen MacArthur Foundation (2015) increasingly being used in a broad range of management and innovation studies (e.g., Parchomenko et al. (2019), Albats et al. (2022), Tether and Tajar (2008)). MCA can be useful for early-phase research fields, such as the CE field, that are characterised by limited theory development and small sample sizes.

MCA is conceptually analogous to principal components analysis (Greenacre and Blasius, 2006). However, MCA focuses on categorical variables on the same response scales instead of continuous variables (Greenacre, 2017). No prior hypothesis or distributional assumptions are required to apply this method. This is because MCA measures similarities between objects (i.e. ASO cases in rows and variables in columns) (Hoffman and De Leeuw, 1992). MCA provides solutions with multiple dimensions and produces a low-dimensional solution (i.e., often a two-dimensional plot) by assessing weighted least-square distance to identify the closet plane to the centre, and visualizing the points on the plane for interpretation (Di Franco, 2016; Greenacre, 2017). The MCA low-dimensional plot should include only the most important dimensions (i.e., the numbers of axes), based on the inertia percentage and the interpretability of the dimensions (Hoffmann, 1982). By applying MCA, we can uncover the relationships between variables (i.e., columns), the relationships between ASO cases (i.e., rows), and the relationships between variables and ASOs (Greenacre and Hastie, 1987).

To complement the MCA, we used agglomerative hierarchical clustering to elucidate the profiles of the ASO classification. Agglomerative hierarchical clustering is an algorithm that merges each pair of ASOs based on their nearest similarity distances and builds a dendrogram tree relating to the clustering (Jain et al., 1999; Bouguettaya et al., 2015). This technique enables researchers to identify nested partitions and draw contours around clusters on the MCA plot. Due to the categorical nature of our data, the cluster analysis relates to simple matching coefficients rather than regular Euclidean distances (Gower, 1971; Šulc and Řezanková, 2019). The open-source statistical software packages 'nonclust' (Sulc et al., 2020) and 'ca' (Nenadic and Greenacre, 2007) from the R environment were used.

MCA assesses the proximity between variables and between variables and the cases (i.e., ASOs) to examine the associations between them. The first interpretation of the MCA plot can be based on the proximity of the variables to the centre (i.e. origin point). Each variable and case is displayed as a coordinate point on the MCA low-dimensional plot (Greenacre and Hastie, 1987; Greenacre, 2017). The further a variable or a case locates from the centre, the higher variation of the objects is compared with the object's average patterns (Greenacre, 2017; Di Franco, 2016). It means that variables or cases situated further away from the centre are likely to have more distinctive, unique characteristics compared to the others. Conversely, variables or cases located near the centre have characteristics closer to the average pattern of the categories or appear more often in the dataset. The second important interpretation of the MCA plot relates to the distance between the variables, which shows to what extent the variables can be related. Closer proximity between variables or between cases suggests a higher degree of association between them or that they have similar characteristics (Greenacre, 2017; Di Franco, 2016).

## 4. Results

### 4.1. Characteristics of CE innovations commercialized by ASOs

To identify the types of CE innovations commercialized by ASOs, we used MCA to plot potential relationships between innovation and CE variables as shown in Fig. 3. The first dimension along the horizontal axis relates to the CE strategies of reduce, recover, recycle/reuse, and extend product longevity. The four CE strategies are distributed from left to right, also reflecting the principles of narrowing (i.e., reduce), slowing (i.e., extend product longevity), and closing (i.e., recover, recycle/reuse) the production-consumption loop. This dimension yielded 37 % of total inertia. The second dimension along the vertical axis differentiates

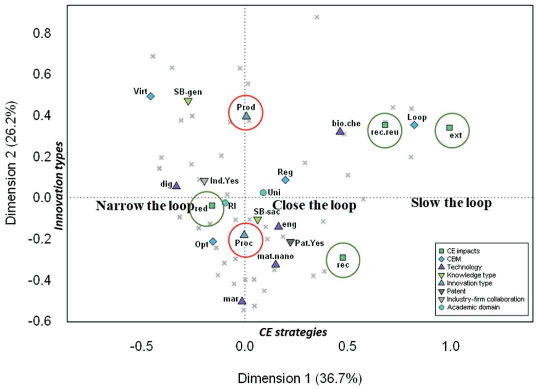


**Fig. 3.** MCA plot of the variables along the two dimensions of innovation types and CE strategies.

between product innovation located above the horizontal axis and process innovation located below. This dimension yielded 26 % of total inertia. Adding the third dimension increased the total inertia by only 10 %. A two-dimensional solution was therefore employed.

The MCA plot shows that the variables reduce, industry partnership, optimize, regenerate, university, research institute, digital technology, and energy/environment technology appear more frequently in the dataset and are therefore located close to the centre of the plot. These variables have values that are relatively similar to the average value of their variable categories. In contrast, the variables virtual, basic research, maritime technology, biochemical technology, recycle/reuse, loop, and extend product longevity, that are located further away from the centre, appear less frequently or seem to have more distinctive attributes.

Regarding the CE strategies, the MCA plot shows that the reduce strategy relating to *narrowing the loop* concerns both product and process innovations, and is most related to the optimize model, digital technology, industry collaboration, and research institutes. The digital technology variable is situated between the virtual and optimizes model variables as well as between the product and process innovation variables. This suggests that digital technology may be widely applicable for both product and process innovations in the virtual and optimize models. However, the virtual model is more likely to involve product innovations, whereas the optimize model is more likely to involve process innovations. Notably, the virtual model variable is close to the basic research and product innovation variables.

The recycle/reuse and extend product longevity strategies for *slowing the loop* tend to be associated with the loop model and biotechnology/chemical technology. They are situated on the upper right quadrant of the plot, and far from the other variables. This group of variables is linked more to product than process innovations. ASOs commercializing CE innovations related to biotechnology/chemical technology tend to adopt the loop model and introduce product innovations for extending product longevity, recycling, and reusing products and materials.

The recover strategy for closing the product-consumption loop is more likely to be associated with process innovations. This CE strategy is related to the material technology/nanotechnology, energy/environmental technology, applied research, and patent variables. The energy/environmental and material science/nanotechnology variables are located close to each other. This closeness suggests that these technologies can be used to achieve the same CE strategy. Conversely, the variables digital technology and biochemical technology are located at the opposite ends of the plot.

### 4.2. Constructing the clusters of CE-related ASOs

Using MCA and agglomerative hierarchical clustering analysis we constructed a taxonomy of five distinct types of CE-related ASOs: smart product-service providers, technical process enhancers, biochemical cycle extenders, renewables providers, and biosphere regenerators. These five clusters were positioned along two dimensions relating to the innovation types (i.e., product versus process innovations), and the CE principles (i.e., narrowing, slowing, and closing the production-consumption loop) as visualised on the MCA plot in Fig. 4. A profile of each cluster including the innovation and CE variables in percentages is presented in Table 4. Table 5 summarises the five clusters and their main innovation and CE attributes.

#### 4.2.1. Cluster 1: the smart product-service provider

Cluster 1 is labelled 'smart product-service providers' and relates to 8 ASOs offering virtual products and services. The location on the upper left quadrant of the MCA plot and far from the other clusters suggests that Cluster 1 has distinct characteristics compared to the other four clusters. The ASOs in this cluster focus on the *narrowing the loop* principle, use only digital technologies, and are strongly associated with the reduce strategy. These ASOs adopt the virtual model to deliver digital artefacts and digital platforms for substituting or dematerialising physical products to simultaneously increase resource efficiency and reduce costs, resource consumption, and waste. All CE innovations in this cluster are product-oriented. Several CE innovations of this cluster are relatable to the collaborative or access-based consumption of the 'sharing economy' concept (Sánchez-Pérez et al., 2021). For example, e-learning courses increase virtual collaborations between users and reduce the use of materials for paper books, transportation, and logistics related to organising physical teaching. Another example is the virtual laboratories that minimise prototype waste, resource use, and energy consumption. Further, these CE innovations make not only environmental impacts but also economic impacts by helping reduce the unit costs of collaborating, training, and developing products and services. The CE innovations in this cluster derive from both applied and basic research mostly by universities. None of the firms in this cluster patent their digital CE innovations.

#### 4.2.2. Cluster 2: technical process enhancer

Cluster 2 is labelled 'technical process enhancers' and relates to 35 ASOs commercializing CE innovations to increase productivity and efficiency. This cluster is centrally located on the MCA plot. The ASOs also focus on the *narrowing the loop* principle and exploit technological advances relating to different types of technologies to improve production performances (i.e., oil drilling, fish farming, or energy generation). The ASOs in this cluster typically use process innovations (94 %) to reduce the consumption of natural resources and energy, as well as to reduce waste emissions. For this cluster, digital technologies (e.g., cyber-physical systems integrating real-time data, sensors, simulation, and robotics) are the key enabler to achieve resource efficiency, optimize production performance, reduce shutdown time, decrease resource inputs, and lower carbon dioxide output. The CE process innovations of Cluster 2 rely heavily on applied research and are more often created by research institutes than universities. About half of the CE innovations in Cluster 2 are patented and most ASOs have industry partnerships. The largest subgroups of ASOs in this cluster relate to the oil/gas/offshore sector and the maritime/aquaculture sector.

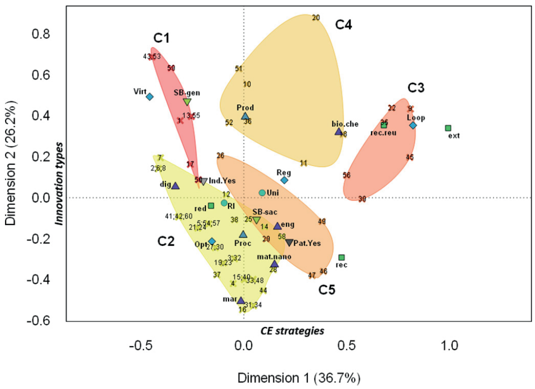


**Fig. 4.** The five clusters (C1–C5) visualised on the MCA plot.

#### 4.2.3. Cluster 3: biochemical cycle extender

Cluster 3 is labelled 'biochemical cycle extenders' and relates to 6 ASOs commercializing innovations to extend the biochemical lifecycle of materials and products. This cluster is situated on the right periphery of the MCA plot, quite far from the centre and near Cluster 2 and Cluster 4 but opposite Cluster 1. The ASOs in this cluster focus on the *slowing the loop* principle and exploit technologies (i.e. biotechnology/chemical technology or material technology/nanotechnology) that keep materials and products in longer, recursive use and revive end-of-use products and materials for a second life. This cluster engages in the recycle and reuse, and the extend product longevity strategies. The ASOs contribute to reducing biomass waste. Cluster 3 ASOs commercialize both product innovations (i.e. new instruments or substances) and process innovations (i.e. new logistics or production methods) and adopt the loop model. The CE innovations tend to be based on applied research by universities and often include patented technologies. None of the ASOs are established with industry partnership.

#### 4.2.4. Cluster 4: renewables provider

Cluster 4 is labelled 'renewables provides' and relates to 5 ASOs commercializing innovations to shift to renewable materials and products. This cluster is located in the upper-middle space of the MCA plot. The ASOs focus on the *closing the loop* principle and produce biomaterials, biofuels, bioenergy, bio proteins, sustainable chemicals, and pharmaceuticals to replace the use of fossil fuels and the extraction of finite natural resources. Moreover, the ASOs optimize the use of renewable natural resources, for example, microalgae, aquatic plants, and microorganisms, and recycle natural gas and carbon dioxide to create values of renewable ingredients and energy inputs. They rely primarily on biotechnology/chemical technology and energy/environmental technology to transform from a fossil-based to a more circular, bio-based economy. Their CE strategies are reduce, recycle, and reuse to be adopted in the regenerate model in various sectors progressing a shift towards biomaterial consumption. Their CE innovations tend to introduce CE product innovations and are based on basic research. Their parent organisations are often research institutes. They report lower rates of patented innovations but higher rates of industry collaboration compared to firms in Cluster 3.

#### 4.2.5. Cluster 5: biosphere regenerator

Cluster 5 is labelled 'biosphere regenerators' and relates to 6 ASOs commercializing innovations to convert non-recyclable waste into energy and resources through by-product exchange between actors in a production system and make material flow regenerative. This cluster is located in the lower space of the MCA plot near Cluster 2. The ASOs focus on the *closing the loop* principle and relate to the recover and reduce strategies and the regenerate model. Energy technology is the primary technology in this cluster, together with biotechnology/chemical technology. Cluster 4 ASOs are involved in industrial symbiosis, whereby the wastes from one firm become valuable resources for another firm. They have the highest patent rate and the highest rate of industry partnerships. Further, Cluster 5 ASOs are more inclined to

**Table 4**
Cluster profiles with the percentages of innovation and CE variables in each cluster.

| Variable | Description | Total | Cluster 1 (8 firms) | Cluster 2 (35 firms) | Cluster 3 (6 firms) | Cluster 4 (5 firms) | Cluster 5 (6 firms) |
|---|---|---|---|---|---|---|---|
| Dig | CE innovations related to digital technology | 43.33 % | **100.00 %** (56.67 %) | **52.94 %** (9.61 %) | 0.00 % (−43.33 %) | 0.00 % (−43.33 %) | 0.00 % (−43.33 %) |
| Mat.nano | CE innovations related to material technology or nanotechnology | 10.00 % | 0.00 % (−10.00 %) | 14.71 % (4.71 %) | 16.67 % (6.67 %) | 0.00 % (−10.00 %) | 0.00 % (−10.00 %) |
| Bio.che | CE innovations related to bio technology or chemical technology | 21.67 % | 0.00 % (−21.67 %) | 5.88 % (−15.78 %) | **66.67 %** (45.00 %) | **85.71 %** (64.05 %) | 20.00 % (−1.67 %) |
| Eng | CE innovations related to energy or environmental technology | 18.33 % | 0.00 % (−18.33 %) | 14.71 % (−3.63 %) | 16.67 % (−1.67 %) | 14.29 % (−4.05 %) | **80.00 %** (61.67 %) |
| Mar | CE innovations related to maritime technology | 6.67 % | 0.00 % (−6.67 %) | 11.76 % (5.10 %) | 0.00 % (−6.67 %) | 0.00 % (−6.67 %) | 0.00 % (−6.67 %) |
| Prod | CE product innovations | 31.67 % | **100.00 %** (68.33 %) | 5.88 % (−25.78 %) | **33.33 %** (1.67 %) | **100.00 %** (68.33 %) | 0.00 % (−31.67 %) |
| Proc | CE process innovations | 68.33 % | 0.00 % (−68.33 %) | **94.12 %** (25.78 %) | **66.67 %** (−1.67 %) | 0.00 % (−68.33 %) | **100.00 %** (31.67 %) |
| SB-gen | CE innovations based on basic research | 18.33 % | **37.50 %** (19.17 %) | 8.82 % (−9.51 %) | 0.00 % (−18.33 %) | **57.14 %** (38.81 %) | 20.00 % (1.67 %) |
| SB-SAC | CE innovations based on applied research | 81.67 % | **62.50 %** (−19.17 %) | **91.18 %** (9.51 %) | **100.00 %** (18.33 %) | 42.86 % (−38.81 %) | **80.00 %** (−1.67 %) |
| RI | CE-related ASOs originated by research institutes | 48.33 % | 25.00 % (−23.33 %) | **58.82 %** (10.49 %) | 16.67 % (−31.67 %) | **71.43 %** (23.10 %) | 20.00 % (−28.33 %) |
| Uni | CE-related ASOs originated by universities | 51.67 % | **75.00 %** (23.33 %) | 41.18 % (−10.49 %) | **83.33 %** (31.67 %) | 28.57 % (−23.10 %) | **80.00 %** (28.33 %) |
| Ind | CE innovations that involves Industry partnership | 38.33 % | 37.50 % (−0.83 %) | 41.18 % (2.84 %) | **0.00 %** (−38.33 %) | 42.86 % (4.52 %) | **60.00 %** (21.67 %) |
| Pat | CE innovations that was patented | 48.33 % | **0.00 %** (−48.33 %) | 55.88 % (7.55 %) | 66.67 % (18.33 %) | **28.57 %** (−19.76 %) | **80.00 %** (31.67 %) |
| Red | CE innovations related to reduce strategy | 81.67 % | **100.00 %** (18.33 %) | **100.00 %** (18.33 %) | 0.00 % (−81.67 %) | **71.43 %** (−10.24 %) | 40.00 % (−41.67 %) |
| Rec | CE innovations related to recover strategy | 5.00 % | 0.00 % (−5.00 %) | 0.00 % (−5.00 %) | 0.00 % (−5.00 %) | 0.00 % (−5.00 %) | **60.00 %** (55.00 %) |
| Ext | CE innovations related to ‘extend product longevity’ strategy | 5.00 % | 0.00 % (−5.00 %) | 0.00 % (−5.00 %) | **50.00 %** (45.00 %) | 0.00 % (−5.00 %) | 0.00 % (−5.00 %) |
| Rec.reu | CE innovations related to recycle and reuse strategy | 8.33 % | 0.00 % (−8.33 %) | 0.00 % (−8.33 %) | **50.00 %** (41.67 %) | **28.57 %** (20.24 %) | 0.00 % (−8.33 %) |
| Opt | CE innovations related to ‘optimize’ circular business model | 55.00 % | 25.00 % (−30.00 %) | **91.18 %** (36.18 %) | 0.00 % (−55.00 %) | 0.00 % (−55.00 %) | 0.00 % (−55.00 %) |
| Virt | CE innovations related to ‘virtual’ circular business model | 11.67 % | **75.00 %** (63.33 %) | 2.94 % (−8.73 %) | 0.00 % (−11.67 %) | 0.00 % (−11.67 %) | 0.00 % (−11.67 %) |
| Loop | CE innovations related to ‘loop’ circular business model | 11.67 % | 0.00 % (−11.67 %) | 0.00 % (−11.67 %) | **100.00 %** (88.33 %) | 14.29 % (2.62 %) | 0.00 % (−11.67 %) |
| Reg | CE innovations related to ‘regenerate’ circular business model | 21.67 % | 0.00 % (−21.67 %) | 5.88 % (−15.78 %) | 0.00 % (−21.67 %) | **85.71 %** (64.05 %) | **100.00 %** (78.33 %) |

The significant percentages of dominant clusters in each CE innovation attribute.

**Table 5**
Taxonomy of ASOs pursuing CE innovations.

| CE principles<br><br>Innovation | Narrow the loop (reduce) | Slow the loop (extend, reuse) | Close the loop (recycle, recover) |
|---|---|---|---|
| Product innovations | CLUSTER 1: SMART PRODUCT-SERVICE PROVIDER<br>Offering virtual products and services<br><br>• Product innovations<br>• Virtual (dematerialise)<br>• Reduce resource consumption and waste<br>• General knowledge<br>• No patent rate | CLUSTER 3: BIOCHEMICAL CYCLE EXTENDER<br>Extending the biochemical lifecycle of materials and products<br><br>• Product innovations<br>• Process innovations<br>• Loop (extend lifecycle)<br>• Extend product/material longevity, reuse, recycle<br>• Applied knowledge<br>• High patent rate | CLUSTER 4: RENEWABLES PROVIDER<br>Shifting to sustainable renewable materials and products<br><br>• Product innovations<br>• Regenerate (shift to renewable energy/resources)<br>• Reduce resource consumption, recycle, reuse<br>• General knowledge<br>• Low patent rate |
| Process innovations | CLUSTER 2: TECHNICAL PROCESS ENHANCER<br>Increasing productivity and efficiency<br><br>• Process innovations<br>• Optimize (enhance production process)<br>• Reduce resource consumption and waste<br>• Applied knowledge<br>• High patent rate | | CLUSTER 5: BIOSPHERE REGENERATOR<br>Converting non - recyclables into energy and resources<br><br>• Process innovations<br>• Regenerate (convert non-recyclable waste into resources)<br>• Reduce resource consumption, recover<br>• Applied knowledge<br>• Very high patent rate |

commercialize process innovations that are based on applied research and they originate mostly from universities.

## 5. Discussion

More than half of the CE-related ASOs belong to Cluster 2 'technical process enhancers'. Accordingly, the majority of CE innovations involve the *narrowing the loop* principle, the reduce strategy (81 %), and the optimize model (55 %). This empirical evidence appear contrary to several studies suggesting that the *closing the loop* principle and the recycle strategy are dominant among firms initiating CE efforts (Ghisellini et al., 2016; Merli et al., 2018). However, this difference may be related to the sample of ASOs in this study. Hence, our findings confirm the claims of Henry et al. (2020), Parchomenko et al. (2019), and Merli et al. (2018) that CE innovations introduced by new entrants are mostly related to the reduce strategy to optimize resource efficiency and minimise waste residues. This also aligns with other studies finding that many firms focus on technical solutions to achieve resource efficiency and production circularity (Rajput and Singh, 2019).

CE innovations relating to the reduce strategy, the optimize model, and digital technologies seem like an attractive basis for establishing ASOs. The improvements in productivity and efficiency from these innovations could result in clear economic gains, such as reducing raw material and energy costs by minimising resource scarcities, reducing value loss through waste, and paving the paths for new markets by retaining the value of goods and materials (Korhonen et al., 2018; Lieder and Rashid, 2016). Thus, resource efficiency and production optimization through highly innovative technologies and the reduce CE strategy could be more prevalent among new firms with fewer resources, while the recycle and reuse strategies are more relevant to large firms with structural inertia that add incremental CE innovations to their existing business models. The divergence in the CE strategies of large firms versus small and start-up firms underscores the value of developing taxonomies for specific types of firms.

ASOs commercialize CE innovations related to both the biological and technical cycles (Leipold and Petit-Boix, 2018), but predominantly in the technical cycle. Cluster 1 'smart product-service providers' and Cluster 2 'technical process enhancers' are both related to the technical cycle to improve cleaner production and reduce the amount of waste residual and resource use. The main difference between these two clusters is that Cluster 1 focuses on downstream activities with product-service innovations on the consumption side, while Cluster 2 focuses on upstream activities with process innovations on the production side. Cluster 1 and Cluster 2 can together generate combinatory effects on the technical side of the production-consumption system. Digital technology is dominant among ASOs in Cluster 1 and Cluster 2. The smart product-service providers focus on developing digital artefacts and platforms (i.e. new configuration, features, digital products, and services) through the virtual model to deliver products and services to end-user consumers. The technical process enhancers provide digital infrastructure (i.e. the Internet of Things, automation, sensors) through the optimize model to improve manufacturing and logistics processes.

The biogeochemical cycle and the CE are tightly intertwined (Leipold and Petit-Boix, 2018). We found that the CE innovations of Cluster 3 'biochemical cycle extenders', Cluster 4 'renewables providers', and Cluster 5 'biosphere regenerators' are related to the biogeochemical cycle. These innovations entail recycling and converting residuals into inputs and energy, thereby replacing crude-oil substances with bio-based substances or extending product longevity. Although ASOs in both Cluster 3 and Cluster 4 relate to the same biogeochemical cycle, their business activities and CE principles are largely different. Cluster 3 relates to the *slowing the loop* principle, and entails the loop model to extend product longevity and bring second lives to materials and products. Cluster 4 relates to the *closing the loop* principle and entails the regenerate model of shifting towards biomaterial uses. Cluster 3 uses biotechnology/chemical technology and entails the loop model to enhance the quality and extend the longevity of organic products. The CE literature shows that the product-service system (also called servitised model) can also be used to extend the longevity of technical products by sharing ownership and reusing products (Tukker, 2015). However, Cluster 3 firms did not engage in activities extending the lifecycle of technical products. This may be because ASOs tend to be high-technology firms rather than service-based firms.

Cluster 5 uses the same regenerate model as Cluster 4, but their innovations relate to different CE strategies. Cluster 5 captures the value loss of non-recyclable items by converting residual outputs of one production process into new forms of energy resources or inputs to another production process. Conversely, Cluster 4 focuses on sustainable product designs and replacing non-renewable with renewable resources by using, reusing, and recycling abundant natural materials. Consequently, the technologies of Cluster 4 and Cluster 5 are also dissimilar, as the renewables providers exploit biotechnology/chemical technology, while the biosphere regenerators use energy technology/environmental technology.

In terms of the CE benefits from the interactions among actors (Ghisellini et al., 2016), CE innovations of the ASOs may entail industrial symbioses and firm partnerships to supply and transfer technologies from one firm to another (i.e., Clusters 1 and Cluster 2 relating to the *narrowing the loop* principle), or to facilitate the exchanges of CE materials and products between firms (i.e., Cluster 4 and Cluster 5 relating to the *closing the loop* principle). We found that industrial symbiosis is particularly important to Cluster 4 and Cluster 5 that facilitate resource exchanges and by-product utilisations among organisations in a network to retain residual value in the 'take-back' system and replace non-renewable with renewable material inputs (Ghisellini et al., 2016). Value retention can focus on retaining the value of recyclable materials and products (i.e., the recycle strategy) or the value of non-recyclable materials by converting them into other types of resources, such as waste into energy (i.e., the recover strategy). Finally, both Cluster 5 and Cluster 2 create process innovations to reduce resource inputs and waste outputs. Although the results are similar, their processes differ. While Cluster 2 reduces consumption by increasing production efficiency, Cluster 5 regenerates non-recyclable waste into energy to minimise new resource extraction.

## 6. Conclusions and implications

This study examines the potential roles of innovative start-ups, such as ASOs, in commercializing science-based innovations with potential CE impacts. Our results indicate that ASOs play an important role in converting scientific knowledge and radical innovations into applications that facilitates the CE transition of narrowing, slowing, and closing the production-consumption loop. By developing a taxonomy based on innovation and CE characteristics, our study provides three key contributions.

First, by focusing on technology supply, this taxonomy adds an important dimension to the growing CE literature which has predominantly considered the role of policy regulations and market demand (Cainelli et al., 2020). A relatively large share of the ASOs in our sample pursued CE-related innovations and our taxonomy shows that the ASOs rely on different types of CE principles and commercialize both product and process innovations. The technologies developed by ASOs can be a significant source of CE innovations. The largest cluster of CE-related ASOs is Cluster 2, the 'technical process enhancers', which develop technologies that optimize production processes and thereby reduce resource consumption and waste by narrowing the production-consumption loop. It shows that most ASOs do not primarily introduce new CE-oriented products and services, but play an important role in helping to optimize existing industrial processes. In addition, the most frequently used CE strategy was the reduce strategy, used by 81 % of the ASOs, followed by the recycle and reuse strategies at 8 % each. This result aligns with the findings of Henry et al. (2020) and Parchomenko et al. (2019) that reduce, recycle, and reuse are the most adopted CE strategies. By mainly contributing through the principle of narrowing the production-consumption loop, the ASOs are likely to provide innovations that make processes in larger firms more effective, rather than developing new products and services. Thus, partnering with ASOs may be an efficient strategy for larger organisations to respond to regulations and demand changes that require innovations towards a more CE.

Second, by using CE contributions to classify ASOs, our taxonomy of innovative firms adds to existing innovation taxonomies relating to the firm- and industry-level characteristics (Libaers et al., 2016; De Jong and Marsili, 2006). This adds to existing taxonomies that mainly relied on data from larger and more established firms (De Marchi et al., 1996; Pavitt, 1984). Our empirical evidence provides a foundation to better understand the development paths of innovative start-ups and shows that Pavitt (1984)'s taxonomy should be extended with more detailed taxonomies showing the diversity of small innovative firms in general (Libaers et al., 2016) and science-based firms in particular. Furthermore, the addition of the CE context variables provides a groundwork for developing innovation taxonomies that conceptualize the potential role of innovation for sustainability transitions (Fagerberg, 2018). Adding the CE variables helps conceptualize the potential wider societal impacts of ASOs (Fini et al., 2018) and innovative start-ups in general (Audretsch et al., 2020). ASOs may introduce new technologies that are developed into circular business models, convert scientific knowledge into CE practices, and enable technological changes in their innovation ecosystem for higher levels of circularity.

Third, our findings add to the science commercialization and academic entrepreneurship literature by mapping specific ways that ASOs can provide societal impacts (Fini et al., 2018). Our taxonomy conceptualizes how ASOs can play an important systemic role in facilitating the conversion of new scientific inventions and knowledge into applications, for instance by optimizing industrial processes (Autio, 1997). This role may be particularly crucial for facilitating CE-related innovations that often require extensive collaboration between actors across the value chain (de Jesus et al., 2018). Radical innovations may be required to reform new customer value propositions in a CE (Ranta et al., 2020) and ASOs may play a particularly important role in developing such innovations. Hence, ASOs may be in a unique position to provide innovations that facilitate for example industrial symbioses or other improvements to make industrial processes more circular. Understanding the potentially unique roles of different types of firms in developing CE innovations, and in the 'circular ecosystems' (Konietzko et al., 2020), is crucial for achieving CE targets. Our taxonomy takes an important step in this regard.

### *6.1. Implications for practice and policy*

Our findings provide implications for managers and policymakers regarding the role of innovative start-ups in facilitating the transition to a stronger CE. A new wave of innovation policies aiming for system-wide transformation referred to as the Innovation Policy 3.0 frame (Grillitsch et al., 2019), calls for policies that include the objective of contributing to the sustainability transition. ASOs can potentially introduce CE innovations that are more radical than those developed by large firms. Our taxonomy of five distinct types of CE-related ASOs can help design more targeted policies and customized supports. In particular, the role of ASOs in optimizing industrial processes shows the importance of considering their CE contribution not only at the firm level but also in terms of the firm being an ecosystem actor. Hence, promoting the creation and development of ASOs that commercialize CE innovations may be an important part of the policy mix for the sustainability transition (Kivimaa and Kern, 2016). More policy supports should be established to foster collaborative synergies, reinforce networks, and build capabilities for the actors such as CE ASOs and their partners in CE entrepreneurial ecosystems (Ferreira and Dabic, 2022). Furthermore, our empirical evidence on the significant initiatives of CE ASOs also suggests more entrepreneurship education focusing on CE could be provided at academic institutions to increase the value creation of CE entrepreneurship (Del Vecchio et al., 2021).

Our taxonomy adds to the understanding of the roles played by different types of CE-related ASOs, as the societal impacts and the contributions to more sustainable development are gaining strong attention. ASOs can contribute to a more CE in several ways using different CE principles and types of CE innovations. Our empirical evidence shows relevance and consistency with the EU's Circular Economy Action Plan 2020 which emphasized digital technologies, resource efficiency, and entrepreneurial firms as key enablers of the CE transition. "Building on the single market and the potential of digital technologies, the circular economy can strengthen the EU's industrial base and foster business creation and entrepreneurship among SMEs" (the EU's Circular Economy Action Plan 2020, p.2). The significant role of digital technologies can be seen in the dominance of the two largest clusters of ASOs (Cluster 1 'smart product-service provider' with 8 ASOs and Cluster 2 'technical process enhancer' with 35 ASOs) to narrow the loop by adopting the reduce strategy. Digital technologies are crucial to facilitate the virtual products and services of Cluster 1 and improve the production resource efficiency of Cluster 2 to minimise resource consumption and waste emissions.

Critics have questioned whether the narrow the loop principle by optimizing production processes is sufficient for a CE transition (Bocken et al., 2016). The EU's Circular Economy Action Plan 2020 (p.12) reported that "despite efforts at EU and national level, the amount of waste generated is not going down" and that more efforts of recycling and reuse are needed. Optimizing the production process may lead to the use of fewer resources, but is essentially the same as a resource efficiency strategy used in the linear economy. Hence, if the resource efficiency gained by these innovations is used to increase production output by using the same amount of resources, there is no shift to a CE. To make sure the innovations provide a real CE contribution, the time dimension has to be addressed. Otherwise, a high share of the ASOs in our sample (i.e. Cluster 2) may not only narrow the production-consumption loop but also speed up the loop. Hence, the narrow the loop principle is likely to have a stronger impact if combined with principles to slow and close the production-consumption loop.

To increase more slowing and closing of the production-consumption loop, more policy incentives should also be focused on Cluster 3 'biochemical cycle extender' to slow the rate of waste emission and Cluster 5 'biosphere regenerator' to reduce the waste amount (e.g., burn to convert into energy or be the inputs for other production processes). As mentioned in Section 2.3 of the EU Circular Economy Action Plan 2020 as well as explained by our taxonomy, industrial symbiosis is vital to enable circularity in the production processes, especially those belonging to the biochemical cycles. Therefore, stronger systems of industrial symbiosis should be reinforced to enable and facilitate the CE innovations of Cluster 4 and Cluster 5.

### *6.2. Limitations and directions for additional research*

This study comes with several limitations and associated directions for further research. First, we relied on an extensive media search to identify CE-related activities and events in ASOs. However, some activities and events likely went unnoticed by the media, leading to an under-reporting of cases. We attempted to minimise underreported cases by combining media data with other data sources, such as company websites, financial data, and firms' history and legal data. Further studies may use other types of data to complement our results, such as survey data and patent data, but these data sources also face distinct weaknesses.

Second, the MCA method unveils the relatedness patterns of variables and cases but does not confirm the significance of these relationships. We reveal several patterns of CE ASOs that call for further investigations. For example, we observed that the product CE innovations occurring in Cluster 4 tend to be based more on basic research and general knowledge than innovations occurring in other clusters. The waste-to-energy conversion innovations that were frequent in Cluster 5 were associated with a higher patent rate compared to the digital product innovations of Cluster 1 and the biochemical product innovations of Cluster 5. Some clusters have a higher likelihood of industry partnerships than others. Additional studies are warranted to explore why and how these patterns arise. Multivariate regression analysis is required to validate and test the emergent patterns reported in our study.

Third, our study mapped the activities of ASOs at a relatively early stage. Hence, we cannot assess whether some types of ASOs are more successful than others in terms of financial performance or survival. A promising line of enquiry would be to examine the performance implications for ASOs commercializing the distinct CE-related innovations in our taxonomy. Different types of ASOs likely follow distinct pathways to reach the market. For instance, Cluster 2 'technical process enhancers' may be more dependent on partnering with large firms to reap process benefits, while Cluster 1 'smart product-service providers' can scale their activities more independently. ASOs in the different clusters may develop and perform differently over time. For example, bio-based CE innovations may require more time for development and commercialization than digital CE innovations. Hence, our taxonomy may provide a starting point to examine these distinct development paths and their implications for both firm performance and the societal impacts of ASOs in terms of CE contributions.

## Data availability

The data that has been used is confidential.

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Digital Innovations for the Circular Economy

Modern industrialization has caused serious societal problems such as resource depletion, contamination, pollution plastic ocean, and biodiversity loss. The circular economy is an emerging concept to replace the linear process of "take-make-dispose" with "make-use-return" by reducing, reusing, recycling, and regenerating. Digital innovation is believed a crucial enabler for the circular economy transition, especially at the firm level.

This thesis examines how firms and especially academic spin-off firms innovate and commercialize digital innovations to contribute to the circular economy. The five types of academic spin-off firms commercializing circular economy-innovations with different roles are identified, including the smart product-service provider, the technical process enhancer, the biochemical cycle extender, the renewables provider, and the biosphere regenerator. Also, the research identifies two different paths to the success of digital-based academic spin-offs.

Furthermore, the thesis also finds the three digital circular business models (e.g., the service-based model, the blockchain-based supply chain model, and the pull-demand model) essential to address the urgent issues of the fashion industry. The novelty of circular economy innovation is varied among firm sizes and circular economy-innovation types.

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