# 21. The circular economy impacts of digital academic spin-offs

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## INTRODUCTION

Digital technologies are often seen as essential enablers for the transition to a more circular economy (CE) (Antikainen et al. 2018; Ranta et al. 2021). New digital technologies, such as the Internet of Things (IoT), additive manufacturing, automation, and artificial intelligence, are transforming the sociotechnical system rapidly (Kopp et al. 2019; Li et al. 2020). The sociotechnical system entails the co-evolution of technology and society in which organizations adopt and adapt technologies into the organization and application contexts (Geels 2004; Li et al. 2020). The trajectory of new digital technologies impacts both the processes and outcomes of innovation and entrepreneurship (Nambisan 2017; Zaheer et al. 2019). Entrepreneurial firms play a vital role in harnessing and exploiting the opportunities of digital technologies to build a broad range of innovative products and services or upgrade production processes (Kraus et al. 2018; Nambisan 2017; Sahut et al. 2021).

Digital entrepreneurship not only promotes growth but may also tackle social and environmental issues (Bocken 2015; Giones and Brem 2017). In recent years, severe resource degradation and environmental pollution problems caused by the linear 'take-make-discard' production model have required an alternative and more sustainable model – the CE (Korhonen et al. 2018). The core of the CE is to transform the economy from a linear 'take-make-dispose' system to a circular 'make-use-return' system in which obsolete materials and goods are maintained, regenerated and restored to narrow, slow, and close the production–consumption loop (Lieder and Rashid 2016). Thus, natural resources are preserved, and waste and emissions are minimized.

Among entrepreneurial firms, academic spin-offs (ASOs) are new ventures initiated in the context of a parent university or research institute to commercialize scientific knowledge and technology (Rasmussen 2011). ASOs are highly knowledge-intensive firms associated with significantly higher inventiveness and growth rates than other firms (Shane 2004). Thus, ASOs are potentially important firms for commercializing digital innovations contributing to the CE transition. Although the economic impacts of ASOs are emphasized in the literature (Mathisen and Rasmussen 2019), little is known about the CE impacts of ASO firms, especially ASO firms that rely on digital technology. Given the potential of digital technologies for the CE (De Sousa Jabbour et al. 2018; Pagoropoulos et al. 2017) and the potential impacts of ASOs (Fini et al. 2018), digital ASOs may contribute to the transition to a CE in several ways. This chapter examines the role of ASOs that introduce digital innovations to potentially benefit the CE. Our research question asks *how ASOs commercializing digital innovations can contribute to the CE.*

## LITERATURE REVIEW

### The Emergence of Digital Technologies

Over the last decade, the evolution of digital technologies has transformed innovation and entrepreneurial processes, redefined market patterns, and created new markets (Nambisan 2017; Nambisan et al. 2019; Zaheer et al. 2019). There are various types of digital technologies such as the IoT, artificial intelligence, big data, sensors, blockchains, platforms, and software. Nambisan (2017) classified digital technologies into three main categories:

- A digital artefact is a "component, application, media content that are parts of new products or services and offer a specific functionality or value to end-users" (Nambisan 2017, p. 1031; Ekbia 2009;) and they "exist as stand-alone products or as parts of a platform" (Zaheer et al. 2019, p. 2).
- A digital platform is "a shared, common set of services and architects that serves to host complimentary offerings, including artefacts" (Nambisan 2017, p. 1031).
- A digital infrastructure is "digital technology tools and systems that offer communication, collaboration, and computing capacities to support innovation and entrepreneurship" (Nambisan 2017, p. 1031).

The three types may be combined to generate innovative solutions. A popular example is the service provider Airbnb, which combines a digital platform with digital artefacts in the form of a mobile application with app functions to deliver shared accommodation services to end-users.

### The Influences of Digital Technology on Entrepreneurship

The advent of digital technologies has shifted both the processes and outcomes of entrepreneurship (Nambisan 2017). The term 'digital entrepreneurship' refers to "all new business ventures and the transformation of existing businesses that drive economic and/or socio values by creating and using novel digital technologies" (European Commission 2015, p. 2). The infusion of digital technologies mitigates the inherent uncertainty of the entrepreneurial processes (i.e., how and when entrepreneurial activities are implemented) and the entrepreneurial outcomes (i.e., the types, scopes, and markets of product and service offerings) (Nambisan 2017).

Digital technologies can improve the product development phase so that it is more quickly created, modified, and repeated (Kraus et al. 2018). Digital infrastructures, such as 3D printing and artificial intelligence, can also make entrepreneurship and innovation processes less predefined and more quickly adopted, modified, and enacted (Nambisan 2017; Ries 2011). Hence, the behaviours of entrepreneurial firms, such as how they collaborate and interact with other actors in the innovation ecosystem, are also altered due to these unique attributes (i.e., openness and generativity) of digital technologies (Nambisan 2017; Zaheer et al. 2019). For example, the blockchain increases the traceability and reliability of shared information, and digital platforms allow more open and interactive communication and collaboration among actors in the ecosystem. The liquidity of cash flow increases due to the flexibility and generativity of digital technologies, which also allow more new ventures to innovate without deadlock investments.

Digital advantages allow more start-ups to lead technological developments, explore unaddressed market demands, and create new markets. Many entrepreneurs find digital-based business models more dynamic than traditional business models (Kraus et al. 2018). For example, Airbnb and Uber are forerunners of the sharing economy by creating new markets for sharing accommodation and transport. The sharing business model is a significant digital-based business model that can benefit the CE (Bressanelli et al. 2018). The model illustrates how digital technologies, when combined with appropriate new business models, can create substantial sustainability impacts such as reduced new demand, reduced resource consumption, and reduced waste. Other entrepreneurial companies rely on, for example, blockchain-based business models to increase traceability or tailored-made business models using 3D printing and artificial intelligence to reduce overproduction, resource consumption, and waste.

## Digital Academic Entrepreneurship for a More Circular Economy

Rippa and Secundo (2019) draw attention to the intersection of digital transformation and academic entrepreneurship research. We define a digital CE-related ASO as one that commercializes digital innovations with potential CE impacts. Following the acceleration of digital technologies in academic entrepreneurship, the term 'digital academic entrepreneurship' indicates "the use of new digital technologies to improve the emerging forms of academic entrepreneurship, such as the development of digital spin-offs and alumni start-ups" (Rippa and Secundo 2019, p. 907). Secundo et al. (2020) show that digital innovations impact not only the outcomes but also the entrepreneurial processes of academic start-ups. For example, digital technologies can shift the traditional entrepreneurial incentives of academic entrepreneurship from pure scientific knowledge commercialization to broader socioeconomic values with a higher level of stakeholder engagement (Secundo et al. 2020).

In sustainability transitions such as the CE that may require radical technological shifts and market reforms (Ranta et al. 2021), ASOs may play an important role by initiating necessary changes in the technological trajectory, transferring technology, and infusing knowledge spillovers (Autio 1997). Indeed, small, new firms have a higher likelihood of introducing radical innovations and taking CE actions compared to large incumbents (Henry et al. 2020). Large incumbents tend to innovate by applying marginal changes in their existing systems because of their organizational inertia and risk avoidance (Hockerts and Wüstenhagen 2010; Schaltegger et al. 2016). Despite the potential ability to solve sustainability issues, the roles and impacts of digital academic entrepreneurship have yet to be explored. Zaheer et al. (2019) called for more research on digital entrepreneurship related to social and sustainability issues.

## The Influences of Digital Technologies on Sustainability and CE

The CE concept offers alternative solutions for a more sustainable production and consumption system. The CE, designed as a 'make-use-return' system, is replacing the traditional linear business model of 'take-make-dispose', which is causing severe resource degradation, environmental pollution, and waste emission problems (Geissdoerfer et al. 2017). The CE aims to reduce resource consumption; increase the product lifetime by reusing, repairing, and refurnishing; dematerialize physical products; and close the loop using recycling activities (Lieder and Rashid 2016). Therefore, the production and consumption loop is expected to be narrowed, slowed and closed. At the operational firm level, many circular business models involve digital technologies (Bressanelli et al. 2018; Ranta et al. 2021).

Entrepreneurial firms adopt different types of digital innovations in new business models to tackle sustainability challenges (George et al. 2020) and contribute to a more CE. For example, the blockchain decentralizes transaction activities in more transparent, trustworthy, reliable, and informative ways (George et al. 2020) and increases traceability for better recycling and reuse. Artificial intelligence and the IoT allow production automation to achieve resource efficiency by reducing false prototypes. Through digital technologies, decision making based on real-time data becomes more effective, and collaborations between actors in the innovation ecosystem are less geographically bounded.

Several studies examine the role of digital innovation in the CE. Digital innovations optimize material flows and enable reverse material flows (Pagoropoulos et al. 2017), integrate value chains through data collection and sharing (De Sousa Jabbour et al. 2018), and improve traceability and transparency through the product timeline (Antikainen et al. 2018). Digital technologies enhance the knowledge on the locations, conditions, and availability of materials and products, which facilitates predictive maintenance, refurbishment, recycling, and reuse (Antikainen et al. 2018). Hence, consumption patterns are shifted by engaging consumers in the digital system (De Sousa Jabbour et al. 2018). Most studies of digital innovation for the CE are either conceptual or literature reviews, and there are few empirical studies. Additionally, the current stream of the digital innovation CE literature predominantly centres on one type of digital technology, one company, or one CE process. De Angelis and Feola (2020) and Henry et al. (2020) examined spin-offs and start-ups, but those firms did not rely on digital technology; furthermore, other studies did not distinguish the application of digital technologies for CE by different types of firms (i.e., large incumbents, SMEs, and start-ups).

## METHOD

We employ an exploratory, inductive multiple-case study of 25 digital CE-related ASOs. Our sample is identified from the population of 374 Norwegian ASOs established during 1999–2011 and by using media coding in a stepwise process, as outlined in Table 21.1. The number of CE-related ASOs is likely to be higher than 25 because of limited media coverage

*Table 21.1 The process of identifying the sample of digital CE-related ASOs*

| Step | Sample | Coding tasks |
|---|---|---|
| 1 | Population of 374 ASOs | Searched the Atekst/Retriever media archive and downloaded 4,252 news articles written on approximately 295 of the ASOs until 2016. The remaining firms were early failures with no media coverage. |
| 2 | 295 ASOs with media coverage | Trained student assistants read all articles and identified 1,041 articles that provided information on the impact of each ASO and its activity. These articles were re-read to identify 60 CE-related ASOs. |
| 3 | 60 CE-related ASOs | The CE impacts were coded according to the specific types of CE impacts such as resource efficiency, extending the product lifecycle, reuse, and recycling. The types of technology and innovation were also coded. |
| 4 | 25 digital CE-related ASOs | We sorted the 60 CE-related ASOs by technologies to obtain a sample of 25 CE-related ASOs using digital technologies. |

on many firms. However, for the purpose of our study, this sample allows us to gain new insights into the CE-related activities of the most profiled ASOs in this population.

We conducted qualitative content analysis to analyse the 25 cases. Content analysis is defined as “a research technique for making replicable and valid inferences from texts (or other meaningful matter) to the contexts of their use” (Krippendorff 2018, p. 18). Through the coding stages of content analysis, we examined a total of 195 news articles written on digital CE-related ASOs to find emergent categories from the data and compared the differences and similarities among the cases and the categories for empirical interpretation. The coding analysis involved two research assistants and one author of this chapter. The coders worked independently and in parallel on the same sample to reduce personal biases during the coding process. Another author was involved in cases of disagreement between the coders.

The coding process included two levels. First, the codes consist of direct quotes from the articles concerning CE objectives, digital technologies, and innovation (e.g., product versus process, or novelty). The following example is one first-order code of digital technology.

> Badger Explorer ASA, develops an autonomous robot that will drill into the ground to search for oil, without it coming back to the surface (Article 1). Sensors are also mounted in the tool that continuously monitors the mass that is passed through the tool. These sensors can tell if there are hydrocarbons in the mass, and thus indicate that there is oil in the sublayers in which it is drilled. Sensors run on pressure, and temperature can provide information about the mechanical properties of the ground such as pore and fractional pressure. It is important for later well and drilling operations (Article 2).

These codes explicitly explain the type of digital innovation and how digital technologies are used.

At the second level of coding, we identified the keywords that emerged from the first-order codes and then inferred and assigned them to specific categories. The categories include the types of innovation (i.e., incremental, radical product, and process innovation), the types of digital technology (i.e., sensor, automation artificial intelligence, real-time data, and software), the subcategories of digital technology (i.e., digital artefact, infrastructure, platform), CE impacts (i.e., resource efficiency and waste minimization), and performance (i.e., commercialization and survival).

In the previous code example, we identified the keywords ‘*sensor*’ and ‘*robot*’. According to the predefined literature concepts, we assigned the digital technologies of Badger Explorer AS into the digital infrastructure category. In this study, we refer to the radical innovation of ASOs as the first digital product or process innovation in the market. The incremental innovation of ASOs identifies significant improvements based on existing knowledge or products in the market. For example, in the coding of the company DolphiScan, “this is the first product of its kind configured for composite materials in the market and can be easily used by maintenance personnel” or “the company DolphiScan on a groundbreaking invention: An ultrasonic code reader”, the terms ‘first product in the market’ or ‘groundbreaking invention’ were defined to refer to digital radical innovation. Another example is the company Kognita with an e-learning platform. The coding “the e-La application will be built upon a current application developed by the entrepreneurs whilst employed at MARINTEK” indicates that this product innovation is built upon some existing application; thus, it is identified as incremental product innovation. Finally, to interpret the results, we compared the similarities and dissimilarities of the coded categories across the 25 cases.

## FINDINGS

Among the 60 ASOs found with CE-related businesses (Table 21.1), 25 rely on digital technologies. This indicates that digital innovation holds a central role for ASOs commercializing innovations with potential CE impacts. Table 21.2 provides more details on 10 of the digital CE-related ASOs. These ASOs employed digital platforms, digital artefacts, and digital infrastructure technologies (i.e., sensors, robotics, platforms, software, and data analytics) to introduce digital product and process innovations.

Two main types of digital innovations are found in our sample. First, some ASOs entail digital product innovations by embedding digital platforms and digital artefacts that target final users' experiences. This type of digital product innovation is often known as 'Product-Service Systems (PSS)' (Tukker 2015). PSSs aim to fulfil final users' demands by combining tangible products and intangible services (Tukker 2015) and increasing the ownership sharing of products (Bressanelli et al. 2018). The ASOs in this study introduced e-learning portals, virtual interfaces, or digital laboratories that enable collaboration, interaction, and communication between multiple users. The locus of communication hosted by digital platforms and artefacts is not spatially bounded. Numerous users from different locations, within or outside the organization, can easily access the same platform and the same data to interact with each other in real time. Physical objects such as paper books and laboratory equipment are virtualized and dematerialized to reduce the consumption of energy and material resources and then reduce the logistical waste of physical classrooms and laboratories. Examples are Cyberlab and Smart Energy (Table 21.2). The digital platform and digital artefacts are closely embedded rather than functioning alone. Hence, if the digital platform hosts the users' activities, digital artefacts enable operational activities.

The second type of CE-related ASO involves digital process innovation using digital infrastructure technologies such as sensors, robotics, big data, and the IoT. This type of digital process innovation relates to the concept of Industry 4.0 (De Sousa Jabbour et al. 2018). Digital infrastructure optimizes the production processes by coordinating physical and virtual objects based on real-time data. Smart sensors and data analytics connected via wireless networks allow 'real-time' prediction and decision making. Thus, managers are provided with more precise information to prevent failures and errors because the combination of digital infrastructure technologies can help validate, inform, and verify potential issues in production and logistic processes. This could minimize prototype failures and resource inputs using pre-maintenance instead of repair. In addition, the automation enabled by artificial intelligence and robotics with big data (or so-called cyber-physical systems) substantially increases productivity and efficiency in manufacturing. Examples are Comex, DrillScience, and Thelma (Table 21.2).

CE-related ASOs seem to pursue digital process innovations more often (16 firms) than digital product innovations (9 firms). Nearly all digital process innovations are radical and provide unique solutions to the market. In contrast, digital product innovations are mostly incremental and tended to be built upon knowledge or products that already existed in the market. This ratio of radical versus incremental and product versus process innovation also corresponds to the patent rate. Among the 25 CE-related ASOs, 8 firms patented their innovations. All these patented innovations are radical process innovations based on digital infrastructure technologies whereas no product innovations based on digital platforms and artefacts were patented.

*Table 21.2* *Illustrative cases of digital CE-related ASOs*

| ASO | Status | Products/services | Innovation types | CE impacts |
|---|---|---|---|---|
| Kognita | Established: 2000<br>Status: Acquired | E-learning platform and application that allows training providers to access a library of online learning materials and promote online courses over the internet. | - Innovation type: incremental product innovation.<br>- Digital technology: digital e-learning platform and digital artefact (i.e., software). | - Reduce the raw material and energy consumption of traditional classes such as paper books and electricity, respectively.<br>- Increase the efficiency of connecting people through a software platform for online teaching.<br>- Reduce the emissions from travels to attend workshops/seminars abroad. |
| PrediChem | Established: 2001<br>Status: Changed purpose | - Virtual laboratory software that can be used to integrate and simulate computational chemistry, experimental design and chemometrics for research and development in medicine. Reduces the expensive testing costs of laboratories using a cheaper and easier testing program performed in a virtual laboratory.<br>- First in the market to introduce this innovation. | - Innovation type: radical product innovation.<br>- Digital technology: digital platform (i.e., virtual laboratory platform) and digital artefact (i.e., software). | - Dematerialize physical laboratory to reduce logistic resources such as laboratory material inputs, electricity, and fuels.<br>- Reduce physical lab prototypes and waste.<br>- Increase efficiency and reduce time and costs of laboratory testing and medical product development. |
| Octaga | Established: 2001<br>Status: Bankrupted | - Multiple user 3D visualization software for training, simulation, operation and maintenance. Enhances visualization and offers users new ways to communicate and collaborate.<br>- Developed the innovation based on an existing innovation. | - Innovation type: Incremental product innovation.<br>- Digital technology: digital platform and digital artefact (i.e., 3D visualization and software). | Optimize the communication and collaboration process to reduce the consumption of resource inputs. |
| Pronavis | Established: 2002<br>Status: Acquired | Multiuser network platform for internal collaboration and interaction in the maritime and offshore logistics. Technology allows everyone to have access to what others are doing and can coordinate with them. | - Innovation type: Incremental product innovation.<br>- Digital technology: Digital platform. | - Optimize the logistic process to reduce fuel consumption and fuel costs up to 10%.<br>- Reduce environmental impacts. |
| Smart Energy Applications | Established: 2002<br>Status: Acquired | Wireless device plugged into the power grid to track power consumption and transfer information on power consumption to a portable device such as a cell phone. Helps household consumers and large buildings optimize their electricity consumption. | - Innovation type: Incremental product innovation (a version of the old wattmeter needle).<br>- Digital technology: Digital artefact (the tracking device and software). | Optimize power consumption, reduce the consumption and costs of electricity and energy. |

| ASO | Status | Products/services | Innovation types | CE impacts |
|---|---|---|---|---|
| Thelma | Established: 2000<br>Status: Bankrupted | - Sensor mounted on a fish to record the fish breathing patterns to measure the well-being of the fish because farmed fish are more susceptible to illness when they are stressed.<br>- First in the market to introduce this innovation. | - Innovation type: Radical product innovation.<br>- Digital technology: Digital infrastructure (a tracking device and software). | - Reduce the number of sick fish and enhance fish quality.<br>- Reduce the resource inputs for fish farming and reduce waste because of fish disease. |
| Comex | Established: 2003<br>Status: Active | - Sensor-based sorting system for the production and classification of fine powders and optical separation of large particles based on colour, shape, size, surface pattern, thermal, and magnetic properties. Technology can be used in the process of crushing and grinding minerals in the mining industry.<br>- First in the market to introduce this innovation. | - Innovation type: Radical process innovation.<br>- Digital technology: Digital infrastructure (sensor and data). | Makes the mining process less energy intensive by removing waste first with a reduction of approximately150 terawatt-hours (TWh) if the mining industry uses this technology. |
| Drilltronic | Established: 2004<br>Status: Active | - Digital system with AI, a sensor, real-time data, and software to visualize and automate the drilling process and detect the errors and faults in the oil drilling.<br>- Unique drilling technology for complex reservoirs and in more inaccessible and environmentally sensitive areas.<br>- First in the market to introduce this innovation and achieved commercial success. | - Innovation type: Radical process innovation.<br>- Digital technology: Digital infrastructure (AI, sensor, real-time data, and software). | - Optimize process via decentralized real-time data updates.<br>- Significantly reduce downtime and resource consumption in drilling.<br>- Reduce incidents and environmental risks during the drilling process. |

| ASO | Status | Products/services | Innovation types | CE impacts |
|---|---|---|---|---|
| Badger Explorer | Established: 2003<br>Status: Active | Autonomous robot with a sensor that will scan the seabed and drill into the ground to search for oil without it coming back to the surface. These sensors can identify the hydrocarbons in masses and thus indicate the potential oil in the sublayers. The sensors and real-time data can provide information about the mechanical properties of the ground, such as pore and fractional pressure.<br>- First to introduce this innovation in the market. | - Innovation type: Radical process innovation.<br>- Digital technology: Digital infrastructure (AI, robotics, sensor, and real-time data). | - Significantly increase efficiency and productivity.<br>Reduce resource inputs during oil exploration, thus reducing the costs of oil exploration by 50%.<br>- Make the drilling process safer and reduce the environmental impacts of dangerous gas emissions during the oil exploration process. |
| Franatech | Established: 2008<br>Status: Active | - Sensor for measuring CO2 and methane in connection with oil and gas wells.<br>- First in the market to introduce the technology, which was believed to be game-changing technology for subsea leak detection. | - Innovation type: Radical process innovation.<br>- Digital technology: Digital infrastructure (sensor). | Helps offshore operations to map and reduce the emissions of environmental gases and $CO_2$ in oil wells. |

Noticeably, the majority of CE-related ASOs are technology suppliers who took the lead as first-mover innovators in their market. ASOs collaborate with and supply technological solutions to large incumbent firms or public organizations to enhance production and logistic processes. Only a small number of the ASOs in this study directly provide products or services to final users. ASOs are start-up firms that typically lack complex in-house manufacturing systems. Thus, ASOs contribute to the CE with technology and sustainable, circular solutions that can be implemented by larger incumbents. This may be attributed to the fact that ASOs are knowledge intensive and highly innovative firms (Clausen and Rasmussen 2013); thus, ASOs play an important role in leading technological trajectories and incubating radical innovations in their innovation ecosystem (Novotny et al. 2020). These ASOs have strong horizontal integration (with peer research organizations) and vertical integration (with client companies).

Our findings confirm the potential role of technology-based start-ups as sources of innovation and technological initiatives for large incumbents and manufacturers (Autio 1997). Start-up firms with more flexible organizational structures and fewer resources are more incentivized to search for unique market ideas, to innovate, and to quickly respond to disruptive technological changes (Homfeldt et al. 2019). The collaborative role of the CE-related ASOs as technology suppliers and knowledge transferers also aligns with the study of De Jesus et al. (2018) explaining the multilevel CE transition. At the meso level, the CE transition requires more collaboration, integration, and synergy between firms within the value chain, such as through industrial symbiosis; and the CE innovations of one firm may influence other firms in the same network to achieve a joint circular system.

The empirical evidence in this study also reinforces Hojnik and Ruzzier's (2016) findings that market pull factors and cost reductions are important drivers of eco-innovation in both the innovation development and diffusion stages. This pattern also seems to be true for the digital innovations commercialized by ASOs. We also found that most digital CE innovation ideas are derived from the original needs for cost cutting and market demands before the CE objectives are indirectly achieved through resource efficiency. Our empirical evidence also validates the finding of Ranta et al. (2020) that compared to more linear economy suppliers, the customer value propositions of suppliers in the CE tended to be more market-driven and built for radical innovations that involve the close participation of direct customers and other ecosystem actors. These technological changes and CE transitions in the ecosystem of digital ASOs are led by the combined effects of 'technology-push' and 'demand-pull'.

## CONCLUSION

The hand-collected dataset based on the population of ASOs established in Norway between 1999 and 2011 allowed us to examine the potential CE-related impacts of 25 ASOs commercializing digital innovations based on digital artefacts, platforms, and infrastructure technologies. We identified two main types of digital CE-related ASOs, which were based on digital product innovation and on digital process innovation. While ASOs commercializing process innovations often introduced radical innovations and new knowledge, ASOs commercializing product innovations were more often based on existing knowledge in the market. Digital process innovations tended to relate to digital infrastructure technologies such as sensors, robotics, big data, and the IoT. In contrast, digital product innovations were likely to entail digital platforms and artefacts such as mobile applications, virtual e-learning platforms, and software. The digital platform acts as the medium to be embedded with either digital infrastructures or digital artefacts.

ASOs contribute to the CE mainly in the role of technology suppliers for other large incumbents and public organizations. They closely collaborate with partners to facilitate both horizontal and vertical integration of their value chain. ASOs may facilitate technological changes in their innovation ecosystem and enable a meso-level industrial symbiosis of the CE. Most digital innovation ideas of ASOs are derived from resolving particular issues of their clients or markets. Hence, ASOs offer solutions to increase resource efficiency, cut costs, and address new market demands. Through economic incentives derived from more efficient processes, the CE impacts are indirectly generated by, for instance, reducing resource consumption, prolonging the product lifecycle, and closing the production-consumption loop.

Among the six circular business models (i.e., Regenerate, Sharing, Optimize, Loop, Virtual, Exchange) of the ReSOLVE framework, which has been most widely used in circular business model classification (Merli et al. 2018), digital CE-related ASOs employ mostly the optimize model and the virtual model. Hence, our findings align with Merli et al. (2018), stating that optimize is the second most popular circular business model, while the most popular circular business model is the Loop concerning the ‘reuse’ and ‘recycle’ strategies. To enable a resource-efficient CE, societal and environmental sustainability should be aligned with economic incentives (Ghisellini et al. 2016). This indicates that digital CE-related ASOs can provide important contributions to the CE transition because their original business purposes are often cost savings through advanced production automation and collaborative interaction enabled by radical digital innovations.

Our findings can also be related to the three common Rs of the CE literature, ‘reduce, reuse, recycle’ (Ghisellini et al. 2016; Prieto-Sandoval et al. 2018), which are attributed to the resource flow of narrowing (by reducing), slowing (by reusing, repairing) and closing (by recycling and recovering) the loop (Bocken et al. 2016). Resource efficiency related to the ‘reduce’ strategy is one of the essential CE objectives to narrow the loop by lowering resource consumption and emissions and increasing the efficiency of the technical and biological cycles. Compared to slowing and closing the loop, narrowing the loop is a distinct CE strategy because it does not directly influence the speed or cyclicality of the resource flows. However, resource efficiency or narrowing the loop is still considered crucial, especially at the CE microlevel aiming for cleaner production (Ghisellini et al. 2016). We contribute to this growing stream of resource-efficient CE literature by adding knowledge on the role of digital CE-related ASOs as potentially important facilitators of the ‘narrowing the loop’ strategy by enhancing the efficiency of both the demand (through digital products and services) and supply sides (through digital production processes).

Hofmann (2019) argues that the ‘slowing the loop’ strategy is irreconcilable and incoherent to our current economy based on growth, ceaseless technological progress, and fast consumerism. “What is truly required to reduce environmental impacts is less production and less consumption” (Zink and Geyer 2017, p. 600). Perhaps digital CE-related ASOs can be forerunners in the transition to a more CE by helping to narrow the loop by orchestrating industrial symbiosis, by optimizing value creation and offering higher efficiency production, by using minimal resources and costs per unit, or by optimizing new demand while maintaining profitability thanks to higher productivity. The condition for this to happen, however, is that the increased efficiency does not lead to a further increase in production and consumption, causing ‘circular economy rebound’ effects (Zink and Geyer 2017). Hence, the potential role of digital CE-related ASOs in the transition to a CE depends on how they are integrated in a larger transformation of the economy.

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