Digital Circular Business Models

Subjects: Engineering, Industrial
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The concept of circular economy (CE) is receiving increasing attention worldwide as a way to overcome the issues of the current production and consumption model. It requires companies to rethink their supply chains and business models (BM). The CE is a regenerative economic system that necessitates a paradigm shift to replace the end of life (EoL) concept with reducing, alternatively reusing, recycling, and recovering materials throughout the supply chain, with the aim of promoting value maintenance and sustainable development, creating environmental quality, economic development, and social equity, to the benefit of current and future generations.

circular business model digitalization circular transition digital transformation

equipment life cycle extension

1. Introduction

The reverse supply chain is slowly making headway and trying to account for EoL products in the most environmentally friendly manner possible [1]. Sustainable EoL management can be enabled by long-lasting design and the optimization of maintenance, repair, reuse, remanufacturing, refurbishing, and recycling strategies. Sustainable action must comply with, and account for, the complexity of socio-economic systems by encompassing economic, ecological, social, and political factors and addressing the hierarchical organization of nature [2].

Digitalization, intended as the process of employing digital technologies and information to create value from firms' ordinary operations and inter-organizational relationships [3], has been identified as an enabler for the adoption of CE practices. Recent studies have demonstrated the potential of digital technologies to support companies' digital transformation, life cycle management, supply-chain management, and adoption of the circular business model (CBM), and product-service systems (PSS) [4]. While conventional BMs' value propositions are mainly geared towards sales of products, circular business models (CBMs) keep materials, components, and products at their highest utility and value [5]. CBMs gained popularity along with the spread of the CE, and involve recycling, extending, intensifying, and/or dematerializing products and energy loops to reduce the resource inputs into and the waste and emission leakage out of an organizational system [6].

A product is how the value proposition materializes in practice; a product encompasses both goods and services. Products are the economic output of production activities. Products are exchanged and used as inputs in the production of other goods and services, as final consumption, or for investment [7].

Using digital technologies embedded in machinery can improve EoL management by enabling predictive maintenance, monitoring of machinery conditions [8], and facilitating more effective recycling or disposal strategies [9]. Digitalization can (i) enable machine monitoring to predict when a machine is likely to fail or require maintenance; therefore, (ii) supports failure prevention and machine life cycle extension, which likewise can (iii) help improve EoL management of components by tracking their status, making it easier to identify materials for recycling or disposal and to make a decommissioning plan, or share data within the related supply chain on production processes and machines. Nevertheless, the application of digital technologies to machines already in use is still scarcely documented in the literature. Experiences from the field show limited applications of sensors to gather data on single machine components, difficulties in data transmission and elaboration, and the necessity for training operators to properly manage the EoL of components safely and in compliance with any regulations [10].

Machinery lifetime extension can be digitally enabled for both old and new machines, depending on the different relationships established by original equipment manufacturers (OEMs) with the other value-chain actors. A new product comprises parts that did not accomplish any function before; it may be composed of recycled materials, but all parts were bought (brand new) or produced for the product. All cases involve old products (i.e., the product was previously used, some parts were retrieved from other products, some parts were downcycled, etc.). Therefore, it is reasonable to affirm that an old product has already reached the used phase while the new one has not. In addition to the customer, three primary actors take the stage on the machinery value chain. OEMs are all the original producers; in traditional selling models they own the products until they are sold (to a retailer or the customer). Sometimes, they are remanufacturers themselves. Since they ran the process for the initial product to commercialization, they have the expertise and knowledge of the information valuable for remanufacturing. Moreover, they gain benefits out of remanufacturing, such as material, labor, and energy savings, while creating new market opportunities and a positive social image [11]. Outsourced remanufacturers are one kind of third-party remanufacturer; they carry out operations under contract from either the customer or the OEM (who continue to own the product). There might be close cooperation between outsourced remanufacturers and OEMs (for example, delivering information and training workers). The second type of third-party remanufacturer is the independent remanufacturer, who buys the used products from users and remanufactures and resells them. However, unlike the previous one, it has no cooperation with the OEM [12].

2. Digital Circular Business Models for Machine Life-Cycle Extension

Traditional BMs can ease or obstruct products’ circularity. Over the last decades, a multitude of innovative, sustainable BMs have arisen, and launching a product now requires identification of which BM most appropriately creates, delivers, and captures economic value while simultaneously contributing to environmental and/or social sustainability [13]. There are several methods to assess the circular performance of a system [14] and several frameworks and new practices have been developed to assist organizations in the implementation of circular products and processes [15]. ReSOLVE is one of the most frequently used [16].

In their review, Fontana et al. [17] summarize the field of CE and LCES through a revised taxonomy, drawing on relevant papers so that new strategies and methods can be implemented. In fact, there are many obstacles related to EoL management, such as product return via the reverse logistic, inspection and disassembly, and continuation of activities relating to cleaning, remanufacturing, reassembly and re-introduction to the market. There are multiple aspects to be considered, such as product and volume uncertainties, design constraints, brand reputation, and intellectual property [18]. Several technologies were created to specifically deal with goods at their EoL [19], especially relating to recycling and material treatment and breakdown [20]. Other products use the same technologies as manufacturing processes, also combining subtractive and additive ones [12].

Scholars widely agree that digital technologies (DTs) are crucial in facilitating the transition from the existing linear economy to a CE, as evidenced by numerous studies [9]. A digital CBM is a type of economic model that incorporates digital technology and data to support the principles of a CE. In a digital CBM, companies use digital tools and platforms to manage their resources and supply chains more efficiently and sustainably. This can include using sensors and tracking technology to monitor the use and movement of resources, as well as using data analytics to optimize production and distribution processes. By leveraging digital technology, companies can better understand their operations and make more informed decisions about how to use their resources in a way that reduces waste and promotes sustainability. On the other hand, digital technologies can support companies in waste minimization by adopting LCESs, such as recycling, reusing, remanufacturing, or even predictive maintenance.

Nowadays, shop floors are pervaded with multiple tools intended for digitizing products and processes. Industry 4.0, with Key Enabling Technologies (KETs) such as Internet of Things (IoT), Big Data, Cloud technology, Artificial Intelligence (AI) and Machine Learning (ML), enhanced robotics, Data Analytics, 3D Printing, and Blockchain, is transforming industrial businesses on a vast scale [21], and is boosting the development of systems that monitor industrial processes and prevent machines' downtimes. The IoT refers to a network of physical devices embedded with sensors, software and network connectivity, which collect and share data. The IoT is characterized by a shared understanding of the situation of its users and their applications, a software architecture and pervasive communication networks and the analytics tools for autonomous and intelligent behavior [22].

The IoT can transform products into intelligent and interconnected ones, providing the ability to monitor the status and condition of products. As a result, companies can benefit from real-time remote monitoring of product usage and status [23]. Data collected through the IoT, combined with data analytics tools and data mining processes are necessary to unlock valuable insights, identify patterns, make predictions, and deliver advanced services like preventive and predictive maintenance. Consequently, in the literature, the combination of Big Data and appropriate analytics is widely acknowledged as an effective approach to facilitating better sustainability-oriented decision making [24].

Industrial scouting has been conducted to examine how CBMs are implemented in industrial contexts. In the machinery sector, CBMs are spreading widely. Together with selling new machinery, Liebherr is now providing their customers' with fleets for hire too, together with the fleet management system—LiDAT. The benefits are multiple: Liebherr machinery may require high initial investments, but the OEM does not encounter the risk of cannibalization, since companies that often make use of specific machinery would buy them anyway. Furthermore, by letting the machinery be rented, Liebherr can reach all the construction companies that would not stand the investment. This allows the company to extend its market share, while also ensuring a greater management of resources. In addition, the OEM owns the machinery for the whole time and is responsible for maintenance, the product life cycle is elongated, and resources are saved. Liebherr has been extending the remanufacturing program over the last decades and can now offer different options for specific ranges of components, such as exchange, general overhaul, and repair [25]. Likewise, Liebherr is exploiting the potential of digitalization and product service systems (PSSs), while Hilti is similarly managing its portfolio, optimizing the repairing process, providing equipment at monthly fixed fees and guaranteeing full-time tools availability in case of damages or reduced effectiveness [26]. The threat for OEMs is that independent organizations provide a similar service independently. Many companies have realized that firms' environmental responsibility is not inconsistent with the creation of economic value and that remanufacturing generates higher environmental gain than recycling. Caterpillar perceives remanufacturing as a new era of profitability, and their Cat Reman is an independent remanufacturing division that generates up to 8% of the total revenue and has established a proper program—Cat Certified Rebuild—that guarantees the quality of re-manufactured products [27].

Nederman, with its Insight solution, addresses its customers' major difficulties with air filtration with sensors that monitor key performance parameters and functionalities, and deliver real-time data. Digitalization allows the new company division to sustain the customer and let him focus on his business activities [28]. Digitalization offers the opportunity to introduce, aside from the traditional selling–buying BM, additional services which improve the customer experience by providing alerts about product performances or monitoring its status. For example, EMTrack provides real-time reports that show tire performance. Tires can, thus, be tracked when they are currently in service or logged in inventory when they are removed from service. EMTrack also can help predict tire longevity in terms of hours, cost, and wear, which helps to enable more accurate forecasting and budgeting [29]. Those services come as additional maintenance or stand-alone services. They are package(s) of services to address the customers' needs and willingness to pay, as in the case of Alstom transport [28].

When approaching the new paradigm of CE, each company evaluates which solution best combines environmental benefits with overall revenues. Some focus only on core elements or parts with high added value, while others put into practice extended producer responsibility (EPR) by (re)working the whole product. Bosch, with the program Bosch eXchange, is making repair shops for standard rail components more and more competitive, both in time and cost terms [30]. In its remanufacturing plan, Volvo trucks give a new lease of life to worn-out engines for heavy-duty trucks, bringing them to like-new condition by passing them through a process which has less impact on the environment [31]. French-based Schneider Electric employs 142,000 people, uses recycled content and recyclable materials in its products, prolongs product-lifespan through leasing and pay-per-use, and has introduced take-back schemes into its supply chain. Circular activities account for 12% of its revenues [32]. Valtra is one example of agricultural machinery that provides customers with spare parts, new and/or remanufactured, and who also rely on outsourced remanufacturers like SR Harvesting OY [33].

There are sectors in which customers, or people responsible for product functionality, are unwilling to give up on traditional design, or where products have such long phases of use that when they were designed sustainability was not considered. OEMs are willing to get as much value as possible out of them with proactive approaches. For example, in the latter case, the PAMELA and AFRA aircraft projects, responsible for studying the potential benefits of recyclable materials in aircraft, produced a de-manufacturing hangar. Tarmac Aerosave is now the company in charge of disassembling aircraft, and sorting and tracing the parts intended to be recovered [34]. Smartphones, tablets, and laptops are included in the former case. Here, design is too focused on functionality and aesthetics, and there are almost no cases of design for de-manufacturing. There are isolated exceptions, but they are not the standards yet. See in this regard the Fairphone case. In order to minimize resource exploitation, the phone is not sold with a charger or headphones, and the smartphone is made out of modules that make the product easily repairable even for non-experts [35]. Hyla Mobile remanufactures standard mobile phones, giving them new life (lives) [36]; similarly, Taitonetti finds new applications for old business computers, selling them to private individuals [37]. When reintroducing IT products onto the market, it is important to guarantee that all sensitive data from previous owners are destroyed and there are companies specialized in these activities, like CCL North [38]. To comply with regulations, organizations in this sector mainly address disassembly and recycling. Apple built two robotic cells, called Liam and Daisy [39], to disassemble specific models of smartphones and retrieve as many components out of them. The disassembly process is highly efficient, since a robot is designed for only specific products. Indeed, it is not an outstanding example of life-cycle thinking [40], but the first step toward more sustainable resource exploitation. Philips shortened the distance between OEMs and recyclers by suggesting that designers disassemble the products they design [41]. Over recent years, targets have been set [42], but the distance to circular systems in these sectors is still very far, despite the results achieved [43][44][45].

The office-printing sector has been a leader for a long time in remanufacturing and PSS practice, starting from the single-use, almost entirely remanufacturable and recyclable cameras of Kodak [46]. This was a starting point for the company that still today is engaged in finding new means to be more responsible, without compromising on quality [47]. Further examples, such as Xerox [48] and Canon [49], etc., describing the success of their take-back programs (with related remanufacturing of multifunction and recycling of consumables) are strewn all over the literature [50][51].

More examples of the implementation of CE are biofuels made out of waste [51], cases that involve making batteries [52] and their life cycles [53] good for the environment, and responsible packaging [54] that becomes returnable instead of being disposed [55]. Among them, the materials of tires and asphalt [56] are widely being revisited and replaced with greener ones, coming from products of extremely different supply chains, or the opposite direction, as is the case with Eldan Recycling [57], Lehigh Technologies [58] or Timberland shoes' soles [59].

An example of the inclusion of multiple stakeholders in the circular system is Kalundborg, the world's first industrial symbiosis, run by the main principle of a residue from one company, becoming a resource at another, benefiting both the environment and the economy. A local partnership allows attendees to share and reuse resources, save money, and minimize waste [60]. Clusters and networks ease the establishment of communities and ideas circulation, and a validated process for one company may become an inspiration for another.

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