Enabling Circular Economy with Software: A Multi-level Approach to Benefits, Requirements and Barriers

Juha-Matti Väisänen, Valtteri Ranta(✉), and Leena Aarikka-Stenroos

Tampere University, Korkeakoulunkatu 7, 33720 Tampere, Finland
valtteri.ranta@tuni.fi

Abstract. Digital and software-based solutions have been identified as key enablers of circular economy, a recently emerged phenomenon that promises more sustainable business through better systemic material efficiency. Opportunities reside on multiple implementation levels. For example, optimizing resource use within processes, engaging in business models enabled by software development, sharing information to optimize resource use on a network level, and creating infrastructures that support systemic tracking and optimization of resource usage.

This conceptual paper contributes to both circular economy and information systems research by identifying the most prolific technologies underlying software-based solutions enabling circular economy. Furthermore, this paper discusses requirements and barriers for successful implementation of identified solutions residing on each of the application, network, and infrastructure levels, providing a framework for researchers analyzing digital solutions and software business in the context of circular economy, and for practitioners seeking to leverage the potential of digital technologies for their customers.

Keywords: Circular economy · Software-intensive business · Digitalization · Micro-meso-macro perspective

1 Introduction

Software-based solutions have recently been identified as a crucial step towards improving sustainability of business through circular economy (CE) [1, 12]. In comparison to traditional consumption called the linear economy model, circular economy is a new model for material flows, which strives to improve sustainability through maintaining the value of products and materials at their highest possible level for longer, thus reducing the need for production of new products, the extraction of virgin materials from our finite planet, and reducing the amount of materials being disposed of as waste [5].

In order to maintain the value of products and materials at the highest possible level, information is needed for efficient management of processes that maintain the value, such as remanufacturing products [8]. Similarly, as circular economy often

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leverages the idea that waste for one actor is a resource for another [12], information is required to match the resources that are considered of low value with the actors that have higher value uses for the resource. Software solutions provide the means to collect, disseminate, and analyze this information. While developing technologies thus play a role of crucial enablers for circular economy, research on how to successfully capture these opportunities is still scarce. To address this gap, we adopt the multilevel approach [5], and address the implementation of software solutions on a micro-level, i.e. applications that a single company implements to improve the circularity of their operations, meso-level, i.e. systems that networks of companies collaboratively leverage to improve circularity between them, and macro-level, i.e. infrastructural digital technologies that improve systemic resource efficiency.

Our paper aims to answer four distinct research questions. To map out the underlying technologies for software-intensive solutions in circular economy we seek to answer: *what are the technologies that enable circular economy?* Acknowledging that circular economy actions take place on multiple levels (micro, meso, and macro) by different stakeholders [5], we answer: *how the technologies affect different levels of circular economy?* To address the potential pre-requisites for successfully enabling CE through software solutions, we answer: *what are the requirements to implement the solutions on the different levels of CE?* Lastly, to identify existing barriers that can undermine the potential of software-based business in CE, *we answer what are the barriers on each level?* Through answering these questions, we create a comprehensive framework for identifying and analyzing the feasibility of implementing a digital solution to enable circular economy, suitable for use by practitioners and academics.

2 Circular Economy and Software Solutions

Circular economy challenges the old linear economy approach to production and consumption, by implementing ways to reduce landfill and emissions, and instead keeping materials and products in circulation [4]. Traditional linear economy focuses on maximizing the results by maximizing production, whereas circular economy aims to break the relation between economic growth and use of resources by redesigning economic processes and maximizing the values of resource use [5]. The focus of the reduction is both in the inputs and outputs of material flows and the aim is to keep the materials in the cycle.

The level of impact or implementation of circular economy principles can be divided into three categories: Micro-, Meso- and Macro-levels. The Micro-level refers to actions and effects regarding products, applications, companies and consumers, the Meso-level refers to Eco-industrial parks (EIP) formed together by organizations and societies and the Macro-level covers the largest scale including cities, regions, nations and even global actions [5]. Thus, on the Micro-level, software solutions enabling circular economy to focus on singular applications, Meso-level implementations focus on applications used within a network of actors, and Macro-level implementations focus on digital infrastructure. The Meso-level differs from micro-level especially through the inclusion of public authorities and the decision-making process of the political system. Even though immediate circular decisions and effects can be hard to achieve on the Macro-level, the importance of wide discussion and cooperation is valuable to the promotion of circular economy implementation. Fundamental changes towards circular economy require simultaneous actions on each level of impact [9].

Software solutions are key enablers of circular economy and the development of the emerging technologies are driving the change towards circular thinking and innovation [9, 10]. Emerging digital technologies are relevant in every part of the product lifecycle [2], and through improving ways of data gathering and analysis, products are transformed into value-creating systems [16]. New solutions are breaking down the barriers on implementation of circular economy principles and forming new ways of operation in the form of new revenue streams generated by new possibilities and the implementation of new business models [19], but also by helping companies increase their resource efficiency and close the material loops of the material cycles [2]. Some identified benefits of software solutions that help drive circular economy are new business models and product service systems [15], enhanced product life cycle management [21], loop-closing platforms [16] and more efficient supply-chain management [17], which is why circular economy has attracted major global companies in the hopes of large financial, social and environmental benefits [10].

3 Research

To evaluate the factors and development of software solutions in circular economy, we use the multi-level approach by analyzing existing literature with the aim to form an understanding of the current technologies, requirements for their implementation and the barriers for implementation on each level of impact. The research was done by searching information on uses of digital technologies in the context of circular economy. Scopus and Web of Science were used as primary databases by searching information with phrases such as digi* AND CE or digi* AND "circular economy" between April and May in 2019. The research is conducted by approaching the findings through the different levels of the multi-level approach resulting in better understanding of each level and categorization of the technologies, benefits, implementation and barriers based on their uses in literature. Additionally, the findings and the ways they can be used were discussed with experts, to provide further insight and reliability for the results. Questions one and two are addressed in Sect. 3.1, the third question in Sect. 3.2 and the fourth in Sect. 3.3.

3.1 Mapping the Technologies and Their Benefits

The technologies that can be identified to be used in the context of circular economy are: radio-frequency identification (RFID) [6], internet of things (IoT) [11], big data and analytics [1], cloud computing [19], cyber physical systems, [13], additive manufacturing [8], distributed ledger technologies [16] and artificial intelligence and machine learning [15]. Many of the technologies are used together and may require the use of other technologies to be relevant, for example the RFID sensor technology is a key enabler of other digital technologies, which enables data gathering and communication between objects [17].

On the micro-level many technologies and benefits can be identified through the innovative solutions provided by companies. Internet of things, cloud manufacturing, cyber physical systems (CPS), and additive manufacturing can be used to develop the design, production and logistic processes in a company to promote circular economy [8]. On a company level, internet of things and RFID technologies help companies gather information on product usage, CPS can be used to help with waste sorting and production assembly [13] and also to avoid overproduction [7]. Cloud computing helps companies to handle massive data amounts and reduces energy consumption and additionally it can be used to help logistic processes in selective waste collection [13]. The bundling of IoT solutions with big data analytics, allow the large amount of data gathered to be used in strategic analysis and support decision-making [3] The results gained from big data analytics can be further developed with artificial intelligence solutions which support the process and system optimization even further [15]. New business models are also increasingly being taken into consideration and IoT related emerging technologies seem to be the missing link to enable the use of service business models [7].

On meso-level the digital technologies in circular economy are focusing around the ways of cooperation in the networks. In network communication distributed ledger technologies are being developed to allow safe sharing of information and databases between the different operators [16]. By closing the loops with network cooperation, product lifecycle management needs to be effective to keep track of the quality and availability of products [21]. The RFID and IoT technologies are used to create so called “product passports” to enable the possibilities of reusing products and collaborating in production processes [6]. On meso-level the technologies enable the transformation towards a collaborative environment and the use of platform-type operating [16]. In the available research and literature, the use of technologies on macro-level are not addressed and have been researched only limitedly. Many of the technologies could undoubtedly promote circularity on macro level, but clear examples of the technologies being utilized in the macro level were not found in the context of circular economy during the research.

3.2 Identifying Requirements

The change to favor new disruptive innovations not only require large investments in the technologies [2], but also support from institutions, governments and foreign investors [14]. Information management is a key part in implementing data-based CE-solutions, and the realization of the data-information-knowledge-wisdom-cycle helps to understand the requirements and components in the data structure [20]. When handling data as core business problems, companies need to also cover new knowledge areas for example relating to data security [3].

Development of software for circular economy would benefit from an integration and redesign of industrial systems, infrastructure and delivering services [5], to better facilitate data-driven systemic resource efficiency [5]. Systematic development of the public sector is also needed as it plays a key role as part of the potential networks [18]. The economy needs to support investments as they are a key part in implementing new technologies and building the digital infrastructure and the regulation needs to support circular solutions for example, in the form of favorable taxation and standardization [4]. Lastly, the general awareness of circular economy needs to improve among the consumers and companies, to make the transformation intriguing for companies [4].

3.3 Identifying Barriers

There are still some risks in the development of the technologies, for example in printed QR-codes, which result in 15% failed scans in testing [6]. The reliability between machines is a critical problem, so the barrier of technical development is relevant [8]. Many companies use old information systems which might prevent implementing CE solutions [20] The technologies need to also be coordinated across different organizational areas simultaneously [8]. Circular economy being a new trend that brings in new thoughts and innovations, lack of talent may also form a barrier for corporations, if they have not implemented circular solutions before [8]. At the transition phase, digital and circular competences inside the organization need to be combined [1].

On the consumer perspective, the new service focused business models might affect the behavior of consumers through the loss of ownership. If consumers do not acknowledge the effectiveness of the new business models both for the customers and the service providers, the implementation of new business models enabled by software solutions might fail. However, through servitization, often enabled with software solutions, the financial and operational risks transfer from the customer to the service provider. This might encourage the consumers towards switching from owning products to using services, but the companies need to be able to cover the risks [2].

On the meso-level the challenges are realized in networks and cooperation management. Collaboration and ownership, sharing and access of data can be identified as challenges for CE implementation in meso-level [1]. The ownership of information is a problem that needs to be solved, for example in the cases of jointly created information. In shared data bases, which are used in innovation processes, the ownership of the information and thus the innovation might be unclear [16]. At the same time, the integrity of data might cause problems in collaborating databases and networks [8].

On macro level the barriers coordinate with the requirements identified on the same level. Wrong focus on taxation creates a strong barrier to the development of circular economy and thus the need for software solutions supporting it. Through political decisions the attitudes towards implementing circular decisions are formed as the taxation affects the profitability for circular transformation [8]. Through the national decision-making the general awareness also forms a barrier for the circular solutions to be implemented nationally as the society needs to accept the transition towards circularity [4].

4 Discussion and Conclusions

The distinction between the different levels can be seen clearly in Table 1, displaying the results. Reported possibilities and examples of software supporting circular economy reside mostly in the micro level. On the meso-level, the findings are related to the cooperation and networking of organizations, helping to build a collaborating environment to promote circular economy. On the macro-level, the findings are only limited to identifiable requirements and barriers, indicating that circular economy is not yet thoroughly achieved on the macro-level or the solutions are not applied yet on large scale.

Table 1. Identified technologies, benefits, requirements and barriers

	Technologies	Benefits	Requirements	Barriers and challenges
Micro	• Radio Frequency Identification • Internet of Things • Cloud computing • Additive manufacturing • Cyber physical systems • Big Data analytics • Artificial intelligence and machine learning	• Development and optimization of operational processes • Gather information on product usage • Help in waste sorting • Avoid Overproduction • Data management • Resource and energy efficiency • Support decision-making • Enable service business models	• Investments • support from the public sector • Information management • Data Security • Knowledge on materials and product development • Skills in circular economy • New business models • Reverse cycle development	• Coupling of resource use and economic growth • Development of the technologies • Old information systems in use • Indoor organizational coordination • Lack of talent • the loss of ownership. • Financial and operational risks
Meso	• Distributed ledger technologies • Radio Frequency Identification • Internet of Things	• Allow safe sharing of information and databases • Keep track of the quality and availability of products • Enable the transformation towards a collaborative environment • Platform-type operating	• Dedicated network • Allowing information sharing • Platforms for collaboration • Shared vision	• Coupling of resource use and economic growth • Collaboration • Data ownership • Data sharing • Data access • Data integrity
Macro	• No identified results	• No identified results	• Development of the infrastructure • General awareness • Legislation • Good economical phase that supports investments	• Coupling of resource use and economic growth • Taxation • General awareness

Based on the results, digital technologies can be seen to drive the circular transformation from micro-level towards the meso- and macro-levels. The broader implementation of software-based business requires large grounds of digital infrastructure, and from the perspective of circular economy, industrial companies are the key operators in the infrastructural development due to their closeness to material and energy flows. The solutions that are achieved on a micro-level can be further utilized on the upper levels, when the digital infrastructure on public and national operators are developed as well and the micro-level solutions can be generalized.

Meso-level requirements and barriers rely heavily on networking and collaboration, which leads to focusing on data management. The rise of distributed ledger technologies like blockchain are key for enabling safe collaboration and data sharing. Though the data technologies are developing fast the questions related to the ownership of data still remain unsolved. The success of meso-level implementation is only achieved if all the operators dedicate to operating towards a common goal, which might be a challenge to organize and bring out new challenges related to operating methods and general cooperation. The simultaneous competition and co-development might be hard to fit into certain ecosystems, which is why meso-level implementations might not work even though the software technologies could be utilized.

The slow development of the macro level infrastructure might be one of the key reasons why software is not utilized more in the context of circular economy. On the other hand, the development of circularity seems to need the development of the lower levels, before macro-solutions and benefits might be achieved. Even though, the macro-level benefits are yet unrealized, the actions towards circular economy on macro-level are important, as support to the transition on lower levels. The support of the public sector and government can tip the scales on whether new business models and other new forms of operations are profitable and thus motivate organizations to pursue them.

The concluded study contributes to the prior research done on the areas of circular economy, software-intensive solutions and their combined effects. The study develops the understanding on the technologies, benefits, requirements and barriers among each level on the perspective of software solutions supporting circular economy and provides information on the differences between the levels.

The results of the conducted study are conceptual and limit only to the available literature and the findings that have been reported in previous research. The focus of the findings is mainly on the theoretical side, which is supported by few concrete examples on individual operators or cases. Thus, we suggest that further research should be made with a case-based empirical focus on the software solutions and their effects on circular economy on each levels of the multi-level approach. The use and effects of the technologies should be researched in an organizational environment that already focuses on software solutions and have the infrastructure ready for circular development in order to empirically test the findings and provide information for circular economy development. We also suggest that the macro-level solutions need to be researched thoroughly as the current findings on this level are very limited.

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