Tampere University

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ENABLING CIRCULAR ECONOMY WITH DIGITAL SOLUTIONS

Multiple-case study in Finland

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ABSTRACT

Juha-Matti Väisänen: Enabling Circular Economy with Digital Solutions: Multiple-case study in Finland
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Circular economy and the benefits of digital solutions are constantly gaining interest among researchers, companies and organizations. The two trends have separately received much attention during the recent years, but the cooperative opportunities of digital solutions in the area of circular economy are still to be further researched. While circular economy is introducing a new approach to consumption by keeping materials in a continuous cycle, digital solutions are generating new opportunities and innovations. The correlation between the two trends has been recognised but the empirical research results on the subject have been missing.

The conducted research focused on gaining insight into benefits, requirements and challenges related to the use of digital solutions in circular economy operations. Four organizations that operate with different circular economy solutions in Finland were interviewed based on current understanding on the subjects gained from scientific literature and expert interviews. As the interviewed companies focused on different areas of circular economy, the research provided results on all three value drivers of circular economy listed as resource efficiency, extending product lifetime and closing material loops.

The different digital technologies used in the context of circular economy were identified and sorted under the categories of data collection, data integration and data analysis technologies. The different categories also resemble the development and implementation status of digital solutions as the earlier technologies are required to achieve development in the next category. Despite large attention on data analysis technologies and the opportunities of Big Data, the development status of most organizations still focuses on data collection solutions revolving around Internet of Things and its applications. Clear benefits can be seen to be achieved with data analysis solutions, but implementations on that level remain to be identified especially on a large scale. Even though the focus is still on data collection technologies, several benefits and effects to promote circular economy through digitalization were identified. This indicates that digital solutions have an important part in circular economy development as large potential is still to be researched with the benefits of data integration and data analysis technologies.

The results on interviews indicated that the requirements on implementing digitalized circular economy match the literature-based results, adding also new findings to the discussion. Customer interaction and consumer decision weighted heavily in the development of circular and digital solutions as the users need to agree on the development decisions for the solution to succeed. Additionally, the challenges found differed largely from the earlier research as the literature-based challenges focused on physical limitation and terminology discussion, where the interviewed organizations pinpointed the importance of finding top experts and solving data ownership issues. At the end, future development areas and directions of digitalized circular economy was discussed where four repeating key areas were identified. The upcoming key areas to follow and develop are the implementation of data analysis technologies, accessibility of customer information, solutions to promote preventive maintenance and effective use of cross-organizational unified systems.

Keywords: Circular Economy, Digitalization, Digital Solutions

TIIVISTELMÄ

Juha-Matti Väisänen: Digitaaliset ratkaisut kiertotaloudessa: Monitapaustutkimus Suomesta
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Kiertotalous ja digitaaliset teknologiat keräävät jatkuvasti lisää huomiota tutkijoiden, yritysten ja organisaatioiden keskuudessa. Näitä kahta trendiä on tutkittu viime vuosina huomattavan paljon erillisinä kokonaisuuksina, mutta niiden yhdistelmästä ilmenevät mahdollisuudet ovat vasta äskettäin nousseet tutkimuksen keskiöön. Ilmiönä kiertotalous haastaa perinteisen kulutusmallin, jossa raaka-aineet päätyvät valmistuksen ja käytön jälkeen kaatopaikalle, pitämällä tuotteet mukana materiaalikierrossa. Samaan aikaan digitalisaatio mahdollistaa uusia toimintamalleja ja innovaatioita, joilla materiaaliratkaisujen toteuttamista voidaan tukea entistä tehokkaammin. Näiden kahden trendin välillä voidaan havaita selkeä korrelaatio, mutta sen hyödyntämistä ei vielä ole empiirisesti tutkittu.

Toteutettu tutkimus keskittyy perehtymään digitaalisten ratkaisujen hyötyihin, vaatimuksiin sekä haasteisiin kiertotalouden prosesseissa. Tutkimuksessa haastateltiin neljää suomalaista yritystä, jotka toimivat kiertotalouden parissa ja hyödyntävät ratkaisuissaan digitalisaatiota. Haastattelut perustuivat kirjallisuuteen ja alan ammattilaisilta hankittuun ajankohtaiseen tietoon aiheesta. Tutkimuksessa tarkastellaan kiertotaloutta kolmen kiertotalouden ajurin avulla, joita ovat resurssitehokkuus, tuotteiden elinkaaren pidentäminen sekä materiaalivirtojen sulkeminen. Valittujen yritysten ratkaisut rakentuvat eri ajurien ympärille, joten tutkimuksessa digitalisaation hyötyjä on tarkasteltu laajasti eri lähtökohdista.

Tutkimuksessa tunnistettiin eri digitaaliset teknologiat, joita hyödynnetään kiertotalouden yhteydessä. Teknologiat jaettiin dataa kerääviin, dataa integroiviin ja dataa analysoiviin teknologioihin, joiden tunnistettiin vastaavan myös teknologisen kehityksen tasoja. Seuraavan tason teknologiat vaativat edeltävän tason teknologioiden hyödyntämistä, jolloin dataa analysoivien teknologioiden käyttöönotto vaatii ensin suuria investointeja dataa integroivien ja keräävien teknologioiden implementointiin. Dataa analysoivien teknologioiden suuresta suosiosta huolimatta, niiden hyödyntäminen on vasta vähäisellä tasolla sillä suurin osa yrityksistä kehittää vielä ratkaisuja dataa keräävien teknologioiden ympärillä. Analysoivilla ratkaisuilla koetaan olevan paljon potentiaalia, mutta etenkin suuren mittakaavan ratkaisuja ei kukaan vielä ole toteuttanut. Vaikka digitaalinen kehitys kiertotalouden alueella on vielä alkuvaiheessa, tutkimuksissa tunnistettiin useita hyötyjä, joilla etenkin esineiden internetin avulla kiertotalouden toteutusta voidaan tehostaa.

Tutkimuksen tulokset osoittavat, että yritysten haastattelutuloksista sekä alan kirjallisuudesta voidaan havaita yhtenevät vaatimukset digitaalisen kiertotalouden implementoinnille. Vaatimuksissa korostuu asiakasyhteistyö sekä kuluttajiin vaikuttaminen, joilla on suuri merkitys kiertotalouden uusien ratkaisujen kehitykselle. Jotta uusia menetelmiä voidaan onnistuneesti ottaa käyttöön, tulee kuluttajien hyväksyä ja omaksua muutokset omiin käytäntöihinsä. Toisin kuin vaatimukset, listatut implementoinnin haasteet eroavat merkittävästi kirjallisuuden ja haastattelutulosten välillä. Kirjallisuudessa haasteet perustuvat luonnollisiin rajoituksiin sekä jätteen määrittelyyn, jotka asettavat haasteita toiminnalle, kun haastattelutuloksissa haasteet keskittyvät alan osaajien löytämiseen sekä datan omistajuuskysymysten ratkaisuun. Haastattelujen lopuksi yritysten kanssa keskusteltiin digitaalisen kiertotalouden kehityssuunnista ja tärkeimmistä kohteista, jotka tulevat muuttamaan alaa. Tärkeimmiksi kehityskohteiksi tunnistettiin, analysointi teknologioiden implementointi, asiakastietojen hyödyntäminen, ennakoivat huoltamismenetelmät sekä yritysten välisten järjestelmien rakentaminen.

Avainsanat: Kiertotalous, Digitalisaatio, Digitaaliset ratkaisut

PREFACE

This thesis concludes my six and a half years long journey through university to the first steps of my career. During my studies I've enjoyed student life to the fullest experience by participating in a wide range of activities and responsibilities, which has given me lifelong friends and experiences I will never forget. Through studies, Tampere will always have a special place in my memories.

I would not be standing here without the help and support that I have received from all the associations I have had the chance to be a part of. I want to especially thank the Guild of Industrial Engineering and Management Indecs and all the boards I've been part of for all the great experiences, TTYY board 2017 for teaching me important lessons, Kiltaneuvosto 2016 for the day long trips and cottage weekends, excursion group Elram for countless activities and friends, Turvoke boards 2017 and 2018 for giving me a different perspective on making lobbying fun and last but not least Indecs fuksis 2013 for making my journey through university exciting and full of surprises. These experiences have made me a better person and have critically helped me proceed both in my career and my personal life.

On top of student experiences, the work with my thesis has shown me a different side of research and how enthusiasm on a subject, leads to great results. I had the chance to complete my thesis as part of a research project, which opened my eyes to research culture and allowed me to participate in research activities that were exciting to complete.

In the end I would like to especially thank my supervisors Leena Aarikka-Stenroos and Valtteri Ranta for making my thesis experience interesting and pushing me towards goals I am now proud that I completed. Thank you for the continuous support and motivation, which have had an important impact on completing this thesis and making the journey memorable. You both have an inspirational take on doing research and motivating your teams, and I wish the best for you in your future projects.

Helsinki, 18th February 2020

Juha-Matti Väisänen

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LIST OF SYMBOLS AND ABBREVIATIONS

3R	3R-principles, reduce reuse recycle
CE	Circular Economy
CPS	Cyber Physical Systems
I4.0	Industry 4.0, Fourth industrial revolution
IoT	Internet of Things
PSS	Product Service Systems
RDM	Re-Distributed manufacturing
RFID	Radio Frequency Identification
ROI	Return on Investment

1. INTRODUCTION

The pressure caused by traditional ways of production and consumption are changing the ways that individuals, companies and even nations are approaching sustainability. Today sustainability is not just observed on company levels as it has achieved even larger attention in social, economic and environmental discussion (Nasiri, Tura and Ojanen, 2017). Landfills and emissions generated by waste and unrecycled materials are generating a new challenge to economies (Ghisellini, Cialani and Ulgiati, 2016) as the increase in population is resulting increases in the amount of consumption (Yang et al., 2018). At the same time new trends are transforming the ways companies operate, allowing new kinds of business models and value creation to be applied in the processes. Circular economy, digitalization and servitization can be seen as three different trends of transformation towards sustainability (Parida and Wincent, 2019) that try to answer the environmental problems identified globally.

Circular economy (CE) is a phenomenon that has recently gained large amounts of momentum as a concept consisting mainly of methods driving the development of resource efficiency, product lifecycle management and material loop closing (Bressanelli *et al.*, 2018a). As the innovations and new approaches around the concept of circular economy are blooming, the fourth industrial revolution is developing the production methods towards smart factories and products, which allow new ways of gathering, analyzing and managing data. Digitalization and innovative digital solutions are making implementation of trendy methods available for most operators and new ways to operate are constantly being generated through unique revenue streams. New possibilities and the implementation of new business models promoting sustainability are increasing in popularity as they appear to provide a new competitive edge in markets (Stock *et al.*, 2018). Sensor technologies are changing the fundamentals of products and systems by allowing everything to be connected to data driven systems or internet. With the development of 3D-printing the reusing and remanufacturing methods are enabling companies to manufacture spare parts on demand and answer differing needs on location (Zhong and Pearce, 2018). Distributed ledger technologies are assuring secure and private data sharing (Rajala *et al.*, 2018). The massive amounts of data enable new ways of analysis and operation and smart products, smart facilities and even smart ecosystems are becoming

even more popular. New technologies are creating solutions to the traditional problems and through their development organizations are on a point of transformation.

Through new possibilities generated by digital development of organizations and societies, the implementation of circular methods is becoming easier and more accessible. At the same time the global pressure of transforming towards sustainability is forcing organizations to change the way they think, with the United Nation targeting to achieve sustainable management and efficient use of resources by 2030 documented in United nations 2030 goals for sustainable development. For the sustainable targets to be achieved, societies need to take on critical steps in order to reduce their environmental impacts. Companies have a critical part in the resource use and if the regulations begin to force a change in the ways of production, companies will need to transform and come up with new efficient ways to operate. Circular economy provides solutions that at the same time can increase profitability and lead to cost savings (Bressanelli *et al.*, 2018a), but also function as a precaution for tightening sustainability regulation. Achieving sustainability in production is a solution for developing efficient material processes in a long term perspective (Stock *et al.*, 2018).

The changes in the production ways aren't yet forced on companies, but still many large companies have already implemented new ways of operation and implemented circular production methods. For example the bio-economy has already taken big steps towards circular economy, which are driven by digital solutions (Watanabe, Naveed and Neittaanmäki, 2019). Before digitalization, the benefits to go for service-oriented business model weren't interesting enough for companies, as the technologies and methods to do service-oriented business were not developed to a suitable level. A transformation from pure manufacturing business towards having a larger impact on service-side easily seemed like a significant risk for companies. After the development of new technologies several business models have emerged in the market which are being taken into consideration much more as the cost of technologies are shrinking and the knowledge on their use is constantly growing (Parida and Wincent, 2019).

At the same time as circular economy aims to increase sustainable development the actions also increase environmental quality, economic prosperity and social equity (Bressanelli *et al.*, 2018b) and the results of sustainability can affect the surrounding ecosystems on a wide scale (Nasiri, Tura and Ojanen, 2017). The solutions used in production facilities and eco-industrial parks also interest cities and nations if the solutions can be scaled to fit even larger needs. Large steps can already be seen in key areas as for example Internet of Things (IoT) -solutions are already being develop to answer the needs of smart cities in waste management (Beliatis *et al.*, 2018).

Even on small scale the public sector plays an important role on achieving the maximum potential on sustainable solutions as the transition towards circular economy requires changes both on the side of companies and their networks (Parida and Wincent, 2019) The companies are not necessarily closing their own loops, but the loops of the ecosystem (Antikainen, Uusitalo and Kivikytö-Reponen, 2018) and on those ecosystems the public sector plays an important role (Ellen MacArthur foundation, 2016). The circular economy innovations on production level are highly valuable in order to solve circular issues and improve sustainability globally, but the innovations need to be radical in order to challenge the current technologies and make a change in the focus areas of corporations (Nasiri, Tura and Ojanen, 2017).

To solve the environmental issues globally, new innovations need to be implemented as the change from linear economy to a circular economy is radical. Instead of focusing on optimizing material flows, companies should think about their role in the industrial systems in order to responsibly handle materials and develop business (Rajala *et al.*, 2018). Through circular solutions the correlation between increasing economic growth and resource use can be broken (Yang *et al.*, 2018), and digitalization makes the transition towards circular economy easier. Therefore, the research between the two trends is critical.

1.1 The aim of the study

The current literature indicates that the digital solutions are a key enabler of circular economy and the emerging technologies are supporting the change towards circularity and innovations (Hansen and Alcayaga, 2017; Stock *et al.*, 2018; Gligoric *et al.*, 2019). Yet many research gaps can be identified regarding the empirical evidence on the benefits achieved by using digital solutions to promote circular economy (Nasiri, Tura and Ojanen, 2017). Rajala et al. (2018) also note that there is only little empirical work done on utilizing information resources on business ecosystems in circular economy. *"This is a critical gap in the knowledge, because firms in technology-enabled business ecosystems need to play an active role for the circular model to work."* (Rajala *et al.*, 2018)

In Finland circular economy questions have come up in the form of discussion among different environmental problem cases around the country. The circular solutions are being researched in collaboration between the six largest cities in Finland based on an EU funded strategy called The Six City Strategy, which promotes sustainable urban development. As part of the acknowledged EU strategy, a research project with the name CircVol focuses on researching circular economy in large volume material flows in different case sites in Turku, Helsinki, Tampere and Oulu. The listed cities have identified

problems in landfill generation and new solution to reuse and reduce the landmasses need to be implemented. As part of the project, the impacts and possibilities of digitalization in the circular economy are being researched, thus forming the motivation for the study. There is a critical need for new solutions in the case sites and in the research area of large volume material management, where digital solutions could provide favourable outcomes and enable the cities to solve the cases through being able to implement circular solutions.

The need for circular solutions, the research gaps in circular benefits and empirical research on digitalization in the context of circular economy are driving the need for further research. In addition to trying to connect new circular solutions to the case sites, research is conducted with the material flows of companies that operate with circular economy solutions and digital solutions. The research done on company perspective aims to give differing knowledge on the implementation of digital solutions, which could support the total results found on the research. Just like cities, many companies generate landfill through material streams, so doing research on company area will maximize the value of the research. The identified need for solutions, the gaps presented in the literature and current research form the aim of the study, where of the following research questions can be deducted.

To form an understanding on the current situation of digital development and its correlation with circular economy solutions, we aim to map the current critical technologies in the area with the first main research question:

1. *Which digital solutions and technologies can support circular economy?*

To increase the understanding on the supporting elements of digital solutions in the context of circular economy, the second main research questions is:

2. *How can the identified technologies benefit circular economy?*

To increase the understanding on the development status and implementation as well as to gain an organizational perspective on the trends, the third main research question addressed is:

3. *What are the challenges and requirements for implementing digitalization into circular economy processes?*

To deepen the academic contribution of the study and bring a perspective of the upcoming changes to the discussion, an additional fourth research question is addressed as:

4. *What are the expectations for digitalized circular economy development?*

The research aims to find clear results by combining knowledge and information gained through literature, previous research, expert interviews and company interviews. The data collected is then used with the aim to generate clear objectives and guidance for the partners selected for the research to increase circularity in their operations and provide them with up-to-date knowledge on the digital development and its possibilities. Another practical aim is to fill the gap presented in literature relating to the lack of empirical research in the context of digital solutions in circular economy. The results presented can hopefully be scaled and implemented into other similar cases.

The conducted research is limited to Finland, which narrows down the possibilities to generalize the results. All parts of the research are done in limited time period of seven months, which limits the inclusion of all perspectives on hand to be covered. As the covered topics are trending as research areas, the scientific literature to be covered in the study might change during the completion of this research, due to the large number of new publications in the area.

1.2 The structure of the study

The paper consists of five parts: introduction, theoretical part, methodological part and results ending with discussion and conclusion. The second and third chapter of the paper consist of theoretical literature reviews on the topics of circular economy and the development of digital solutions. The chapters focus on important information on the key subjects based on current scientific research. The information has been gathered using scientifically approved databases to provide academic and reliable results, and the scientific data is backed up by articles and publications from organizations that promote circular economy and digitalization. Chapter two includes a short theoretical background on circular economy to understand the relationship of the key trends, but the focus of the theoretical research is on the digital solutions in circular economy context. The theoretical part functions as a basis, supporting the generation and conducting of the empirical part of the research. The information and sources for chapters two and three were gathered during April and May 2019 using Scopus and Web of Science as the main databases. In addition, the literature review processes were backed up by two expert interviews on digitalized circular economy, where the findings and understanding on the phenomenons were confirmed.

Chapter four introduces the methodological part of the paper. At the beginning of chapter, the framework approach is introduced as the ground reference to be used in the evaluation of the results presented in chapter five. The planning and conduction of the research are explained providing also arguments on the choices made in the research

process. The research will be conducted through semi-structured interviews in collaboration with selected companies and organizations, which will be chosen to best support the aims of the study.

Chapter five includes the introduction of the cases chosen for the research as well as detailed information on their perspectives on circular economy and digitalization. Descriptions are presented on the case related circular economy solutions, providing insight into different methods to promote circularity. Each case is presented separately, and the results are gathered to a concluding presentation, where similarities and differences can be identified.

Chapter six consists of summing up the results of the introduced cases. Each of the research question is observed separately by combining the findings on all research cases and comparing the empirical findings to the information provided by scientific literature. The results are presented visually to provide supporting and understandable material for the analysis.

Chapter seven consists of the discussion and conclusion section, where the success of the research is analyzed critically, and the conclusions of the research are formed. The chapter aims to generate suggestions that would benefit the organizations participating in the research as well as to generate important research content for academic purposes. Also, the gaps and opportunities for additional research identified in the process are covered.

2. THEORETICAL APPROACH TO CIRCULAR ECONOMY

A strong connection has been identified to exist between the phenomenons of circular economy and digitalization (Ellen MacArthur foundation, 2016). In order to understand the connection between circular economy drivers and possibilities enabled by digital solutions, the theory behind circular economy is briefly introduced in chapter 2.1. The different business aspects and interest related to increased popularity of circular economy are also identified as they provide the need and reason for digital solutions to be implemented. Yet, the focus of the literature review conducted in chapter 2 is put on the digital solutions and how they might enable or enhance the implementation of circular economy principles. The part regarding digital solutions is introduced in chapter 2.2

2.1 Circular Economy principles

In the past, waste management has been considered as just a way to get rid of excess materials by landfilling or incineration. These two are still the most dominant disposal patterns used worldwide. Circular economy is a new model to replace the linear economy, which has resulted threatening effects on the stability of natural ecosystems and economies (Ellen MacArthur foundation, 2013). The concept of industrial ecology, which promotes material and energy loop closing that results less wasteful processes, was already introduced in 1997 in order to change single ecosystems to be both the causer and receiver of environmental damages. Circular economy continues the concept of industrial ecology by promoting circularity in even larger scale apart from single companies. The effects of circular economy include implementation of a greener economy and new business models, but also new employment opportunities powered by new innovations. Circular economy has the potential to radically help society reach increased sustainability and wellbeing possibly without any material, energy and environmental costs. (Ghisellini, Cialani and Ulgiati, 2016) 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 flowing in the lifecycle (Ellen MacArthur foundation, 2013)

Circular Economy vs. Sustainability

In literature the concepts of sustainability and circular economy are easily mixed, but the definitions are clearly different. According to Ghisellini et al. (2016):*"CE may be considered a way to design an economic pattern aimed at increased efficiency of production and consumption, by means of appropriate use, reuse and exchange of resources and do more with less"* (Ghisellini, Cialani and Ulgiati, 2016) and according to Rajput and Singh (2019) *"Purpose of the CE is to enhance the resource efficiency and environmental performance at different levels of the supply chain"* (Rajput and Singh, 2019). Geissdoerfer et al (2017) researched the similarities and differences of the concepts and the main motivation behind them is clearly different. In circular economy the emphasis is put on closing the loops, eliminating resource inputs and the generation of waste and emissions, while the focus on sustainability is much broader. Circular economy is prioritizing the economic systems and their effect on the environment, whereas sustainability is widely seen as a three-dimensional concept taking into consideration the environmental, economic and social benefits. In circular economy the environment and societal dimensions are mainly approached through the benefits gained from the development and implementation of circular practices in the economy. Geissdoerfer et al (2017) identify three types of relationships between Circular economy and sustainability which are a beneficial relationship, a trade-off or as a third possibility circular economy is seen as an enabling condition for sustainability. Circular economy can be seen as regenerative closed loop design of an economic system with the core fundamentals being in the circular flow of materials and energy (Geissdoerfer *et al.*, 2017).

Circular Economy vs. Linear Economy

Circular economy aims to break the relation of economic growth and use of resources by redesigning economic processes and maximizing the values of resource use (Ghisellini, Cialani and Ulgiati, 2016). For example the deconstruction of buildings reduces the waste going to landfills in comparison to demolishing (Ellen MacArthur foundation, 2013). Circular economy should utilize the nature's own cycle of preserving materials and energy, and the waste released to nature should be in a form that nature can easily utilize in its own functions (Korhonen, Honkasalo and Seppälä, 2018).

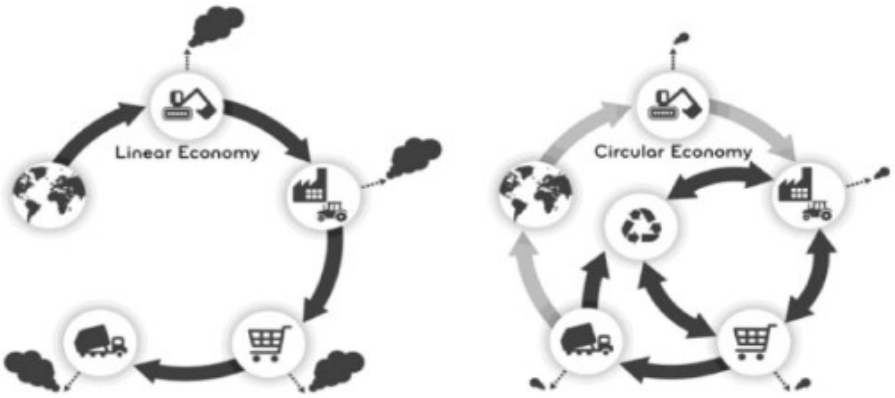


Figure 1. *Linear economy vs. circular economy* (*Okorie et al.*, 2018)

Figure 1 describes the transform from linear economy to the circular economy, which indicates that circular economy aims at reducing both the input and output of the material flow by keeping the materials in the cycle. The cycle is not only closed by processing the disposed waste into new materials that are used in the bottom-end of the production line, but also by other circular economy principles.

Circular solutions affect different parts of the ecosystem at the same time (Korhonen, Honkasalo and Seppälä, 2018). Transforming the ecosystems towards sustainability by implementing circular solutions has an effect on all three dimensions of sustainability which are economic, societal and environmental dimensions (Nasiri, Tura and Ojanen, 2017). These three dimension need to be considered in the context of circular economy as changes may have indirect positive or negative effects on the ecosystem (Korhonen, Honkasalo and Seppälä, 2018). Lieder and Rashid (2016) argue that the finite resources directly affect the social prosperity and a society that can minimize their environmental impact is a strategic goal for nations, governments and individuals (Lieder and Rashid, 2016).

3R Principles

The principles of circular economy can be identified as actions or strategies that increase the effect of circular economy in an ecosystem. Three key actions of circular economy are Reduce, Reuse and Recycle which are called the 3R's principles. The 3R framework is widely used in the context of circular economy to generalize the wide range of circular actions. Reduction appears mainly through resource-efficiency and it describes actions towards minimizing the use of materials and energy as well as reducing the environmental effects. The reuse principle includes actions that make it possible for used products to be used again for the same purpose they were designed for. Reuse of products is

environmentally and economically more efficient in comparison to manufacturing of new products and it reverses the generation of landfills by keeping the once manufactured products available in the material cycle to fulfill the needs of consumers. Recycling includes ways that allow waste to be cycled back to the material flow to produce new products, materials or substances. In comparison to reusing, recycled assets can be manufactured to serve the purpose of the original product or something entirely different. (Ghisellini, Cialani and Ulgiati, 2016)

The R3 principles have been adjusted by some researchers and there has already been developed 4R, 6R and 9R frameworks, which include more specific strategies to increase circularity. (Kirchherr, Reike and Hekkert, 2017). Recycling for example, can be split into different subcategories like refurbishment and remanufacturing. The 10 strategies to increase circularity, which are included in the 9R framework are Refuse, Rethink, Reduce, Reuse, Repair, Refurbish, Remanufacture, Repurpose, Recycle and Recover (Kirchherr, Reike and Hekkert, 2017).

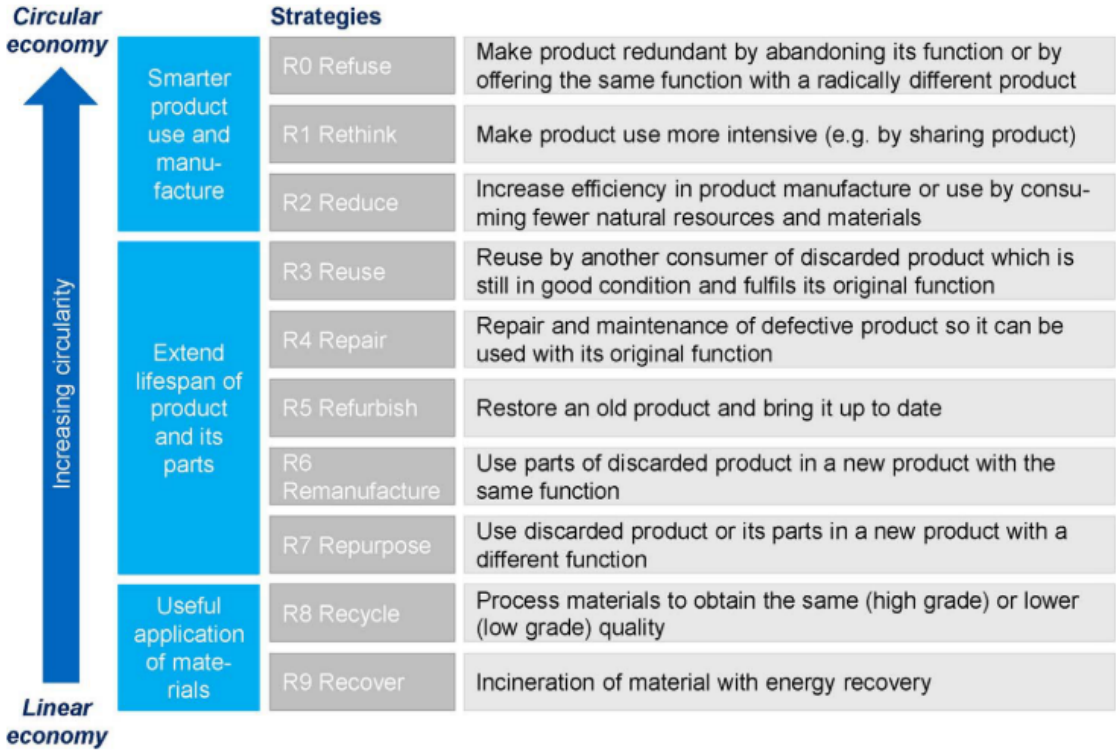


Figure 2. *9R strategies (Kirchherr, Reike and Hekkert, 2017)*

Korhonen et al. (2018) clarify that in order to increase the lifecycle of materials, the circular economy principles should be prioritized in the following order: reuse, remanufacture, recycle and dispose (Korhonen, Honkasalo and Seppälä, 2018). Worldwide the im-

plementation of circular economy still seems to be focused on recycling rather than reusing. If all focus is put only on waste management, circular economy usually fails as the material process then only includes the disposing of materials. Circular economy includes the thought process of best available methods to keep the materials in the circular process (Ghisellini, Cialani and Ulgiati, 2016).

Micro-, Meso- and Macro-level perspective

The level of impact or implementation of circular economy principles can be divided into 3 categories: Micro-, Meso- and Macro-levels. The Micro-level refers to actions and effects regarding products, companies and consumers, which include for example implementation of cleaner production and identifying the potential for environmental improvement on small scale decisions. The Meso-level refers to Eco-industrial parks (EIP) which are ecosystems formed together by organizations and societies in order to promote the sustainable development in a larger scale. The Meso-level differs from micro-level especially by including the public authorities to the mix, as they are an important part in the functions of the Eco-industrial parks. Public authorities' function through the different decision-making process of a political system, which changes the way system wide cooperation should be perceived. The Macro-level covers the largest scale in levels of implementation including cities, regions, nations and even global actions. (Ghisellini, Cialani and Ulgiati, 2016; Kirchherr, Reike and Hekkert, 2017) Even though the immediate circular decisions and effects can be hard to achieve on the large-scale entities, 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 levels of impact (Kirchherr, Reike and Hekkert, 2017).

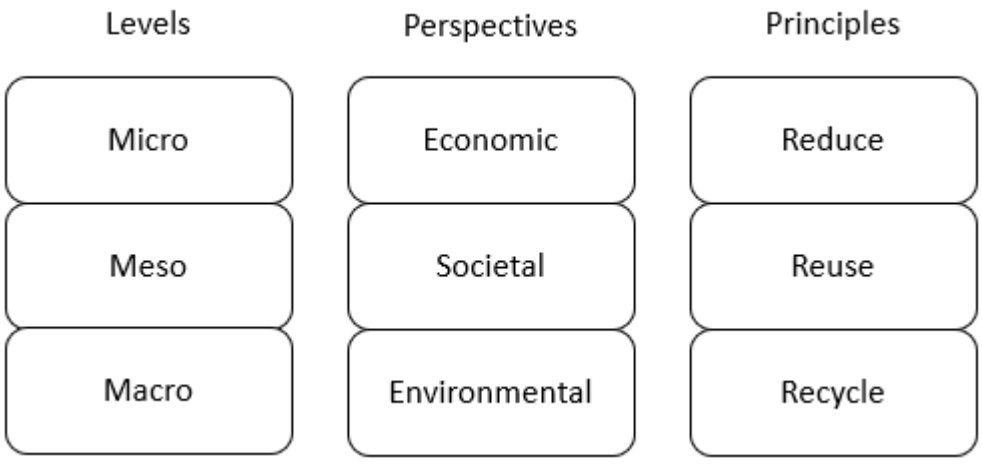


Figure 3. *Aspects of circular economy*

Three different categorizations that define the methods, areas and scope of circular economy development can be identified in figure 3. These categorizations will be used in the next chapters to evaluate the different aspects of circular economy, based on the observed level, perspective or principle.

2.2 Circular Economy as a Business

Two motives drive the change towards CE: New business opportunities and the legislative pressure (Parida and Wincent, 2019). In addition to developing sustainable production, circular solutions are seen to generate increased profitability and efficiency. Bressanelli et al (2018) argue that the application of CE principles can lead to huge benefits, evaluated to 1,8 trillion € in Europe by year 2030 (Bressanelli *et al.*, 2018a). The study of Valkokari et al. (2018) show that the benefits of CE can be seen in lower logistics costs, extended lifetime of products, as reduction in surpluses and in increased efficiency (Valkokari *et al.*, 2018). Sustainability is also seen as one of the ways to nowadays achieve sustainable and continuous growth (Pagoropoulos, Pigosso and McAloone, 2017) and circular economy solutions are a good way to transition toward sustainability. On the other hand, Parida & Wincent (2019) point out that the importance to focus on CE and sustainability now to secure a competitive edge on the field (Parida and Wincent, 2019).

As circular economy is viewed in the economic, societal and environmental perspectives, achievable benefits can also be identified on each dimension. Economically and environmentally, benefits can be seen in the input and output flows of the resources. Through circularity saving in materials and energy lead to direct cost reductions in both purchases and waste management costs and environmentally circulation will lead to reduced use of virgin materials and emission outputs. In addition, circularity will provide new employment opportunities, and circular models like servitization and cooperation will be introduced to the society to support the implementation of new ways for companies to operate. (Korhonen, Honkasalo and Seppälä, 2018) One of the major challenges is balancing between the three dimensions of sustainability as focusing on one dimension might reduce the performance of the other dimensions. This is called generating directional risks. (Nasiri, Tura and Ojanen, 2017) Planning the transformation needs to go beyond the direct effects on the implementing organization to avoid achieving benefits on the environmental, societal and economic cost of other parties of the ecosystem.

Value drivers of Circular Economy

Three value drivers can be identified to increase and implement circularity. The value drivers are increasing resource efficiency, extending product lifecycle and closing loops. (Bressanelli *et al.*, 2018a) The same value drivers are repetitively identified in the literature including the same elements, for example Antikainen et al. (2018) observe the value drivers through their effects on the material and energy loop. The loop related value drivers are slowing, closing and narrowing the loop, where slowing refers to extending product lifetimes and narrowing to minimizing the use of new resources (Antikainen, Uusitalo and Kivikytö-Reponen, 2018). The same three value drivers can be identified in the ideology of figure 2, where the different 9R principles can be sorted under the value drivers (Kirchherr, Reike and Hekkert, 2017). All the actions that support the three value drivers are different ways of promoting circularity, and the actions taken toward circularity should have effects that support some or all the value drivers.

Figure 4. *Circular economy value drivers*

On the side of companies and production, one of the most important ways to promote circular economy according to literature are new business models. Valkokari et al (2018) identify five different categories of business models, which state clear focus areas where companies can promote circular economy principles. The business models are product life extension, product as a service, sharing platform, renewability and resource efficiency & recycling. (Valkokari *et al.*, 2018)

Circular Economy Business Models

Bressanelli et al. (2018) divide business models into three categories which are: product focused, usage focused and result focused business models. Product focused business

models revolve around product and maximizing the profits through focusing on marketing. In product focused business models, the buyer becomes the owner of the product. In usage-focused models the product is sold as a service where the payer can use the product for a certain fee, thus paying only for the usage and not ownership. Result focused business models combine payments with the achieved results. (Bressanelli *et al.*, 2018a) The ownership of the product remains with the service provider, but they also take the responsibility for the expected result and costs.(Parida and Wincent, 2019)

In the circular economy perspective usage and result focused business models are good ways to achieve circularity in the economy through the efficient use of products. Product focused business models don't usually promote CE objectives as they rarely offer solutions for resource efficiency, loop closing or lifespan extension. (Bressanelli *et al.*, 2018a) In comparison, usage-focused business models promote resource efficiency through maximizing the intensive use of products. Leasing in washing machine industry would solve most of the problems with waste, as long-life expectancy machines are more durable and through leasing they can easily be upgraded and updated (Ellen MacArthur foundation, 2013). The downside of usage-focused business model is that it might make customers care less and not take care of the products used (Bressanelli *et al.*, 2018a). This might be solved by increasing the penalties on misuse, but the fear of penalties could have a remarkable impact on the consumer demand.

With the clear indications for waste reductions and product life time expansions, servitization can be seen as a key business model to implement CE (Bressanelli *et al.*, 2018a) One of the models to generate business on servitization is presented by Bressanelli et al. (2018), where a continuous service relationship is formed with the customer through subscriptions. The researched company focuses on household electronics, which rents dishwashers and dryers. Early revenue is gathered by subscription warranties and after that the revenues are generated by pay-per-use method. Possible loss of ownership issues are prevented by offering optimization and predictive maintenance services. (Bressanelli *et al.*, 2018b)

In addition to the implementation of new methods and models, the reasoning for circular economy solutions can be simply in gaining a competitive edge. Salminen et al (2017) state that: *"Combining the principles of circular economy to value network thinking and digitalization of functionality of whole the network give opportunity for remarkable competitive advantage in business"* (Salminen, Ruohomaa and Kantola, 2017). Industrial processes often depend on the management of materials and processes, which is why circular economy has a significant effect in how the basic operations are pursued. Lieder

and Rashid point out resource price volatility and supply risk coverage as direct competitive effects that circular economy can bring out to industrial companies. In addition circular economy solutions on a meso-level require the integration of several cross-company processes, which generate more efficient solutions (Lieder and Rashid, 2016). In a long period business perspective, the traditional linear economy can't answer to the challenges in sustainable growth and responsible business management, which is why circular economy is needed for companies to maintain possibilities for growth (Salminen, Ruohomaa and Kantola, 2017).

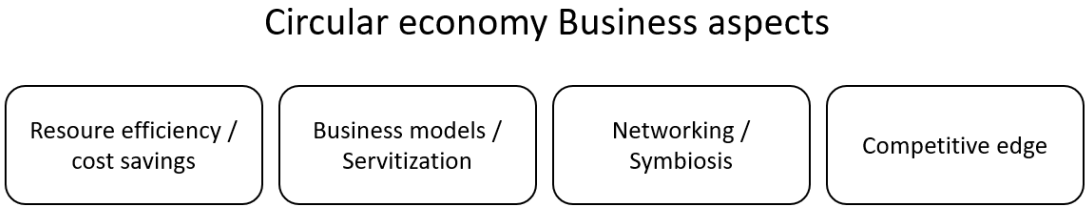


Figure 5. *Circular economy business aspects*

The main motives for organizations to pursue circular economy development and implementation are identified in figure 4. On a company perspective, Germany has been the frontrunner in manufacturing business development and some effects of circular economy can there already be evaluated. Germany has implemented a national strategy to promote resource efficiency and the main way to increase material efficiency is still the optimization of manufacturing processes. Other sustainable development methods are way less utilized, yet the focus is changing towards the development of circular economy especially through the life-cycle management of products. In Germany it can be seen that the most digitalized companies are forerunners in material efficiency and the most digitalized functions are cross-company material-cycles (Neligan, 2018). Thus, the digital technologies must have a critical impact on circular economy and that is why technological developments need to be considered as a part of research in circular economy implementation (Lieder and Rashid, 2016).

3. DIGITAL SOLUTIONS IN CIRCULAR ECONOMY

3.1 Digitalization and emerging technologies

In addition to the results in the development of manufacturing industry in Germany, the potential of digital solutions has also been identified in the field of circular economy. Several circular economy researchers state that the digital solutions are a key enabler of circular economy and the development of the emerging technologies are driving the change towards circular thinking and innovation (Hansen and Alcayaga, 2017; Stock *et al.*, 2018; Gligoric *et al.*, 2019)(nämä esimerkiksi). In manufacturing the digital technologies are considered as part of the fourth industrial revolution, which is called the Industry 4.0 (I4.0) or the Industrial Internet. The term is widely used in the context of emerging technologies and it refers to the industrial transformation, where through data gathering and storing, products are transformed into value-creating systems (Rajala et al., 2018) enabling the formation of connected networks including people, products and systems (Kang *et al.*, 2016). In this chapter the different industry 4.0 technologies and their effects are introduced and analyzed in the context of circular economy.

Categorization of Digital Technologies

In the perspective of circular economy Pagaropoulos et al. (2017) divide the technologies to three categories based on their function. The categories are data collection, data integration and data analysis. Data collection includes the sensor technologies like RFID and the technologies that connect products and users to the internet, for example internet of things. Data integration technologies handle the storage and formatting of data and enable the use of data analysis technologies, which produce and develop information (Pagoropoulos, Pigosso and McAloone, 2017). Lenka et al. (2017) categorize the technologies similarly through the capabilities of digitalization, which are intelligence capability, connect capability and analytic capability. Intelligence capability refers to upgrading the key hardware with digital components that allow data gathering, connect capabilities refer to connecting the products with each other and the internet wirelessly and analytical capabilities function as the data development sector, generating intelligence from the large amount of data provided by the sensors and systems. (Lenka, Parida and Wincent, 2017). The relations with the technologies to the data hierarchy say that data level refers to collection technologies, information level to storage technologies and knowledge level to analysis technologies. The wisdom level isn’t applied to the digital technologies as

human centered decision making still has crucial perspectives in ethics and morality that can't be considered in the use of technologies. (Ardolino *et al.*, 2018) In figure 6 the important technologies related to the circular economy based on the literature are divided into the categories presented by Pagoropoulos et al. (2017) and Lenka et al. (2017).

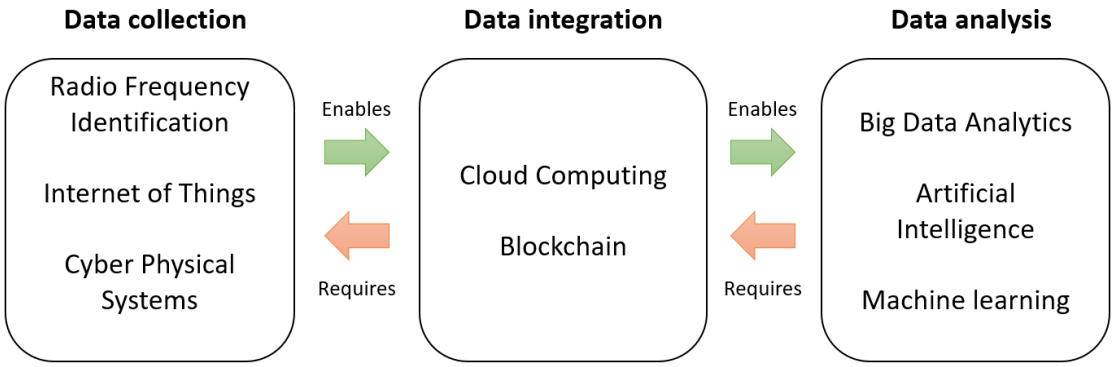


Figure 6. *Categorization and listing of digital technologies (modified from Pagoropoulos et al. (2017) and Lenka et al. (2017))*

Data collection

The categories presented can be also seen as different levels of technology implementation, requiring the technologies on the left to be implemented before the use of technologies on the right sides. The technologies start from the ones related to data collection, which include radio frequency identification (RFID), internet of things (IoT) and the cyber physical systems (CPS). RFID is the early version of the new technologies of I4.0, which has already been implemented to use worldwide in 1999. (Yang *et al.*, 2018) RFID consists of different sensors and tags that can be added to products and systems to trace and collect data in new ways. This includes for example the usage history and process mapping of a unique product sample. The data can be stored into the products through the tags and it can be integrated to and synchronised to systems by scanning them. Sensors can react to the environment for example to the changes in temperature and luminosity. The developed sensor technologies allow the gathering of information that before hasn't been available which can be used in analysing and developing of the product lifecycle. The information can tell the quality of the product and when it needs to be remanufactured, reused or recycled. (Gligoric *et al.*, 2019) The sensor technologies are a key enabler of other industry 4.0 technologies as they enable data gathering and communication between objects (Rajput and Singh, 2019), which are the key elements in Industry 4.0.

Another technology in the data collection and enabling technologies is the internet of things, which is also known as internet of objects. Where RFID tags and identifies communicates with products through sensors, internet of things is about connecting products to the internet for data gathering, remote access and application use. Through intelligence embedded into the products, they can communicate with systems, with people and with each other. Nobre and Tavares (2017) list intelligent sensors on cars, better disease diagnosis, smart supermarket shelves and smart real time stocks monitoring as examples of solutions where internet of things can be used (Nobre and Tavares, 2017). Good example of an intelligent product, is when a replaceable tesla battery can analyze whether it is good to charge the battery with electricity now or sell the remaining power and wait for the price to fall (Rajala *et al.*, 2018). The key function of IoT is that devices can interact with each other without needed human interaction in the process, which in a global network with increasing amounts of data might radically change the way systems and companies function. (Ardolino *et al.*, 2018) In the perspective of circular economy internet of things can be used in logistics and environmental monitoring, resulting in improved efficiency and cost reductions in logistics sector. (Zhou *et al.*, 2018) IoT also allows data collection and transmission efficiently. (Ardolino *et al.*, 2018)

Cyber physical systems (CPS) are mentioned as a key technology several times in participation with circular economy (Antikainen, Uusitalo and Kivikytö-Reponen, 2018; Jabbour *et al.*, 2018; Nascimento *et al.*, 2018; Stock *et al.*, 2018) to describe the structure generated by connecting humans and systems through the internet of things and cloud technologies. CPS can be described as:*" … physical artefacts which are controlled, monitored, coordinated, and integrated into networks of machines and human users through an embedded system."* The human interaction is done in the system through separately generated machine interfaces. The cyber physical systems can also be described as the basis for the development of the internet of things (Hatzivasilis *et al.*, 2018).

Data integration

In the data integration category, the most important technology is cloud computing. The cloud technologies provide platforms for data centralization. (Lenka, Parida and Wincent, 2017), centralized computing and an efficient way for storing data (Ardolino *et al.*, 2018). Cloud computing services can consist of infrastructure that is accessed remotely, applications that function inside the cloud and development of tailored services for cloud infrastructure used (Ardolino *et al.*, 2018). Cloud technologies don't require heavy investments on the equipment, as the services are often provided by third party companies. Cloud services help to gather data and apply technologies to the databases, but also provide tools for developing the machines connected to the cloud. Internet of things is

used to enable connecting smart devices to the cloud network. In addition to the devices, manufacturing industries need to integrate available resources and materials to the cloud, which requires further development from the internet of things. Wang and Wang (2017) use the term Internet of Manufacturing Things to describe the connectivity of materials into internet. The cloud can be used to store information on component recovery and recycling operations, which when integrated to area wide manufacturing processes can be used to support the growth of collaborative production. (Wang and Wang, 2017) Cloud technologies might be a needed enabler for big data analytics, because of the large data storage requirements (Soroka *et al.*, 2017).

Blockchain is a so-called distributed ledger technology which enables companies to generate, maintain and share their databases together. In addition to enabling easier cooperation between organizations, blockchain has been utilized in data related business models for example in the case of Rubicon. The company ensures their profits only by controlling the flow of data and selling information. In the context of circular economy, blockchain and other distributed ledger technologies are answering the problems with data sharing and privacy making them a key technology in peer-to-peer networks (Rajala *et al.*, 2018)

Data collection

On the third level of the listed technologies are the technologies related to data analytics, key technology being big data analytics. The big data definition can either refer to the large amount of data that needs to be managed or it is used to refer to the tools used in analyzing the large data amount. Often the longer term Big Data Analytics is used. (Soroka *et al.*, 2017) The technology consists mainly of the solutions that enable continuous gathering, processing and analyzing large amount of data that can be used to generate value. With the development of internet of things and other data collection methods, the amount of available data has grown massively, and the volume of continuously growing data is large. The technology can identify the different varieties and qualities of data and turn it into knowledge fast. (Nobre and Tavares, 2017) Nobre and Tavares (2017) list that value generation with big data can be achieved for example by automated and real-time analysis or product innovations based on analyzed customer reactions with the data provided by sensor technologies (Nobre and Tavares, 2017). Jabbour et al. (2017) conclude that big data needs to be further researched, but has wide potential in circular business models. (Jabbour *et al.*, 2017) In addition to big data analytics, artificial intelligence and machine learning are mentioned in the context of circular economy as upcoming technologies, but clear solutions and methods to use them have not yet been presented. (Pagoropoulos, Pigosso and McAloone, 2017). The technologies can be used

in developing the analytics even further than the boundaries of big data analytics offer (Stock *et al.*, 2018), which indicates that the technologies might include unresearched potential.

3.2 Benefits of digital solutions in circular economy

Digital technologies are relevant in every part of the product lifecycle (Bressanelli *et al.*, 2018a) and drive the transformation towards sustainable circular economy (Antikainen, Uusitalo and Kivikytö-Reponen, 2018). Industry 4.0 technologies integrate value chains through data collection and sharing, which support sustainable operations management decision making and new business models. (Jabbour *et al.*, 2018). This chapter introduces the literature-based theory behind the effects of digital solutions in circular economy and how they relate to the identified value drivers.

Many benefits have already been identified in literature to help drive the transformation towards circular economy. In data collection RFID can enable the implementation of IoT and smart factories (Stock *et al.*, 2018), IoT enables the access to information on product usage (Bressanelli *et al.*, 2018b) and cyber physical systems can help to avoid overproduction (Hansen and Alcayaga, 2017), help in waste sorting and product assembly (Nascimento *et al.*, 2018). Cloud computing enables the use of massive data amounts without required local machinery, which results in savings in energy consumption (Stock *et al.*, 2018) and blockchain ensures safe data distribution while increasing transparency in operations (Antikainen, Uusitalo and Kivikytö-Reponen, 2018). Big data analytics enable predictive and preventive maintenance (Hansen and Alcayaga, 2017; Bressanelli *et al.*, 2018b) and can provide information straight to the customer to promote more sustainable use of energy and materials (Bressanelli *et al.*, 2018b). Also ways to increase efficiency and sustainability through industry 4.0 might have been documented as increased profitability, which means the effects that promote sustainability may not have been noticed (Tseng *et al.*, 2018). Ellen MacArthur foundation have listed the following factors as direct benefits of digitalization in circular economy: extending the use cycle, increased monitor performance, redefining maintenance, design development and improved components and products (Ellen MacArthur foundation, 2016).

One of the focus areas that develops circular economy is remanufacturing. Yang et al. (2018) have researched the effects of digital technologies in remanufacturing and divide the opportunities provided by Industry 4.0 into three smart categories. First the use of smart life cycle data helps in developing product design processes and makes the remanufacturing process easier by being able to gather and track product data. The second area is smart factories, which provide the business incentive in the form of cost-

effectiveness and sustainable production methods. Third area are the smart services, which enable successful remanufacturing based business models. (Yang *et al.*, 2018)

Bressanelli et al. (2018) evaluate the current relationship of the new technologies and circular economy by listing the different problems they solve. So far, the circular economy solutions have been seen to generate financial risks and operational risks, which can be seen in technology improvement, return flow uncertainties and also with problems in customer behavior through loss of ownership and willingness to pay. Industry 4.0 might be able to provide tools to solve the problems in networked decision-making to enable the formation of industrial symbiosis parks. Trust and efficiency in data sharing is the cornerstone of networked sustainable consumption (Tseng *et al.*, 2018).

Supply chain development

Rajput and Singh (2019) identify three ways to enhance circular economy in supply-chains through digitalization, by making them environmentally efficient by reducing the carbon emissions, enhancing the remanufacturing process and optimizing logistics process. (Rajput and Singh, 2019) Martin-Gómez et al. (2019) claim that smart supply-chain manufacturing is enabled by the use of cyber physical systems (Martín-Gómez, Aguayo-González and Luque, 2019). Nascimento et al. (2018) point out that companies are pursuing the implementation of smart supply chain manufacturing to generate competitive advantage. The companies are forced to implement sustainable solutions because of the stakeholder pressure from the companies' environmental responsibilities. Implementing digital solutions to supply chains is a considered as a feasible solution to at the same time help the environmental discussion as well as generate profit through reducing energy consumption and the use of resources. (Nascimento *et al.*, 2018)

Re-Distributed manufacturing

Re-Distributed manufacturing (RDM) is decentralized, on demand, localized and customizable manufacturing, which is driven by digital technologies. RDM promotes waste elimination and resource management and the transition towards service-oriented business models. Moreno et al. (2017) research re-distributed manufacturing through the case of Shoelab, where shoes are designed from easily reusable material and the reused material is used on remanufacturing the recycled shoes. Customer data is collected in the purchases process, but data on product use is gathered in the product and analysed when the products are brought back for recycling. This helps in generating new and more customised products for the consumer, which can be manufactured locally through RDM. The introduced model was done by subscriptions which provided services in relation to the use of shoes, for example preventing injuries and performance optimisation. The

used business model and manufacturing process resulted in cost reductions in production and especially logistics, improved sustainability and product tailoring. (Moreno *et al.*, 2017)

Customer data utilization

Digital solutions also enable a more connected and tailorable approach towards the customer, where digital intelligence can be used for automated monitoring and resource optimization, which increase circularity both on the side of the consumer and the service provider (Moreno and Charnley, 2016). In additive manufacturing products and spare parts can be produced on demand with low costs, based on the information provided by the smart products (Nascimento *et al.*, 2018). In additive manufacturing the data gained from smart products is used to predict the need of new parts, which can be manufactured globally with 3D-printing. At the same time 3D-printing reduces material costs for companies, the use of energy and also the generation of emissions (Prendeville *et al.*, 2016).

In the research of Bressanelli et al. (2018a) the use of internet of things and big data are observed in a usage-focused business model. The washing machines are rented to customers as a service, where the customer doesn't own the product, but pays for the service either with a monthly fee or per use. In the research, it is noticed that the technologies are helping the service in multiple ways in each stage of the product life cycle. The effect of internet of things can be seen in every functionality analyzed, as it is the key technology enabling the business model. Big data analytics are used to support the system provided by internet of things by allowing new kinds of services to be used (Bressanelli *et al.*, 2018a). Figure 4 presents the findings of Bressanelli et al. (2018a), where the benefits provided by the technologies are shown in relation to the three circular economy value drivers and the stage of life cycle that they affect.

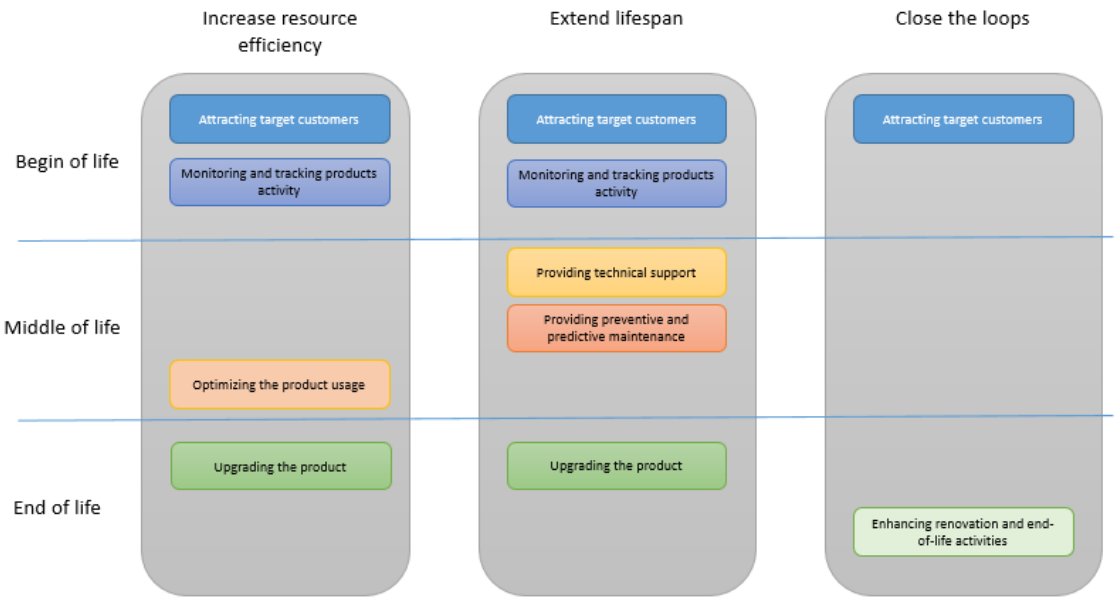


Figure 7. *Effects of IoT and Big Data on CE value drivers based on* (Bressanelli *et al.*, 2018a)

In the analyzed case, only two of the eight functionalities (monitoring and tracking, upgrading) can be applied to promote CE in the company without requiring heavy investments on the big data analytics (Bressanelli *et al.*, 2018a). Extension of product lifespan seems to be the main way of promoting CE through digital solutions and closing the loops seems to be affected the least in the washing machine business. Lieder & Rashid (2016) also mention that one reason for the increasing popularity of extending product lifecycles are the technical innovations that have shortened the lifespan of products critically during recent years (Lieder and Rashid, 2016).

New business models

A meaningful sustainability impact can be reached by service and business model innovations (Nasiri, Tura and Ojanen, 2017). Before digitalization the fundamentals to go for service-oriented business model weren't useful enough. After the development of new technologies the new business models are being taken into consideration much more. (Parida and Wincent, 2019). According to Lenka et al (2017) manufacturing companies are increasingly adopting digital technologies in order to pursue servitization strategies (Lenka, Parida and Wincent, 2017). IoT and emerging technologies seem to be the missing link to enable the use of service business models (Hansen and Alcayaga, 2017). With digitalization, result-focused business models can reduce lifecycle cost and extend product lifespan. These business models might be the most effective way to move towards

circular economy (Bressanelli *et al.*, 2018a). The value gained of digitalization in the servitization models and customer interaction can be divided to perceptive mechanisms, which help the company to analyse the customer and offer tailored services, and responsive mechanisms, which enable agile proactive methods to be used in service solutions. (Lenka, Parida and Wincent, 2017).

Industry 4.0 technologies enable product service systems (PSS), which enable CE implementation to companies (Bressanelli *et al.*, 2018b). IoT is one of the crucial enablers of servitization. (Ardolino *et al.*, 2018) Product service systems describe the system formed in a digitalized servitization model. The PSS modifies the traditional consumption patterns (Fernandes *et al.*, 2019), which is why it might be seen as an uncomfortable choice for consumers. One of the enablers of PSS are also the cost savings for customers, for example in Bressanelli et al.s (2018a) washing machine case, the savings to the customer by using the new model were up to 30% (Bressanelli *et al.*, 2018b) Also the fear for misuse can be neglected with the digital solutions as IoT solutions allow the service providers to monitor the products. Pagoropoulos et al. (2017) state that: *"PSS fills the demands of customers with less environmental impact"* (Pagoropoulos, Pigosso and McAloone, 2017) and combining that with cost savings can offer customers easy ways to change their consuming behavior. With the change in consumer attitudes, the PSS models become even more intriguing for companies. Product Service Systems might also be needed to develop re-distributed manufacturing (Moreno *et al.*, 2017).

Digital platform development

The results of loop-closing platforms are researched in Europe through European Life M3P Project (Material Match Making Platform for the promotion of the use of industrial waste in local networks), where the possibilities are researched in Italy, Belgium, Greece and Spain. The digital platforms have two core functions, which are listing and updating the waste produced in the area and matching the supply and demand of the materials. The available materials offer innovation possibilities to the local technicians and experts by clarifying the amount of reusable materials available. (Dounavis, Kafasis and Ntavos, 2019)

One of the industries, where digitally driven circular economy has taken a huge leap forward is the forest-based bio economy is turning into a digital platform industry. Watanabe et al. (2019) have researched UPM and their integrated mill is a world-class frontrunner in circular economy innovation. UPM build their business model on five circular principles, which are the use of circular supplies, resource recovery, product life extension, sharing platforms and products as a service (Watanabe, Naveed and

Neittaanmäki, 2019). The principles include the circular economy value drivers and business elements presented in chapters 2.1 and 2.2, which indicates that UPM has widely implemented circular economy to their organization and ways of operation. The research points out that all these principles are driven by digital solutions. The findings of Watanabe et al. (2019) point out that the coupling of digitalization and the circular aims of the organization have made it possible for UPM to transform the industry towards new growth. The transformation towards a digital platform industry requires large investments in the digital infrastructure, and it is due to the management strategy of UPM, which has made the transformation on a long term possible. The research reveals that the change towards digitalized circular economy is a long-term goal, which can result in resurgence in an economy. The findings of UPM limit only to the forest-industry, but they might be used in other industries as well. (Watanabe, Naveed and Neittaanmäki, 2019)

Salminen et al. especially point out that: *"The data of waste from one partner means material for the other partner."* (Salminen, Ruohomaa and Kantola, 2017) In the creation of loop closing platforms, the need for product information models and the ways of connecting information with assets is more important than before. Gligoric et al. (2019) present ways how IoT enables the connection of materials with data and data exchange which promote circularity. Glicoric et al. (2019) call the collection and storing model of data related to a product as a product passport. The product passports allow collecting, sensing and reading of parameters from the environment and also able tracking of product lifecycle. The product passport contains information on the assets including the ways for disassembly and recycling at the end of life. Product passports also enable recapturing, recovering and reusing processes. (Lieder and Rashid, 2016) Through product passports product lifecycles can be shared to different systems and among stakeholders. The information enables better decision-making which enables circular economy. (Gligoric *et al.*, 2019)

Product data passports

Normally the product information is reported and stored to a database in the production phase, including for example the use of hazardous materials. Normally the management of product data ends after the product is sold, but with the cloud network the data can be managed even when the product is going through the physical and circular cycles. All the processes done to the product are documented to the cloud, which makes reprocessing easier. (Wang and Wang, 2017)

A common system for handling information in materials and products needs to be established to enable networked manufacturing, as otherwise the data gathered through internet of things and gathered in the cloud will be in different formats. In a shared cloud the original manufacturer and other members in the material network, can all share the same information, which allows the recyclers to optimize the product usage and close the loops. I4.0 improves the data transferability and enables the building of a knowledge and data sharing platform (Yang *et al.*, 2018). Wang and Wang (2017) point out that the database requires contribution from all members of the network to ensure the management of the product lifecycle. (Wang and Wang, 2017)

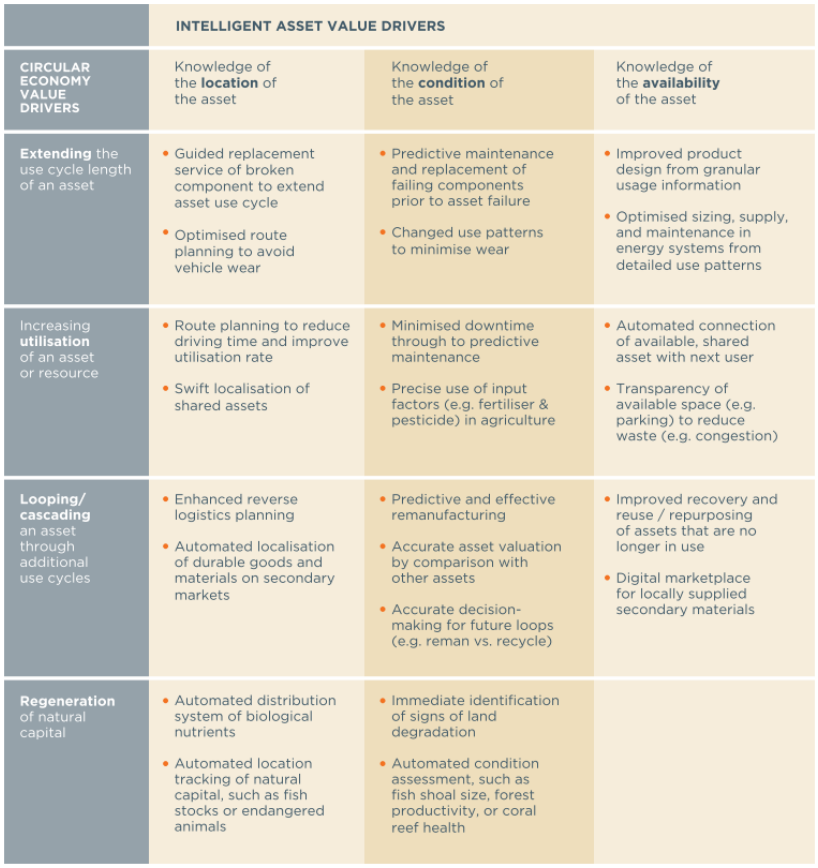
Digitalization enables cooperative operating of resources and processes through merged interaction between companies and customers (Lenka, Parida and Wincent, 2017). Rajala et al note that the traditional relationship between the customer and supplier is changing towards a collaborative management of product information in order to support the needs of both parties. The transition towards collaborative environment requires trust and openness from all collaborating organizations. Rubicon is a good example of a platform type business model that makes it possible for companies to reduce waste and landfill while reducing own costs. (Rajala *et al.*, 2018)

In closing the loops, measuring the quality of the products and materials is a key element, as it determines the possibilities for remanufacturing. Both the internal and external information is valuable as they directly affect the quality and thus the value and processing of the assets. By improving sorting of products and the acquisition process, the profitability of recovery operations can also be improved. (Raihanian Mashhadi and Behdad, 2017)

Normally quality is determined by a numerical grade based on the physical condition and appearance of products, but the use of life cycle data can give much more detailed information on the quality and the products usage. Information extracted from the life cycle data can make the recycling process more accurate and promote more efficient material cycling. (Raihanian Mashhadi and Behdad, 2017)

Raihanian and Mashhadi have researched the use of life cycle data in the remanufacturing decisions of consumer electronics, by developing a life cycle data focused framework to support the quality assessment and sorting of products. This way the recycling operator can efficiently choose the best way to remanufacture products of different quality and material. The research tested the quality assessment by using remanufacturable hard drives, which were evaluated based on their device capacity, age and power on years, which could be used to calculate the remaining use of life. The resulted factors

were measured, and the values categorized the products to be refurbished, remanufactured or recycled. (Raihanian Mashhadi and Behdad, 2017)



	INTELLIGENT ASSET VALUE DRIVERS		
CIRCULAR ECONOMY VALUE DRIVERS	Knowledge of the **location** of the asset	Knowledge of the **condition** of the asset	Knowledge of the **availability** of the asset
Extending the use cycle length of an asset	• Guided replacement service of broken component to extend asset use cycle • Optimised route planning to avoid vehicle wear	• Predictive maintenance and replacement of failing components prior to asset failure • Changed use patterns to minimise wear	• Improved product design from granular usage information • Optimised sizing, supply, and maintenance in energy systems from detailed use patterns
Increasing **utilisation** of an asset or resource	• Route planning to reduce driving time and improve utilisation rate • Swift localisation of shared assets	• Minimised downtime through to predictive maintenance • Precise use of input factors (e.g. fertiliser & pesticide) in agriculture	• Automated connection of available, shared asset with next user • Transparency of available space (e.g. parking) to reduce waste (e.g. congestion)
Looping/ cascading an asset through additional use cycles	• Enhanced reverse logistics planning • Automated localisation of durable goods and materials on secondary markets	• Predictive and effective remanufacturing • Accurate asset valuation by comparison with other assets • Accurate decision-making for future loops (e.g. reman vs. recycle)	• Improved recovery and reuse / repurposing of assets that are no longer in use • Digital marketplace for locally supplied secondary materials
Regeneration of natural capital	• Automated distribution system of biological nutrients • Automated location tracking of natural capital, such as fish stocks or endangered animals	• Immediate identification of signs of land degradation • Automated condition assessment, such as fish shoal size, forest productivity, or coral reef health	

Figure 8. *Opportunities for the use of location, condition and availability data in circular economy (Ellen MacArthur foundation, 2016)*

With the collection of product data and the use of product passports, many circular economy benefits can be identified. Ellen MacArthur foundation list several possibilities in how the data in product location, condition and availability promotes circular economy through the three circular economy value drivers (Ellen MacArthur foundation, 2016). In digital solutions data management is the key (Yang *et al.*, 2018), which provides the development of all the new methods.

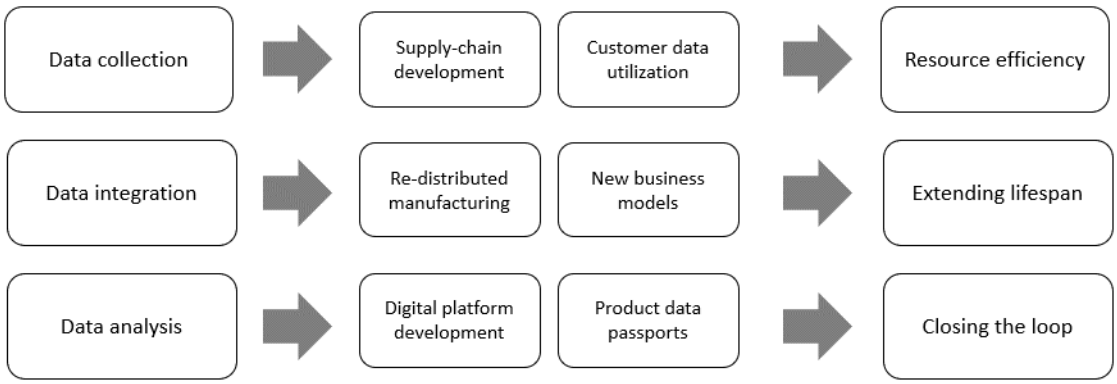


Figure 9. *Theoretical benefits of digitalization in circular economy*

Figure 9 gathers the theoretical benefits of digital solutions in circular economy and provides their relations to the circular economy value drivers. The identified benefits correlate well with the business aspects of circular economy identified in chapter 2.2 and can be easily categorized under the mentioned value drivers. This information answers the first research question on the effects of digital solutions have on circular economy based on the literature on the subject.

3.3 Requirements of CE and digital solutions

Despite the previously identified benefits of circular economy, the digital technologies and circular economy principles are yet not widely applied in organizations. There seem to exist many barriers in applying the digital solutions as so few companies even in Germany, where the industry 4.0 development has first arisen, are implementing them (Neligan, 2018). Both circular economy and digital solutions have different requirements that need to be considered together. Different requirements are applied to different situations and transformation processes, which is why many of the requirements have been identified separately through the work of several different researchers. This chapter provides information on the crucial factors that need to be considered in the implementation process of circular economy and digital solutions and sums up the work and findings of several researchers in the area.

Investments and infrastructure

One of the major problems in circular economy implementation is to define the return of investment (ROI) on CE investments. The change to favor new disruptive innovations not only requires large investments, but also support from institutions, governments and

foreign investors (Nasiri, Tura and Ojanen, 2017). To realize the value of circular economy solutions the entire networks need to be dedicated to implementing the new solutions (Valkokari *et al.*, 2018) and in order to achieve the maximum potential of i4.0 solutions, the systematic development of the public sector is also needed as it plays a key role as part of the potential networks (Ruohomaa, Kantola and Salminen, 2018). The digital infrastructure forms the ground requirements for the application of digital solutions, which is why the implementation can be seen as a long-term process (Watanabe, Naveed and Neittaanmäki, 2019) as both legislative pressure and business opportunities in circular economy require a significant transformation (Parida and Wincent, 2019).

New knowledge

In addition to ground requirements in the digital infrastructure, knowledge in several areas is the key for a successful implementation or transformation process. To understand the required systems in the data flow, 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 (Valkokari *et al.*, 2018). When handling data as core business problems, companies need to also cover new knowledge areas for example relating to data security (Bressanelli *et al.*, 2018b). In comparison on the side of resource efficiency and product development, understanding the materials and constructions of products is a key element in implementing circular economy (Ellen MacArthur foundation, 2013).

Development of circular practices

The Ellen MacArthur foundation lists four building blocks of circular economy, where the first three focus on single organizational requirements and the fourth block on economical and societal factors. The first block requires skills in circular economy so that the production can be designed to fit the goals of circular economy. Materials need to be chosen right to improve the lifetime and the designs need to be designed for easy disassembly and later product processing, in order to help the loop-closing at the end of product lifetimes. The other block consists of new business models and changing the attitudes from consuming and owning towards using and paying for services or performance. The third presents the development of the reverse cycle, by making the collection of used materials efficient and developing the methods of material treatment. (Ellen MacArthur foundation, 2013)

Support of the ecosystem

The fourth block from Ellen MacArthur foundation, which covers the external requirements for the ecosystem, is divided into four parts. The first part includes basis for company collaboration in cross-cycle and cross-sector dimensions. The ecosystem needs to support the company wide cooperation by allowing information sharing and providing reasonable venues for the operators to find each other. The different actors in the ecosystem need to have a shared vision on common goals in sustainable development so that circular economy can be developed to fit the needs of the ecosystem. Secondly the economy needs to support investments as they are a key part in implementing new technologies and building the digital infrastructure. In third, the regulation needs to support circular solutions for example, in the form of favorable taxation and standardization. In fourth, the general awareness of circularity needs to improve among the consumers and companies, to make the transformation worthy. (Ellen MacArthur foundation, 2013)

Business Models

Lewandowski et al. point out that there are three challenges or fits that need to be solved for companies to successfully implement CE business models. First the value proposition needs to fit the customer segments, which results in a need for the change of the company values and public opinions. Secondly the cost structure needs to fit the revenue streams of the new business opportunities. Thirdly the changes need to be possible for the companies. (Lewandowski, 2016)

Implementation process

Jabbour et al. (2018) propose a roadmap for implementing the digital solutions to production in the context of circular economy (Jabbour *et al.*, 2018). According to Bressanelli et al. 2018a, using a roadmap is critical for the implementation of industry 4.0 technologies (Bressanelli *et al.*, 2018a), which supports the use of Jabbour et al.'s roadmap. The roadmap consists of five stages, which are presented in figure 9.

Figure 10. *Roadmap for implementing sustainable digital solutions to production based on* (Jabbour *et al.*, 2018)

In the introduced roadmap Jabbour et al. (2018) propose that the actor should choose the suitable focus areas of the following sustainable approaches to production: regenerate, share, optimize, loop, virtualize or exchange. After choosing the focus areas the available technologies need to be evaluated based on availability, costs and technical constraints, which make choosing the implementable technologies easy. The available technologies have already been categorized based on the sustainable approaches in stage one. The third stage requires the company to implement sustainable operations management for the decision-making in product design, process and logistics. The next part in the implementation process is the process integration within the supply-chain. The changes affecting the inner operations will have an impact on the collaborating parties, which means that the planning for the transformation should be done cooperatively. The last part for implementation is the tracking of the results and developing the implemented system through small steps towards sustainable capability. (Jabbour *et al.*, 2018)

Private and Public sector development

Ellen MacArthur foundation list ideas for enabling digitalized circular economy solutions by dividing the factors to the factors related to businesses and to factors related to policymakers and the public sector. The ideas of Ellen MacArthur foundation are listed in table 1.

Businesses	**Policymakers and public sector**
• Develop technical capabilities • Adapt financing models • Develop flexible business models • Develop • Develop collaboration platforms	• Information and awareness • Collaboration platforms • Business support schemes • Public procurement and infrastructure • Regulatory frameworks • Fiscal frameworks

Table 1. *Ideas to enable digitalized circular economy (Ellen MacArthur foundation, 2016)*

Ellen MacArthur foundation clearly point out that the implementation factors of digital solutions and circular economy can be divided to companies and public sector (Ellen MacArthur foundation, 2016). For new business models to be able to close the loops, the ecosystem must have the required assets to enable them, (Rajala *et al.*, 2018) which is why the motives with companies and policy makers must be aligned for CE implementation. (Lieder and Rashid, 2016) Lieder and Rashid point out that: *"…for succeeding in*

CE implementation a concurrent top-down and bottom-up strategy is required to maintain the interests of all stakeholders, i.e. policy makers, governmental bodies and manufacturing industries." The different parties need to be able to think of the environmental and economic benefits as an ecosystem as they might be developed on the expense of the other factor. Lieder and Rashid also mention that ultimately the objective of CE resides in achieving a fully regenerative environment, which requires contribution from all parties. (Lieder and Rashid, 2016) The Top-Bottom strategy of Lieder and Rashid is presented in figure 10.

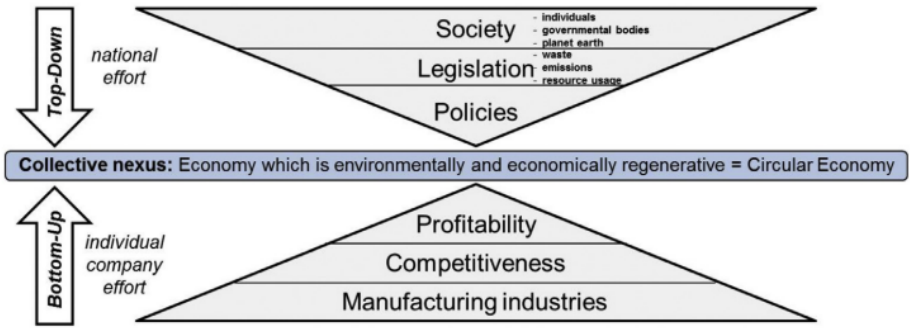


Fig. 6. Proposed CE implementation strategy applying top-down and bottom-up approach.

Figure 11. *Top-Bottom approach for circular economy implementation* (Lieder and Rashid, 2016)

In the figure the implementation of circular economy is presented through the actions of individual companies and the nation. The individual companies will promote circular economy and start the implementation process when clear competitive edge and profitability can be achieved. The national efforts are important in achieving the competitivity and profitability through circular solutions as legislation and government policies heavily declare the profits of businesses in areas where circular economy could be promoted. (Lieder and Rashid, 2016) Salminen et al. also support the bottom-up approach in their research, which indicates that cooperation between all the parties is needed. In their research universities are also noted as an important factor in enabling circular economy as they facilitate the creation of new innovations and help in building large enterprise ecosystems. (Salminen, Ruohomaa and Kantola, 2017)

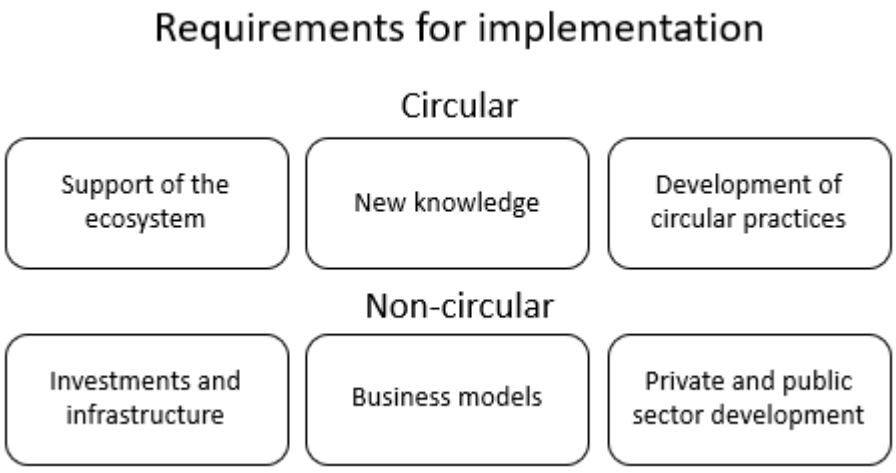


Figure 12. *Requirements for implementation*

The findings on the requirements of digital solution and circular economy implementation are summarised in figure 12, which indicates that both circular and non-circular factors for implementation can be identified. The circular requirements revolve around organizational knowledge and development on the subject as well as the importance of the supporting ecosystem. The support of the ecosystem is especially vital in closing the material loops, to find new material flows where the output material of an organization can be utilized as the input of another one. The non-circular requirements are related to company processes and financial possibilities, which are always required with implementation and transformation. The need for transformation depends on the current process development in an organization and its flexibility to change. As a common factor in both circular and non-circular requirements, the dependency on either the ecosystem or the public sector is introduced, which indicates that applying digitalized circular economy needs to be done in cooperation with unified interests.

3.4 Existing challenges for technology implementation

As the implementation of circular economy has a large number of requirements, it can be seen that digital solutions and circular economies have clear barriers that harm the implementation or decision-making process for circular economy development. Barriers for engaging in new digital and circular solutions can be identified both on the side of circular solutions and digital solutions. In the following chapter, the theoretical findings on the challenges on implementing technologies to circular economy contest are introduced and gathered into a figure where circular and digital factors are separated. Further

on in the study the theoretical findings are used to compare the results on the subject with the empirical findings to answer the third main research question.

Barriers in Circular Economy

Korhonen et al. (2018) have researched and listed different barriers for circular economy. Firstly, circular economy can aim for perfect resource efficiency, but it is important to note that on behalf of thermodynamic limits, nothing can be fully recycled and reused as the circular processes also require energy. Also, the systems have boundary limits that don't necessary allow the use of all possible solutions. One barrier for the new innovations and their limitations is the competition in the market, which makes it difficult or new innovations to reach the market. This might reduce the interest in developing new innovations. The economic growth also poses clear challenges as the economic growth can be prioritized over the environmental benefits. The same effect can be seen in organizational cooperation, as in some cases waste reduction solutions might affect the environmental and resource effects of other companies negatively. It may also be difficult to convince other operators to pursue environmental solutions for the benefit of the whole ecosystem. As last reason the definition of waste is noted, as the definition of material flows compared to waste defines how the material is handled. (Korhonen, Honkasalo and Seppälä, 2018)

Barriers in Digital Solutions

On the side of digital solutions, the formed challenges and barriers have a very different focus. Jabbour et al. (2018) mention as challenges for Industry 4.0 technology implementation: the coordination across different organizational areas, cybersecurity, lack of talent, reliability of connectivity between machines and integrity of maintenance related data (Jabbour *et al.*, 2018). Erol et al. (2016) claim that the main challenge in the implementation are the need for large investments which result high costs, the complexity and required skills in the area and the unsuitability of existing digital infrastructure and technologies to the new software and methods. As presented in Bressanelli et al. case earlier, if companies want to close the loop, they must invest in big data and analytics technologies (Bressanelli *et al.*, 2018a) The implementation of new technologies that don't easily fit the organizational it-systems needs a lot of time and resources, and propose a large financial risk to the continuity of daily operations. Many companies use old information systems which might even prevent implementing new CE solutions (Valkokari *et al.*, 2018). The investments are needed for the new software, hardware and systems, where for example the cost of different sensors can be high, especially if the sensors need to

handle difficult conditions for example rain or heat, which increases the costs dramatically (Beliatis *et al.*, 2018). This is one of the reasons why many companies don't yet pursue new digital solutions (Erol, Schumacher and Sihn, 2016). Also uncertainty on the return of investments is a reason why companies are so reluctant in perceiving CE related technologies (Jabbour *et al.*, 2018).

Total environmental impact

The loops must be closed also for the materials needed for the components used in I4.0 technologies. The saving in sustainability might not cut the impacts of increase in energy consumption due to the increased use of technical hardware. On the other hand, the use of data centers powered by cloud computing is said to have a high potential of energy saving. Stock et al. (2018) claim that: *"It is to be expected that the efficiency increases achieved through CPS will exceed the increase in primary energy consumption."* (Stock *et al.*, 2018)

Uncertainty

A high amount of manual work might form a barrier for the company as the need might not be so important, especially on the side of the workers. The Industry 4.0 technologies are also quite complex and roadmaps and concepts for implementation are still being developed. The implementation process requires a deep knowledge on the subject, which is why uncertainty can form a key barrier. Topic is also so new that available guidance from outside is hard to find. (Erol, Schumacher and Sihn, 2016)

As the technologies are still being developed, the technologies themselves can propose operational risks. For example in Gligoric et al.'s (2019) research on smart tags and RFID sensors, the printed QR-codes resulted in 15% failed scans in testing (Gligoric *et al.*, 2019). Measuring the right data operationally can be hard especially if the process is complex, for example measuring thermochemical data and distribution of elements in metallurgy are problems that even the technologies might not be able to solve (van Schalkwyk *et al.*, 2018).

Cooperation with public sector

As proposed in chapter 2.5 the effect of public sector and the collaboration with the companies has an important role in the success of circular economy as a business. The public sector can change the priorities of the companies with legislation and taxation. (Lieder and Rashid, 2016) Taxation and regulation plays a key role especially in fast implementation of circular economy solutions (Ellen MacArthur foundation, 2013) as wrong focus on taxing creates a strong barrier to the development of CE (Jabbour *et al.*, 2018). The public sector can also choose to have an even more significant role and

participate in the cooperative development. In china the EIPs are dependent on the government for design, support, management of EIP activities and their financial support. CE development on macro-level requires integration and redesign of industrial systems, infrastructure and delivering services, cultural framework and the social system. (Ghisellini, Cialani and Ulgiati, 2016)

Decoupling resource use and economic growth

On the business side the resource use and economic growth needs to be decoupled (Lieder and Rashid, 2016; Camacho-Otero, Boks and Pettersen, 2018) to avoid the need for choosing one or the other. The social and business perspective of creating short-term products to maximize the purchase volume also fight against circular economy implementation (Watanabe, Naveed and Neittaanmäki, 2019). The companies need to see the business advantages to pursue new technologies. (Lieder and Rashid, 2016) In addition to the public sector, banks have a great effect on the companies as their financial status needs to be good. The companies need to be able to finance their investments supporting CE, which means that the financial situation with banks needs to be stable (Ellen MacArthur foundation, 2013).

Challenges with business models

The business models propose also their own challenges, which especially affect the implementation of servitization focused models. The service focus changes the management of related risks, by transferring the financial and operational risks from the users to the service providers. In service focused businesses the companies have to prepare for the uncertainty in the continuous services as the contracts may be suspended early and through providing services the revenue streams might be heavily postponed. This makes it difficult to begin the operation without large risk taking as the costs need to be covered long before the revenue comes. The operational risks change due to the change in caring of the product. Serviced products may be handled more carelessly than owned products, which might increase costs. When the careless behavior of customers can have a large impact on costs, the ownership change can also form a similar problem totally differently. Through servitization the customer gives up the right to own the products, which might not allow the customers to affect the product themselves and for example try to optimize it (Bressanelli *et al.*, 2018b).

Data ownership

Additionally, the ownership of information might in addition to forming new business models form problems for the cooperative environments as there are several unclear situa-

tions that haven't yet been solved. For example if someone uses jointly created information for innovation processes, it is not clear how the ownership of the innovation formed (Rajala *et al.*, 2018) The collaboration with sharing and accessing data needs to be clear for the implementation of CE solutions (Antikainen, Uusitalo and Kivikytö-Reponen, 2018).

Circular challenges	**Non-circular challenges**
• Physical limitations • Definition of waste vs material • Total environmental impact • Cooperation with public sector • Decoupling resource use and economic growth • Old systems integration	• Market competition • Coordination • Lack of talent and complexicity • Cybersecurity • Cooperation with public sector • Old systems integration • Investments • Uncertainty / Resistance to change • Data ownership and circularity of data

Figure 13. *Challenges for implementation*

The findings on the challenges for implementation are gathered in figure 13. Similarly to the requirements, the findings are divided to the circular and non-circular challenges, with several factors in both fields. The cooperation with public sector is introduced as a finding in both chapters which highlights the importance of public sector in the circular economy development. Supportive legislation is needed for efficient operating, yet it is difficult to affect the legislative choices from a company perspective. Also, uncertainty is seen as an individual challenge for new technologies relating to the quality and reliability of new solutions, although the uncertainty could also be applied to the discussion on legislative changes and data operations. It is difficult to predict how the legislative pressure will change, so the support for transformation processes might shift. The regulation and operations for data controlling has not yet been formed, which can also either benefit or hurt the operational choices of an organization. The large amount of unresolved issues in the field help to understand the discussion on large potential, but marginal implementation of digitalized circular economy.

By summarizing the theoretical requirements and challenges in the context of digitalized circular economy, we are able to form an understanding on the situation that organizations face in the field. The identified factors are further used to provide understanding

and data for analyzing and comparing the results from organizations to reflect the differences on theoretical and empirical results. The results are then used to answer the third research questions through several data sources.

4. RESEARCH METHODOLOGY

This chapter explains how the research was designed and conducted and how the analysis of the results was organized. The research and the design process are based on the knowledge gained in the process of studying the theory behind the subject and fitting the gained knowledge together with the aim of the study. The main questions that the research aims to answer are, which digital solutions and technologies can support circular economy, how can the identified technologies benefit circular economy and what are the challenges and requirements for implementing digitalization into circular economy processes.

4.1 Framework introduction

The benefits of CE might be achieved by solving the identified barriers and challenges of CE implementation with digital solutions, but first the challenges for the creation of collaborative environments and partnering need to be solved. This can also be helped with the digital technologies, as solving trust and security related challenges can be helped with innovative technologies for example blockchain (Antikainen, Uusitalo and Kivikytö-Reponen, 2018). Additionally Antikainen et al. (2018) list that co-creation, networking and the sharing of expertise may be the first solutions for the challenges. (Antikainen, Uusitalo and Kivikytö-Reponen, 2018)

Some of the possibilities on the benefits of digital solutions have been introduced in the theoretical part of the research, but in order to understand the connection between the technologies and circular economy achievements, the path from the digital solution to the circular economy benefit needs to be formed. To identify and analyze the connection between the two trends, a framework is introduced.

The introduced framework gathers the identified technologies and possibilities they provide in achieving circularity in organizations and societies. The framework can be used in both directions either to identify the results that can be gained from using digital solutions to promote circularity or to identify the needs of investments to gain the right circular results. Additionally, the framework is produced with a visual outcome so that the connection between the two trends can be easily understood.

Before conducting the empirical research, the results on theoretical findings and expert discussions were gathered in a similar framework by forming a connection between technologies and circular economy. Several paths from the technologies to circular economy

were identified through advantages, effective areas and concrete effects. The figure was used to design a visually effective form to present the empirical results of the research and the structure of the figure was used in designing the current framework. The figure used in the framework process can be found in appendix A.

The technologies used are sorted under the categorization of digital technologies introduced in figure 6. The solutions introduced in the case are connected to the different technologies and the effects of the solutions are listed. Based on the characteristics of the benefitting effect, the effect is then combined with a circular economy benefit. The three value drivers of circular economy introduced in figure 4 were chosen to represent the different areas for circular economy benefits. By combining the technologies and circular economy benefits through the identification of solutions and effects we hope to discover connections between individual technologies and circular economy areas.

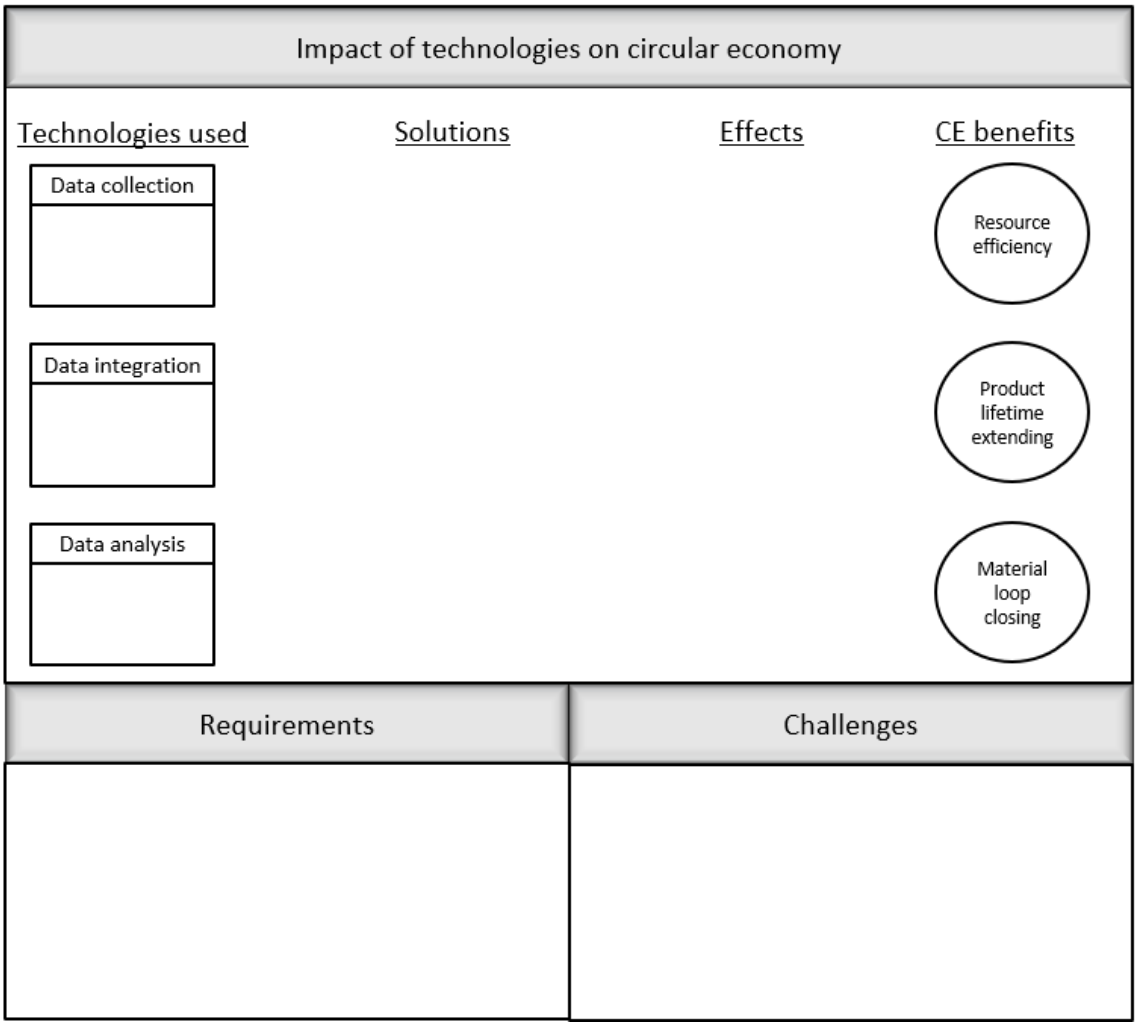


Figure 14. *Framework approach to CE benefits through digital solutions*

In addition to visualizing the paths organizations form from using technologies to gaining circular benefits, the requirements and challenges case organizations face are presented in the framework. By adding the elements to the bottom, the framework gathers all the critical information needed to answer research questions two and three. The visualisation also forms a relation between the technologies, solutions and operational factors, which enables easier understanding of the situation a single case organization is in. In the result section the, areas will be covered separately by analysing the technology impacts, challenges and requirements from the perspective of total theoretical and empirical research.

The introduced framework is used as the basis for constructing the interview, so that the interviews can identify clear points of investments or benefits that can be gained in enabling technologies that already exists in circular ways. By containing the different technologies in the figure, combining them with circular economy benefits and listing the identified requirements and challenges for digitalized circular economy, we aim to contain all the critical information to answer the three main research questions in a single figure per case.

4.2 Research design

The theoretical information gathered on the subject has shown large gaps in understanding the use of digital technologies in circular economy especially on the side of organizations and companies. As the hypothesis behind the introduced framework suggests, there are several different methods, how companies can implement and promote circularity in their operations. Thus, the use of digital technologies in the context of CE also differs. In order to cover the different ways and solutions that digitalization can provide to promoting circular economy, the research needs to cover companies that focus on different areas of circular economy. In the current research we use the three value drivers of circular economy to cover the different aspects of circular economy promotion. The information needed to reach the aim of the research, can't be gained by analysing quantitative data and the methods used need to allow the acquiring of quantitative data from operators engaged both in circular economy and digitalization. The lack of empirical data on the subject area has been pointed out, so in order to move the research forward empirical studies are a good way for new research.

As the focus of the research is on gaining empirical data case study can be interpreted as a good research strategy. Case study fits a research where the context and the target processes of the research need to be understood better and where several different data sources are used to produce comparable results (Saunders, Lewis and Thornhill, 2009, p.146). As the area of digitalized circular economy is still new and empirical research on

the subject has not yet been conducted, the case study as a method helps to understand factors that are not yet too familiar. Case study is also fit to answer questions like what, how or why, which are presented in the main research questions (Voss, Tsikriktsis and Frohlich, 2002). The risk that the case strategy presents is that the results are rarely generalisable (Gable, 1994).

Another possibility to gain insight to the subject can be through using survey approach as a research strategy, which is a common choice in organizational research (Gable, 1994). The survey method enables the researcher to gain large amounts of standardised data from a large audience, through prepared questionnaires. The analysis is easy to do on the data as the results are in a comparable format and can be formatted easily(Saunders, Lewis and Thornhill, 2009, p.44). The strength of the survey strategy is that the researcher can identify common factors across different organizations but as a weakness the survey needs to be well prepared for it to succeed (Gable, 1994). In an environment where the understanding on the subject is not clear the completion of a survey research, could easily focus on wrong areas. Additionally the two mentioned research strategies could be used together, to gain an even more thorough understanding on the area (Gable, 1994).

Based on the differing possibilities in operating with digitalized circular economy, case study was chosen as the most promising research method. Case study as a method allows the research to analyse multiple different operators, who are eager to develop circular economy solutions. To match the need for knowledge on organisations operating in the area of the different value drivers, multiple cases needed to be selected as the target group of the research.

The multi-case approach leads to a smaller focus on each of the researched cases in comparison to single case approach. Yet considering the subject and the information needed to understand the area on the side of the target cases, wide analysing of the case organisations wasn’t needed. Focus of the research is kept on the areas of circular economy and digitalization, to reach the aim of the study more clearly.

4.3 Case selection

Based on chapter 3 we can name the three CE value drivers as the main categories for promoting CE. Based on the value drivers the cases were identified under each category with the aim to identify several different target cases for each category. The target research group can be identified to organizations and companies that are engaged with circular economy solutions and digitalization and have a basic understanding of the

trending discussion and development around the topics. The case amount in a multi-case study can vary from three to up to thirty cases (Voss, Tsikriktsis and Frohlich, 2002), but in the current research the case amount has to be limited according to the schedule in conducting the research. By referencing previous thesis work (Ranta, 2016), completed with a multi-case research strategy, approximately four cases where identified as a suitable amount for a master's thesis.

To identify suitable cases for the research, case sampling can be conducted by gathering information on cases that fit the criteria for research (Voss, Tsikriktsis and Frohlich, 2002). On the research criteria the suitability, focus area on circular economy and the digitalized approach of the organization were evaluated as the main criteria for good case organizations and the sample group was limited to Finnish organizations operating in the areas of circular economy and digitalization. Several sources and networks were used to identify suitable cases. As the research is done as part of the EU funded CircVol projects, the other researchers included in the project were contacted in order to find suitable cases for research. Strong connections to other research projects in circular economy area allowed the identification of suitable project that had been researched previously from another perspective. The discussion on cases known to fellow researchers provided good insight on potential cases as the methods on how circular economy and digitalization were utilized could be better understood already before the case selection.

Additionally, as part of the CircVol project work two expert meetings were conducted regarding discussion around current research and development situation of digitalized circular economy in Finland. One of the meetings was with a Finnish expert focused on circular economy development around the capital area of Finland. The other meeting was with a company, operating with the development and supplying of digital solutions to circular economy focused clients. The meetings were partly focused around discussing the current literature findings on the research and partly on discussing potential cases that could be selected for the ongoing research. The expert meeting confirmed most of the findings done on theoretical level and provided new insight for areas to research more. Some of the potential cases were suggested by the two expert meetings, as they appeared to include interesting and revolutionary solutions to the industry.

Some cases were identified through circular economy related literature, which provided insight of several suitable cases located in Finland. Sitra, the Finnish Innovation fund also provides a list on companies that have circular economy as part of their operations. Sitra's list was used to help in identifying new cases and to gain knowledge on the circu-

lar economy methods of different companies. The suitable cases identified for the research have been listed in table 2. The focus areas of the companies are evaluated based on the gained knowledge in the case discussions and the information provided of the cases by Sitra and the organizations on their own websites.

Organization / Case	Focus area based on value drivers	Source
Hilti	Resource efficiency, Extending lifespan	CircVol, Expert meeting
HSY	Resource efficiency, Loop-Closing	CircVol, Expert meeting
UPM	Loop-closing	Theory material
Kiertomaa Oy	Loop-closing	Sitra
Destaclean Oy	Loop-closing	Sitra
Maapörssi	Loop-closing	Expert meeting
Metsäpirtin multa	Loop-closing	CircVol
Neste	Loop-closing	CircVol
Ponsse	Extending lifespan	Sitra
Tamturbo	Extending lifespan	CircVol

Table 2. Identified cases

The identified cases were evaluated based on preliminary analysis of the cases done on available data gained through internet searches, organisation websites and direct knowledge from other researchers. Then the cases were compared with the findings in the theoretical part of the research to evaluate the suitability of the cases for the research. The analysed information included the level of implementation of circular economy, the level of digitalization, the accessibility, operating area and the processes related to circular economy. On some cases the information available was very limited, which may have affected their position in the case selection. The cases were aimed to provide broad knowledge on the effects of digitalization in circular economy, which is why different fo-

cus areas and different solutions were weighted heavy on the case selection. One criterion for the case selection was to have a minimum of three cases, with all of the circular economy value drivers being present.

Selected cases

The selected cases were Hilti, which provides information on resource efficiency handled through software applied to products, Ponsse, which uses a buyback and replace system in their machines to extend their lifespan, HSY, for providing a resource efficient reuse-process for waste in a city and Neste, for applying digital solutions to loop-closing with tailored solutions. The selected cases cover the areas within the value drivers well and provide information of digital solutions in circular economy in very different contexts.

Hilti as a company was selected as it seemed to be an interesting choice for research. The company works in construction industry as a tool and service provider and they have gone through a large shift towards digitalization, which support the agenda of the research well. The technology Hilti uses was also supported by a large interest from other researchers and the technology was also mentioned as part of the expert meeting. Thus, Hilti was selected to represent the resource efficiency side in the research.

For extending lifespan Ponsse came up as an interesting company from both Sitra and personal contacts. The company proposed an interesting take on the subject, and it seemed more fitting to the research than Tamturbo. Therefore, Ponsse was selected to represent the lifespan extension side in the research.

On the side of loop-closing several potential case organizations were identified. UPM seemed to be a promising company for the research but due to a large amount of publications related to the circular process of UPM, the case was left out of the selection. The other organizations operating with loop-closing systems appeared very similar, except HSY appearing as a regionally unified operator. On behalf of the increased relevance of public sector on circular economy development, HSY was chosen to be researched, with a hope to gain insight into the different aspects that public sector brings to the discussion.

Additionally, Neste was chosen to be researched as they appeared as a success story of circular economy with a heavy focus on digital development. The profile of Neste fit the aim and target group of the research well, which is why it could bring additional insight to the subjects to be covered. Furthermore, each of the mentioned cases could have been included in the research to gain even further information from different areas around circular economy. Due to the nature of the research and the available time period, four cases were selected to cover all the target areas of the research.

4.4 Data gathering

For the research data, the selected case organizations were contacted with the goal to identify the persons responsible for the development of circular economy or digital solutions. Contacting was done by email and meetings were scheduled for the next upcoming weeks. The people that were selected for the interviews were suggested either by the persons contacted in the organisations or straight by researchers who already had the contact information.

Data gathering was done through semi-structured interviews that were conducted alone by the researcher. The interviews were conducted between July and September in 2019. The interviews were recorded with the interviewees permission and additional notes were written down during the interview by the researcher. To obtain a good understanding of the case the aim was to interview several people individually regarding each case. Most interviews were also tried to do face-to-face, but the timing and travel distances of the interviews limited the scheduling and availability of the persons selected to be interviewed.

The structure and questions of the interview were sent to the interviewees one week before the meeting for the interviewees to be able to prepare for the questions. This introduces a risk for the interviewee to not answer truthfully, but on the other hand the questions help the interviewee to prepare with good insight on the circular and digital operations, which indicates the need for the questions to be received beforehand.

The core structure of the interview was made by reflecting the aim of the research and the theoretical findings on the subject. A core structure of questions was used as a basis for all the interviews, and the sections was tailored to better fit the interview in each case. The tailored questions were created based on the circular economy focus area of the company and the knowledge gained in the preliminary research to generate even deeper knowledge on the circular and digital operations of the case organisations. The interview structure consisted of 5 sections that are presented below.

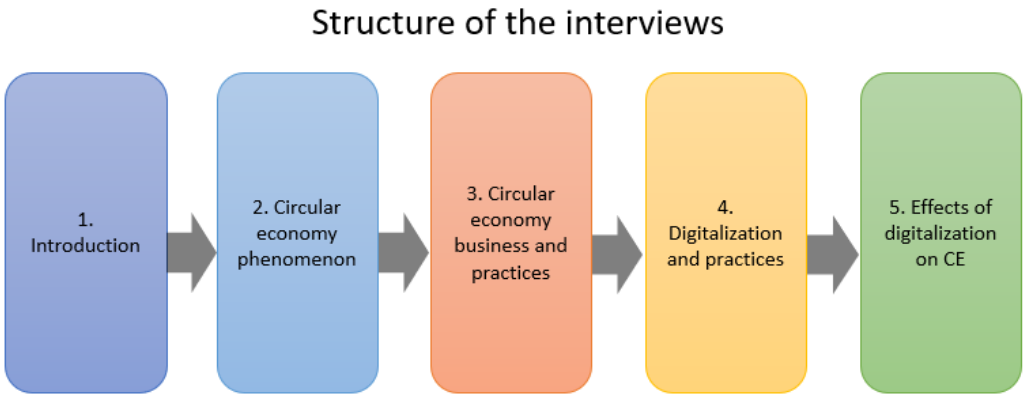


Figure 15. *Core structure of the interview*

The interviews were either done face-to-face or through Skype. One interview included two people at the same time, but all the other interviews were done individually. The time reserved for the interviews was 90 minutes per interview, which was enough, and the time of the interviews differed a lot based on the interviewee and the activity of the discussion. The structure of the questions from the latest interview can be found in appendix B.

4.5 Data analysis

The data gained in the interviews is used to develop the understanding in the relation of circular economy and digital solutions. The benefits that digital solutions can apply to the area have been only assessed theoretically and the interviews provide empirical data on how the digital solutions are used by organisations and what are the possibilities that can be achieved with the development of the technologies. The findings are gathered separately for each case to the introduced framework to present the critical information regarding each case. Afterwards the results are combined and analysed as one result group in order to provide answers and meet the aims of the research questions. Additionally, the empirical results are compared to the theoretical results and based on the findings implications for the participating organizations and future research are made.

5. RESULTS

The following sections introduce the results of the selected cases based on the interviews. The results are presented by first introducing the background on the case and then following with the results in the order of the interview structure presented in figure 15. Before covering the case organization's vision on the upcoming development of digital solutions and circular economy, the results regarding the main research questions are gathered to the framework.

5.1 Case Hilti

5.1.1 Hilti: Background

The first case introduces a company originating from Lichtenstein called Hilti, which manufactures tools for construction purposes. Hilti has a long history in Finnish tool industry, and it has been founded in 1941. The product line includes construction tools ranging from power tools to measuring tool including the accessories and fastening and protection related equipment. The durable quality is a core part of the Hilti brand.

Recently the company has developed from a traditional manufacturer towards a broad service provider that operates much more in cooperation with the client. Digitalization has changed the construction industry and has also provided new methods for Hilti to provide customer-oriented solutions to enable more efficient resource management. With digital solutions Hilti helps customers to keep track of their inventory and the maintenance status of their assets resulting in resource efficient operating. The main three services that Hilti provides are the Fleet Management service, Hilti On!Track asset management service, and tool service. Additionally, Hilti Connect -system is an important part of the portfolio, but it is not considered as a main service, but rather a future included in Hilti tools.

On the case of Hilti, one interview was conducted to gain insight into how circular economy and digitalization are utilized and perceived at the company. The interviewed person works with customers, services and software and provided information on the effects of circular economy, digitalization and the solutions that drive circular economy in the company and also the industry.

5.1.2 Hilti: Perspective on circular economy

At Hilti circular economy is not perceived similarly as in the academic sense. The company discusses the same methodology and principles as resource efficiency. To customers circular economy is concepted as profitability. Hilti says that circularity can definitely be identified as a trend that has recently been raised into discussion on their area, but it hasn't had a large impact on the core functions of the company. The main drivers behind the circular solutions have already been a part of Hilti before the phenomenon was even discussed. Yet Hilti wants to promote circularity and be the main partner of their customers in developing circular solutions.

"It is Hilti's brand to be durable and functional for the customer" - Interviewee.

One of the reasons behind Hilti's circular developments comes from the core values of Hilti, which strategically relate to the quality and brand of their tools. The tools are made for heavy use as well as to last in use, which are the main focuses in the manufacturing process. The quality of the product increases the product lifecycle, which results one of the circular economy value drivers being a core part of Hilti's business.

Circular economy has raised awareness especially in construction industry. Earlier questions of resource efficiency, recycling and material loop-closing have been mainly a tradition, but recently the industry has begun to have a focus on the profitable sides of the circular economy trend. This has led to broader thinking of questions related to resource use and productivity on the perspective of cost savings. Development of the industry has also affected Hilti as a service provider to further perceive circular solutions as part of their operations. The development of the circular economy discussion and the industry also provides new opportunities for Hilti to promote circular economy with their clients.

The focus areas of circular economy at Hilti are resource efficiency and extending the lifecycle. The product lifecycle has been developed the most, but on the customers side, resource efficiency is the most important value driver. Additionally, Hilti aims to reuse or recycle all the material outputs from their processes, and resource efficiency is also seen internally in minimizing material uses for cost reductions. In other words, the business aspect of loop-closing can't yet be clearly defined.

5.1.3 Hilti: Description of the solutions

The circular economy benefits in Hilti's solutions are gained through the circular development of their customers daily operations. The solutions are shaped to help customers keep track of their inventory and optimize their resource use. The different services and

their benefits to customers and circular economy are presented in the following paragraphs.

Hilti Fleet Management service

Hilti Fleet Management service is an alternative option for inventory management, which brings servitization models to the industry. The service introduces a monthly subscription for Hilti tools allowing customers to lease them with a usage based monthly fee. The service allows the customer not needing to buy and own every tool they use. The service includes maintenance and repairing of the tools, thus extending the lifetime of the leased products. The responsibility for maintenance of the products is also transferred from the customer to Hilti, making the service even more valuable from the customer's perspective.

Hilti On!Track

As their second main service Hilti has developed the Hilti On!Track Asset Management service, which enables customers to see data related to their inventory including their location and their maintenance info. The development of Hilti On!Track has its root in customer service as a need for better material and product control could be identified from the clientele. The solution is developed for construction workers to know where their tools are as it has been an industry tradition to buy new tools frequently with products being lost. Construction sites can have several operators, and workers may need to switch sites during the days, which makes tracking the inventory difficult. The service can also include product records, instructions for use, notifications for needed service and management of inventory and reorder of consumables.

Figure 16. *Hilti On!Track tag and mobile application (source: Hilti.fi)*

The products are connected to the On!Track -system with tags, which are available as passive or active versions. The active versions include a Bluetooth connection. The tags

include a QR-code for scanning presented in figure X. The active versions can be used to determine the location of the devices through On!Track mobile application or an internet browser. Also, both the active and passive tags can be scanned on location to see who the tool belongs to, what it is and get access to all important information related to the product. The tags are not limited to only Hilti's machines, and can be applied also to competitors' products as well as items not related to construction. The tags are designed to function in heavy conditions, which enables the tags to be easily used on construction sites.

"Some clients tag coffee machines and ladders" – Interviewee.

The implementation of the system is done by Hilti, where the needs of the customer are analyzed, and the analysis is used to generate a tailored system. The data sets for tagged products are tailored to the customer's needs, so any data can be gathered to the system as long as the customer inputs the information themselves. Regarding the industry Hilti also need to consider the users of the service, as the implementation process also requires training the customer to use the software and all its beneficial features. The customer is shown hand-to-hand, how the products are tagged, listed to the system and accessed with the service. According to Hilti, even though the construction industry is developing and seeing new innovations, several operatives are still used to standard non-digital work methods, which can make the change for new daily routines a big step. In addition, the system can be used to train the customer to manage their storage and inventory better and drive their actions toward more circular methods. Cost savings generated through the methods function as a motivator on the customer's side.

Tool service

Hilti tool management is the most important service on the perspective of circularity in the company's material flows. As a service Hilti offers to repair and clean your products in three days or the service will be free. The service includes both the collection and delivery of the tools straight to the customer and it is used to keep the products in use as long as possible. By making the maintenance service as easy as possible for the client, Hilti can drive the upkeep of tools and long-lasting customer relations instead of focusing on maximizing sales of replacement machines.

Hilti Connect

Differing from the previously introduced services, Hilti connect is an IoT based feature included in every Hilti machine that functions through an application. Every machine can be accessed with a mobile, allowing the customer to order product-based management service, find the serial number of the device, see instructions on its use, see service

status and to know what the machine is. In addition to the previously presented services Hilti Connect is an important part of Hilti's circular and digital development.

5.1.4 Hilti: Circular economy business

The portfolio of solutions offered by Hilti aims to reduce the material use and increase the lifetime of tools in their use. The driver for the customers to implement Hilti's solutions is significant as they can gain clear monetary benefits, avoid risks, and improve daily actions while they are developing their own circular actions through Hilti. According to Hilti changing the focus from product-orientation toward service orientation can be seen to have a positive effect on the sales. On single cases the lifecycle development of products might cannibalize the sales, but generally the client-focused solutions develop the customer relationship and have a positive profitable impact on both sides. Yet, the change towards a more service-oriented business model has had many steps and requirements.

For a 75-year old business to change its core functions, the mindset of the entire company must change. Focusing on servitization is a large decision and transformation process for a company like Hilti, which means that some priorities need to be rethought. According to Hilti, there were no clear barriers for the transformation, but the change had some clients confused especially at the beginning. On Hilti's side the change meant that new knowledge had to be gained in the organization on the side of service operations and the customers had to get on board with the new solutions.

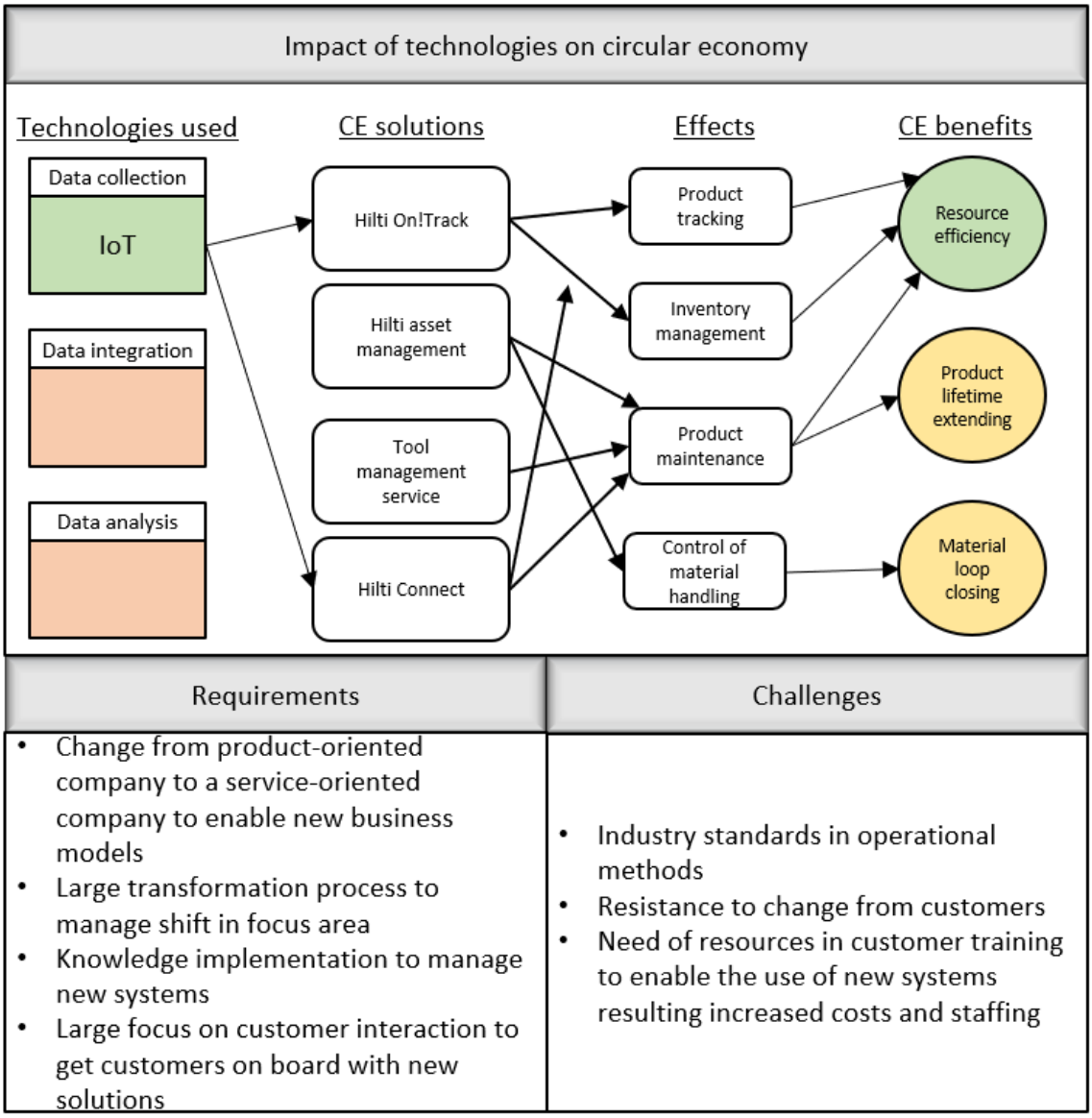


Figure 17. *Hilti: Circular economy impacts of digital solutions*

The results of the interview are gathered in figure 17 in order to answer the main research questions. The figure visualizes the effects that internet of things has in benefitting the resource efficiency of Hilti, but additionally IoT has an effect also on product lifetime extending through Hilti Connect solution. The main focus of Hilti is presented green and the additional benefits are presented yellow. The Hilti fleet management and Tool management service are not directly a result of digital solutions but have an important effect on the circular economy of the company. Data integration and data analysis are presented as red categories as they are not utilized in Hilti's processes.

5.1.5 Hilti: Utilization and development of digital solutions

Hilti also believes that the categorization for technologies presented in figure X resembles the development stages of digitalization well. As a new service and digital solution provider, Hilti has had to start from data collection where most of their technological focus still is. Currently Hilti is managing data collection technologies like IoT and their aim is to move towards data integrating and analyzing technologies. The first steps in the development have already been taken with cloud technology solutions that are used in the On!Track service. Currently Hilti sees that IoT is the most important technology when all its opportunities can be utilized, but on the other hand Big Data will massively change the ways of operation with the efficient analysis possibilities it provides. It is though still difficult to say when Big Data technologies are going to be ready for implementation.

The changes that digitalization has brought to the construction industry have an important meaning in the daily operations. With the digital development, new solutions can be used much faster and manual work can be minimized. Digitalizing paper delivery systems and planning have cut down a lot of the time invested in manual workloads, enabling workers to have more time for other tasks. Smartphones as well have made way for new customer friendly opportunities, that haven't been available before, and are one of the reasons why Hilti On!Track solution can be easily utilized on construction sites. Today networking and connectivity of objects and people is normal. The products are mainly used in areas near cities with good network availability, which solves connection issues. Most of Hilti's solutions work offline as well and synchronize the information with the online databases when connection is restored.

Although the construction industry has helped Hilti bring new innovations to the area, the traditional qualities of the industry still remain a challenge. Large part of the work is still done with pure hands, which makes the implementation of digitality in some cases difficult. According to Hilti the pressure for development may need to come from the customers side, as otherwise it is hard to force changes in the operations of the clientele. In addition, the requirements and resources needed for training clients in the use of new solutions raise the stakes for sales.

According to Hilti, digitalization will definitely change the industry further, but it is yet hard to say how. New technologies will probably bring new services to the market and the transformation towards usage-based services will be even more common. One of the key areas that will drive circular economy will be the utilization of preventive maintenance as smart use and optimization of the tools condition will help product lifecycle manage-

ment. Hilti names the location and usage records as the most valuable data in their perspective. The two are needed to optimize the use of equipment efficiently, but at the current status of development, no other important data sets are mentioned.

5.2 Case Ponsse

5.2.1 Ponsse: Background

The second case is a Finnish company called Ponsse that focuses on forest industry and the manufacturing of machines used in woodcutting and cut to length forest operations. Ponsse operates globally and has its roots in the Finnish countryside. Ponsse has the fundamentals of circular economy deep in their core operations and their mission is to “Succeed together with our clients and partners with sustainable and innovative wood harvesting solutions” (Source: Ponsse.fi).

Customer has always been in the center of Ponsse’s product development and customer orientation has been listed as one of the company’s four core values, the others being honesty, innovativity and Ponsse team spirit. As the products of Ponsse are the heavy machinery used in wood harvesting, they require large investments from the customers and have long lifecycle. On circular economy perspective Ponsse focuses on extending the product lifecycle as well as possible, with innovative solutions based on customer needs.

Two interviews were conducted on Ponsse, with experts from different areas. The interviews confirmed the data gathered and brought different perspectives to the data resulting in a broad set of information covering the areas of circular economy, circular economy solutions and digitalization at Ponsse. Both interviewees had been working at Ponsse at least eight years and were operating in spare parts and health, safety and environment sectors.

5.2.2 Ponsse: Perspective on circular economy

As a company Ponsse is well fit to develop circular economy solutions as it has been a part of their operations and core values since the beginning. According to Ponsse’s history the first machine built by the founder of Ponsse had been constructed out of different recycled parts and the tough financial times have shaped the way Ponsse operates today.

“The responsible approach comes from the roots of the company, when we couldn’t afford to waste anything. This can still be seen in our actions as so-called positive parsimony” – Interviewee 2.

Ponsse has always focused in responsible and ethical operation and the methods fit to the description of circular economy today. According to Ponsse, circular economy has recently become a widely known trend, but at the company it has mostly been implemented as a new term for old things related to responsible operations that have always been there.

“CE as a phenomenon is only talked about in a small group of people yet it is implemented in the whole company” – Interviewee 2.

Altogether Ponsse has positive feelings that circular economy is developing widely, and the matters are taken seriously. Ponsse sees that circular economy trend has gotten many companies to develop their operations with circular economy values upfront, but still many operators lack knowledge and circularity is not seen important enough to be implemented. Ponsse themselves have no separate unit or direct responsible for circular economy development. Yet the circular aims in the company have been implemented to each unit which enable them through their own strategies and knowledge. Ponsse feels that in the future these things will probably be developed more organized.

Circular economy is also an important part of the forest industry as the industry itself is really interested in circular development and new solutions. Through the industry it is a must for Ponsse to be a part of the circular discussion but similarly to the company the industry also has discussed circularity long before it became a trend. The industry has a lot of discussion related to new wood-based solutions and the use of renewable materials, which affect the operations of Ponsse directly. On a business perspective Ponsse needs to be on top of the discussion to keep up with the industry standards.

“At Ponsse circular economy begins with product lifecycle management and customer orientation. We want to offer long-lasting products for the customer.” – Interviewee 2.

At Ponsse all value drivers of circular economy are utilized and can be seen as part of daily operations. Life cycle development and the services related to it have also partly become a needed service on the customers side as the only way to replace some parts is through remanufacturing. Circular thinking is also utilized in material selections and in product development. Ponsse sees that resource efficiency is important on the business side as it has a clear impact on profitability. The company aims to produce minimum amounts of waste and material loops are closed as well as possible already in the product development phase. For example, in Finland oil used in Ponsse’s machines and

manufacturing is sold to other companies for reuse. The material flows are tracked carefully on a sustainable perspective and the origin of components is perceived on a high value. Through audits Ponsse can deploy the circular practices also to its subsidiaries and partners thus developing the circular methods even further in the whole supply chain

For Ponsse there are several factors that make circular economy important. One of the main reasons behind circular economy development is that Ponsse's product is so heavily related to the environment that the company wants to be a part of the development and take the industry further. Other factors are the customer, which is the driver behind efficient and smart solutions, and responsibility of the nature, which is also growing as a need from the customers side. The bigger the client, the bigger the need for responsible business is on the supplier's side. Additionally, at Ponsse developing circular economy has become a personal driver for some workers as with their own actions and choices they can themselves impact the environmental discussion and hopefully achieve something important.

5.2.3 Ponsse: Description of the solutions

Ponsse's circular solutions and services are spread throughout the whole customer interaction process from the purchase to the disassembly of a new machine. The driver behind each solution is to make operating as easy as possible for the customer. Most of the solutions focus around repair and remanufacturing services, which require efficient reverse logistics processes that Ponsse has developed to fit customer needs. The portfolio of Ponsse's circular economy solutions is introduced in figure X.

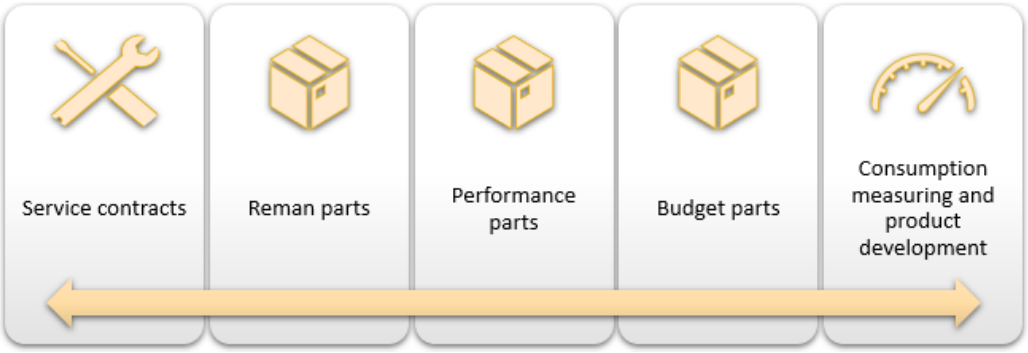


Figure 18. *Ponsse: Circular solutions portfolio*

Service contracts

The largest service Ponsse offers are the service contracts of the machines. The service contract lets the customer focus in their own operations and lets Ponsse take responsibility on the maintenance of the machine. Ponsse aims to sell 90% of their machines with a service contract as it enables the easy tracking and maintenance of the machine throughout its lifecycle enabling more efficient operating for both Ponsse and the customer. With the service contract the operation is done closely together with the customer, which makes the cooperative circular development easier. Through the contracts, Ponsse also has access to all the parts for remanufacturing, which allows Ponsse to manage the material flows and possible waste of their own production. Currently Ponsse has no rental services where the ownership of the machine remains at them, but still they operate very closely with the customer.

"The need for service contracts is constantly growing, because of the constant technical development it is easier for the customer to let the experts handle the maintenance of the machine" – Interviewee 2.

Reman-parts

First steps of Ponsse's circular economy solutions began with a centered remanufacturing workshop called Reman-workshop, which had an aim to offer new possibilities for clients through remanufactured parts that were cheaper than new ones. Before the Reman-workshop was established, part remanufacturing was done separately by individual operators, but the quality didn't meet the customer needs. In the beginning of 2000s, the market had a large need for spare parts, so Ponsse needed to come up with a solution to get them. The answer was old machines and remanufacturing, which created the brand Reman-parts. The remanufactured parts are in average 30 % cheaper than new ones, thus giving the customers possibilities to save costs. Since then remanufacturing at Ponsse has developed into a global process and Reman-activities are being offered around the world.

Performance-parts

Another solution that was developed after the Reman-parts are Ponsse Performance-parts, which provide solutions for larger remanufacturing needs than single parts. The Performance-parts gather all the pieces needed for the most usual remanufacturing needs to a simple kit. Examples of Performance-parts are the filter-kit, which replaces all the filters in a machine or an efficiency increasing -kit, which increases the efficiency of a machine by updating the computer and providing all the supplies needed for it.

Budget-parts

After Performance-parts, Budget-parts were introduced as a third remanufactured solution for the customers. The Budget-parts consist of parts that have already been in use or have been used as prototypes. The Budget-parts are mainly meant to be used in secondary machines and to fix problems that don't necessarily need an entirely new unused part. Budget parts also include parts from out-of-date models, which is why they may be the only solution to remanufacture certain old machines.

"Many customers are small, so we try to help them by minimizing the prices" – Interviewee 1.

In Ponsse's case, the customers have driven the development of different solutions as the spare parts market is heavily price sensitive. Ponsse says that today the need for Reman-parts is much larger than before, but this is more due to price sensitivity of the parts than the importance of circularity. Some of the clients don't have the budget to replace every part with brand-new high-quality parts, which is why Ponsse wants to offer them affordable solutions with great quality. According to Ponsse, the spare part portfolio doesn't cannibalize the sales of different solutions or new machines, but more so supports the machine sales.

Consumption measuring and product development

In addition to remanufacturing on of the most important circular economy solutions Ponsse has are their consumption measurements. The fuel consumptions of the customers are measured, and the data is used in product development and customer training. In Ponsse's machines, most of the emissions are generated from the fuels, which means that at the same time fuels generate a large part of the costs to the customer. The way the driver operates the machine has a significant impact on fuel consumption, which is why correct methods in machine operating directly affect operating costs. The drivers can be trained to use the machine efficiently, lowering the fuel consumption rates Ponsse says that, especially big clients also track the fuel consumption volumes closely so reducing the fuel consumption on the machines reduces the costs of use for the clients operating the machines, which at the same time gives Ponsse a competitive edge in the market.

5.2.4 Ponsse: Circular economy business

By having a large portfolio of remanufactured parts, Ponsse is able to answer differing customer needs dynamically, control the material loops related to their own products, and offer circular solutions that benefit themselves as well as their clients. The solutions

offer improved efficiency and increased time of use for their machines, which result monetary benefits for both Ponsse and their customers. Additionally, the sustainable, ethical and circular aspects that Ponsse values are clearly linked to their brand developing the Ponsse-image internally and externally. Ponsse says that the real business driver behind the solutions is the customer and additionally they want to make their waste into sellable material. Service contracts made with customers make repairing operations easier for the customers but also extend the customer relationships, which bring a business driver to the circular solutions. Also, selling remanufacturing solutions allows Ponsse to manage and control the additional material flows, which itself is a service for the environment and the customer.

The requirements needed to make efficient remanufacturing process succeed are according to Ponsse: investments in marketing operations, development and operation of the reverse logistics and additional work force. Ponsse says that the key to circular economy is that someone takes the responsibility for it and has the courage to develop solutions and use resources to move further. In this case Ponsse uses resources on behalf of their clients to produce circular economy solutions which benefit both sides, indicating that investing in circular economy can have benefits although it is hard to take the first step. Lot of knowledge and skill is required to implement circularly efficient solutions, leading to often doing the same old things rather than changing radically. Also, price sensitivity in spare part markets brings its own challenges to the process that Ponsse needs to consider. The large shift in prices may cause errors, where in some cases the remanufactured parts might be more expensive than the original parts. This leads to Ponsse having to use more resources on price setting and tracking of the changes to offer customers the best prices possible.

In addition to customer and the industry being the main drivers behind circular economy development, Ponsse acknowledges that legislation brings pressure for companies to change. For example, in Ponsse’s case, laws for reporting emissions of manufacturing processes have made the discussion and development around emissions and their effects more active. The legislation changes present a direct need for organizations to change and take the environmental discussion into consideration. In addition, Ponsse’s own values in responsible operations have changed the company’s perception in Finland and also globally to take further responsibility on the environmental effects of their own business.

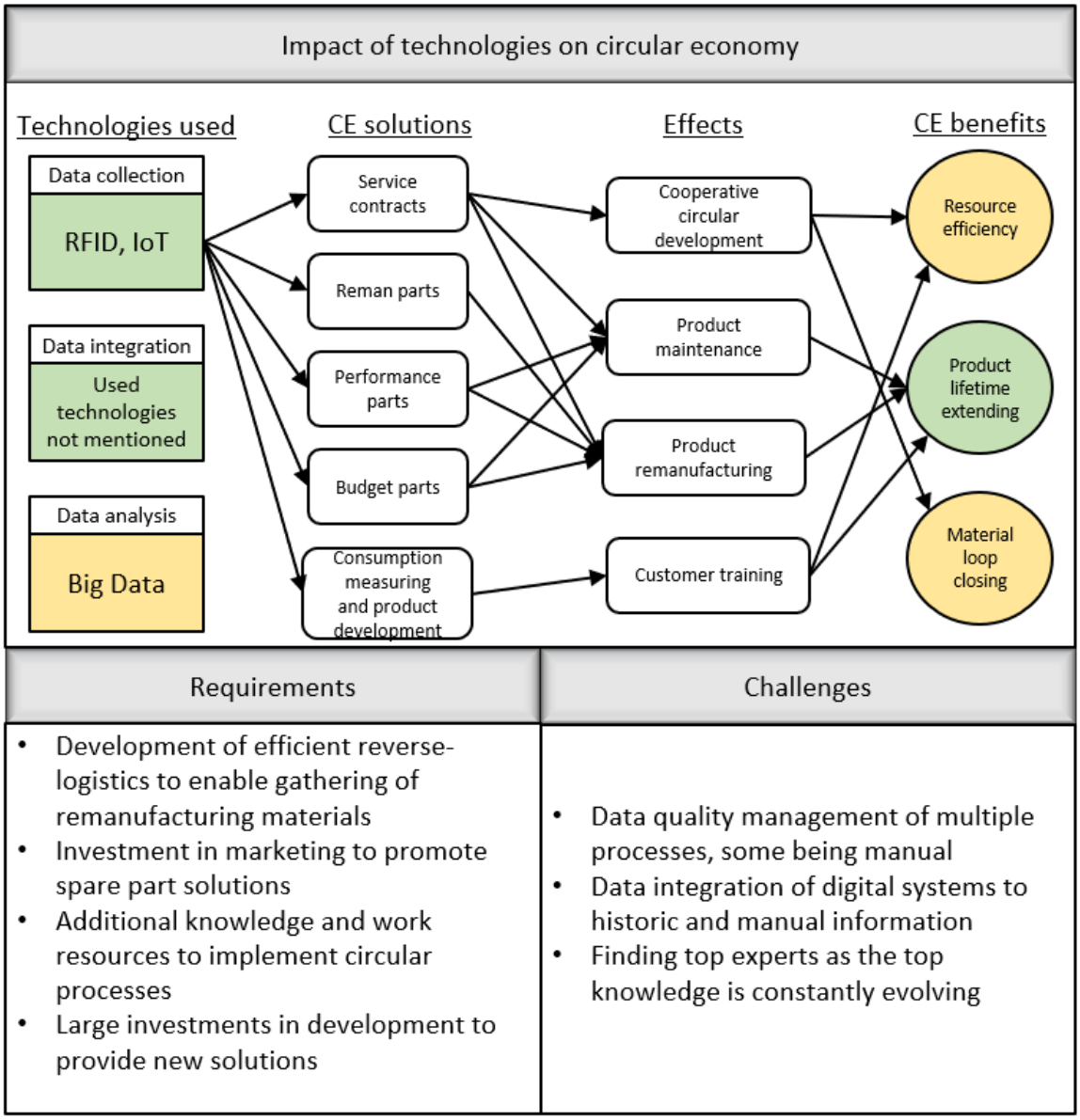


Figure 19. *Ponsse: Circular economy impacts of digital solutions*

The digital solutions of Ponsse and their effects on circular economy are gathered on figure 19. Data collection and data integration technologies are already being utilized in Ponsse's operation, which is why they are presented as green. The development of data analysis technologies has been started, which is why the category is colored yellow. The focus on the utilization of technologies is in the data collection technologies which supports most of the CE solutions. The focus on the circular economy benefits is on product lifetime extending, but at the same time the solutions partly benefit all of the CE value drivers.

5.2.5 Ponsse: Utilization and development of digital solutions

Digitalization has affected the work of Ponsse significantly, which can be seen in the employees and focus areas of Ponsse. One of the indicators of the digital shift is that today there may be more programmers than machine engineers as workers, and the currently unified communication through enterprise resource planning system has previously been done with faxes or emails. Digitalization has brought in an online system for parts, which helps in checking machine info and order parts, and order processes have also been automatized as customers can make orders straight to Ponsse's database. Today the development of the solution revolves around data and new ways of utilizing it.

The level of digitalization at Ponsse has moved from data gathering technologies to data integration technologies and already some testing is done with analyzing technologies. Many different sensors have been implemented to the machines and separate parts of them, which allow the gathering of data collected from processes and machines. The gathered data revolves mainly around the health of the machines. Integration of data is done through sensor portals, which gather the data to the same database, but there is still some development needed to integrate the data for use in analysis technologies throughout the whole organization.

As the most important technologies IoT and Big Data come up in the discussion. Ponsse mentions that internet of things is a technology that has developed a lot and is already in use. Also, big data as a word has been present for long, but the applications and methods are still in development. The analysis technologies aim to generate even more data throughout the whole organization, but the implementation requires the development of an organization wide and generalized dataset. The dataset is being developed by also listening to the customers as they are giving a large pressure for data collection. The customers have their own need for additional services made possible by the data gathered.

Ponsse itself is an innovative company and want to develop a lot of the solutions used in the machines themselves. Ponsse may not want to be the forerunner of digitalization and the discussed technologies but rather benchmark others and prefer well tested technologies before implementation. In the digital innovation processes customers are still kept in the center.

"We don't go into new things if it doesn't help the customer. We want to be testing things, but an organization wide change requires a drive from the customer or legal side." – Interviewee 1.

Recently the main focus area in development of digital solutions has been around product monitoring, which aims to enable preventive maintenance and forecasting solutions to support the spare part services. The development is done in cooperation with research development and information management sectors. A critical challenge in the development are the locations where the machines are usually used. The sites were Ponsse's machines are operated are often out of the functioning areas of network, which poses the challenge on how to get the technology to work in difficult areas. It is hard to implement some sensor solutions to data integration if you can't establish a connection to the machines when they operate.

Ponsse identifies several other challenges related to the development of digital solutions some of which can be solved and some of which Ponsse can't necessarily approach themselves. Data quality is one of them, which in some parts of the process is still done manually. The quality of data provided by sensors can be guaranteed, but the inputs done by human are vulnerable to mistakes. Some information on repairing operations is still done manually by the mechanic and with the lack of a standardized information model, the inputs might not be thorough or exact. With the development of data integration, the including of manual information also provides a new challenge. The aim in data integration is to combine gathered and analyzed data with location data as well as historical data. Most of the historical data can today still be on paper or in the worst case only in someone's own mind, which asserts a need for Ponsse to come up with methods to utilize and identify those data sets as well. Additionally, the investments come up as a crucial challenge for new solutions as from a business perspective the return on investments need to be positive or have a similar positive impact on the customers.

The fast pace of digital development can be seen at Ponsse and even though the company is very technology-oriented it is difficult to keep up with the up-to-date discussion. As digitalization and the best possible solutions progress daily, the inhouse expertise can form a problem for development, if the new technologies aren't followed. Ponsse says that it may be difficult to find top experts when the top knowledge is constantly evolving. A company that wants to keep up needs to find ways to have access to the best expertise if they want to be a forerunner of digitalization. The development of the field also brings up the questions of data ownership and vulnerability of information, which is a new problem to other digitalized companies in addition to Ponsse. The ethical methods need to also be clarified to ensure responsible operating with data. How much data does the company want to share and what is the motive behind gathering data, are factors that need to be explained for the digital operating to be as visible and trustworthy as possible.

5.2.6 Ponsse: Digitalization in circular economy development

In the discussions with Ponsse, the correlation between digital solutions and circular economy can be clearly seen and solutions of Ponsse are just one example of it. According to Ponsse, a big part of circular economy is to make something valuable out of waste, but still today technologies might not yet be developed enough to enable it. If there are no services buying the waste, many organizations don't think it matters where the waste ends or what happens to it. Ponsse acknowledges that in Finland there are several new service providers, which try to generate a market for waste and secondary material flows, but they are mostly localised, which doesn't solve the problem in large scale for example on the range of whole Finland.

Ponsse sees a large potential in digital development in the context of circular economy. In their own field the focus is especially in the development of preventive maintenance solutions. If preventive maintenance can be implemented the cost savings can be very impactful and save several products before they get broken and end up as waste. The change towards preventive maintenance is already happening and its developing constantly. In addition, augmented reality (AR) and virtual reality (VR) technologies are mentioned, as in manufacturing industry they can revolutionize the working methods.

When discussing availability of new data, most of the data Ponsse would like to gather relate to the technical statistics of the machines for example temperature, pressure and machine hours. These are critical for the development of the preventive maintenance and machine optimization, as the different data can be used to generate assumptions on when the machines or individual parts usually brake. This makes a large database of gathered information extremely valuable. As another dataset Ponsse mentions customer knowledge. The information known of customers and how they operate their machines, helps in product development and it as well generates new possibilities for Ponsse. Customers can be individually trained by noticing behaviour patterns in their machine operating methods. Training the driver makes the customer get as much value and efficiency out of Ponsse's machines. Afterwards in optimizing the machine use the next step becomes the intelligent development of the machine. When the machine learns to observe the environment, it can help the driver itself. Still the data visibility needs to be an important factor in the development, and it is hard to see how the data markets, where gathered data is used as a product, will develop and how data legalization will affect the possibilities.

"The better we can cooperate with the customer; the better can circular economy be driven forward. That profits both (us and the customer)." – Interviewee 2.

In a more general perspective Ponsse sees many other possibilities in digitalization. Communication and understanding of information can be made more efficient, the machines producing data can be optimized and thus the amount of data available will increase. More precise analysis can be made and used in observing systems in large scale which then can be used to help raise the knowledge on circular economy and generate easily understandable data. One of the biggest challenges in new solution development are still people as it is hard to affect their thoughts. As a final thought Ponsse sees that Finland is in a great spot in driving the change towards circularity as technical knowledge and innovative solutions have always been good export products of our country.

5.3 Case: HSY

5.3.1 HSY: Background

Helsinki Region Environmental Services Authority (HSY) brings some differing aspects to the interviewed cases as the organization is not a company but instead a municipal body. The organization operates in four member cities: Espoo, Helsinki, Kauniainen and Vantaa and the operations have been formed with an agreement made together with the cities. The organization manages waste and water services around the area and promote environmental knowledge and development for the inhabitants, which makes the organization an important contributor to the circular development in the Helsinki Metropolitan area. This can as well be seen in the company's brand which is being changed from a waste management organization to a circular economy operator.

HSY handles several different material processes, but in the current research we focus on the waste management process done with contractor Alpha to gain insight into the loop closing process between two companies and its circular and digital aspects. The process handles all material gathered from the residential properties and public administration, which is processed in cooperation with contractor Alpha. The process is also a good example of a large volume circular process that relates to the daily operations of consumers.

Two interviews were conducted with HSY where 3 people altogether were interviewed. The first interview was done through Skype with two people at the same time. The interviewees were from different units, which gave even broader knowledge on the process and organization. The operating areas of the interviewees were in field management, research and development and networking of the organization. Some of the interviewees had been a part of the cooperative development process of HSY and Alpha since the

beginning, which means that the interviewees had a strong knowledge on the whole history of the cooperative process and its development.

5.3.2 HSY: Perspective on circular economy

For HSY circular economy is still finding its place at the organization. The processes focus around material reuse, but circular economy is not the main thing people talk about. Circular economy as a phenomenon is rather seen as a trend word that has recently come up in discussions, but still other terms are used in describing the operations with circular qualities.

Even though the operations are not discussed as part of circular economy, the organization has a wide variety of circular solutions in their business. In the context of circular economy drivers, the focus of the organization is naturally around loop-closing done in cooperation with Alpha. Resource efficiency and material lifecycle are still considered and developed, but the methods to drive them revolve around different and indirect actions for example affecting consumer behavior. The current research focuses around the process of material management of household and public administration waste, where the consumers and their actions have a large impact on HSYs operations as the material used in HSYs processes comes directly from the consumers.

Apart from developing the organizations own processes, one of the core tasks of the organization is to raise the awareness and knowledge on environmental subjects especially regionally. HSY also is and has previously been part of several projects developing circular economy and they want to be a part of the circular development of their local area. This means that HSY has an important part in the regional development of circular economy and all the positive circular effects of HSYs actions may not necessarily be traced back to HSYs own material management processes.

5.3.3 HSY: Description of the solution

The introduced process has been developed to generate an efficient way to manage the large material flow of waste in the Helsinki Metropolitan area. The material management process that is done in cooperation with operator ALPHA, includes the material processing of waste coming from households and public services. The cooperation started in 2008 when HSY began the planning of a facility meant for material processing. HSY needed a contractor that would begin to utilize the materials and Alpha was chosen as a result of competitive bidding. In addition to Alpha an additional party Beta was part of the planning of the facility to help their operations as well. The operating of the process began in 2014. A visualisation of the process is described below in figure X.

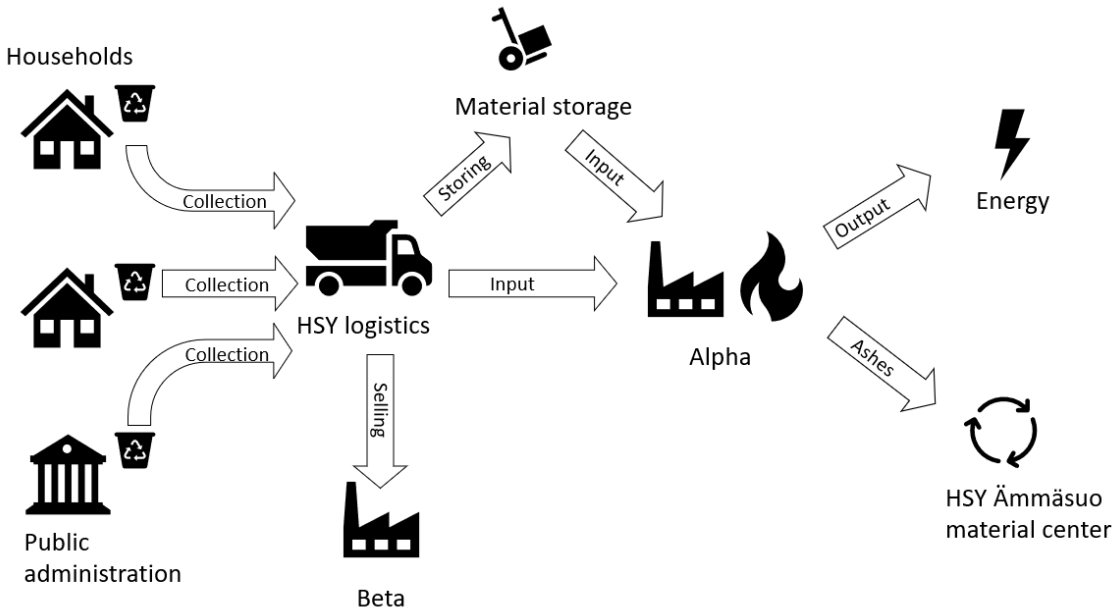


Figure 20. *HSY and Alpha material flow process*

The circulation process for materials begins from the households were consumers put their sorted materials to recycling containers provided by HSY. On regular intervals the containers are emptied by HSY trucks, which then deliver the materials to the processing facility of Alpha. At the facility gate the material trucks are weighted and an operating system registers the received amount of materials from the truck. In the facility the materials are incinerated efficiently to generate energy and the remaining ashes are delivered to Ämmässuo eco-industrial center for further processing. The material volumes are managed with an additional material storage to balance input capacity to Alphas facility. Additionally, in cases where the capacity in the material storage or the facility are exceeded the additional material are sold through another market operator, referred to as Beta, to enable the processing of those materials.

Alongside the material flow described in the figure the cash flow is an important part of the process. In the process Alpha functions as a service provider that treats the materials HSY brings them. This means that HSY pays for all the material they bring to Alpha for incineration. Additionally, the ashes formed in the process are bought back from Alpha in order to be further used in Ämmässuo for additional purposes. At Ämmässuo the ashes are either stabilized or processed before reuse for example in construction operations.

The contract between HSY and Alpha includes a minimum amount of material needed to be provided for incineration, which is why the material volumes need to be measured

and evaluated carefully. HSY has a storage for themselves which they can use to balance the material flows. The facility has a maximum operating capacity for the materials that can be incinerated at a time and among HSY there are other operators that use the facility for material incineration. All the organizations operate in cooperation by sharing data and evaluations of upcoming material flows. This allows all the parties to dynamically manage the logistics and make sure that the facility operates all the time at full capacity. It is a benefit that both parties are interested to cooperate and to optimize to volumes for the efficiency of both operators. The storages help in operating the supply chain and through data sharing every operator knows what is happening in the process in real time.

Pre-sorting of materials, regular checks and material analysis is conducted on HSYs behalf as much as possible to prevent malfunctions in the facility. Certain materials can shut the process down by generating problems and produce unwanted fumes when being incinerated. Metals and biohazards are the most common pre-sorted materials that produce problems and other large objects for example furniture, need to be left out of the process. Even if all materials can't be burned, the aim is to recycle everything, by finding a suitable way to process the materials. In order to solve problems and keep the process functioning, the cooperation between all the parties needs to be efficient and problems need to be solved dynamically when the occur.

5.3.4 HSY: Circular economy business

Incineration is not a new process in waste management and in several contexts, it is a solution companies are trying to replace. Yet the incineration process is an efficient way to manage the large volumes of household material, to enable its transformation to reusable energy. The energy generated in the facility provides a significant part of the energy consumed in the local area. In comparison to the historically earlier methods, where material was disposed by bringing them to landfills, the incineration reduces the use of landfills and enables possibilities for the ashes to be reused. The solutions and planning for the facility and material process originally began as landfills were to be prohibited, which meant that a new solution for material management had to be created. HSY says that it is hard to find a better solution than burning and due to the costs related to the process, it is not a favourable solution for companies. For individuals the costs are low and marginal.

HSY has to operate very differently when compared to a regular company due to the nature of them being a municipal body. Every contract needs to be decided based on a

fair competitive setting and the focus of the operations is much rather on providing services to fulfill the organizations agenda rather than generating profit. The nature of the organization limits their possibilities and also forces them to be open and responsible in their operations. Even though the incineration process produces costs for HSY, the organization needs a way to manage the material, whereas incineration is the best possible method available at the moment. The process is handled professionally with the environmental and circular values in mind, which also bring up the responsible brand of both HSY and Alpha in the eyes of the consumers. According to HSY the process is already quite far optimised and the material is managed well, which means that for further development of the process, new solutions need to be identified.

In HSYs case public decision, legislation and consumer behaviour have a significant impact in the operating methods. The development of the process depends a lot on the behaviour of the consumers as the aim is to make material management and sorting easy for the consumer in order to generally manage the materials on the Helsinki Metropolitan area. As a large part of the responsibility relies on the consumers own decisions, whether to sort the waste or not, HSY needs to use resources in trying to change consumer behaviours towards sorting their waste. HSY acknowledges that ultimately, they can't force all their customers to sort their waste, which is why problems in material flows occur. On the other hand, promoting sorting and material management methods and their positive effects in public discussion helps HSY develop their process. Some resistance to changes can clearly be identified from the consumers side as waste sorting of households is a part of routines and daily activities, which are hard to affect. This introduces a challenge to implementing new methods and technologies as the consumers may not want to change their ways even though they would be more efficient from the perspective of the material management process.

The material sorting industry is very vulnerable to public decisions and changes in legalization especially as environmental and material cycling related subjects have lately had a crucial role in public discussion. Due to the active development of the discussion, new changes to the operation are applied often, which is why HSY and their partners in the material process need to be able to cope with the changes. The legislation is a good way to change the working methods towards the public opinion, but in fast paces the organization needs to be able to apply the changes dynamically.

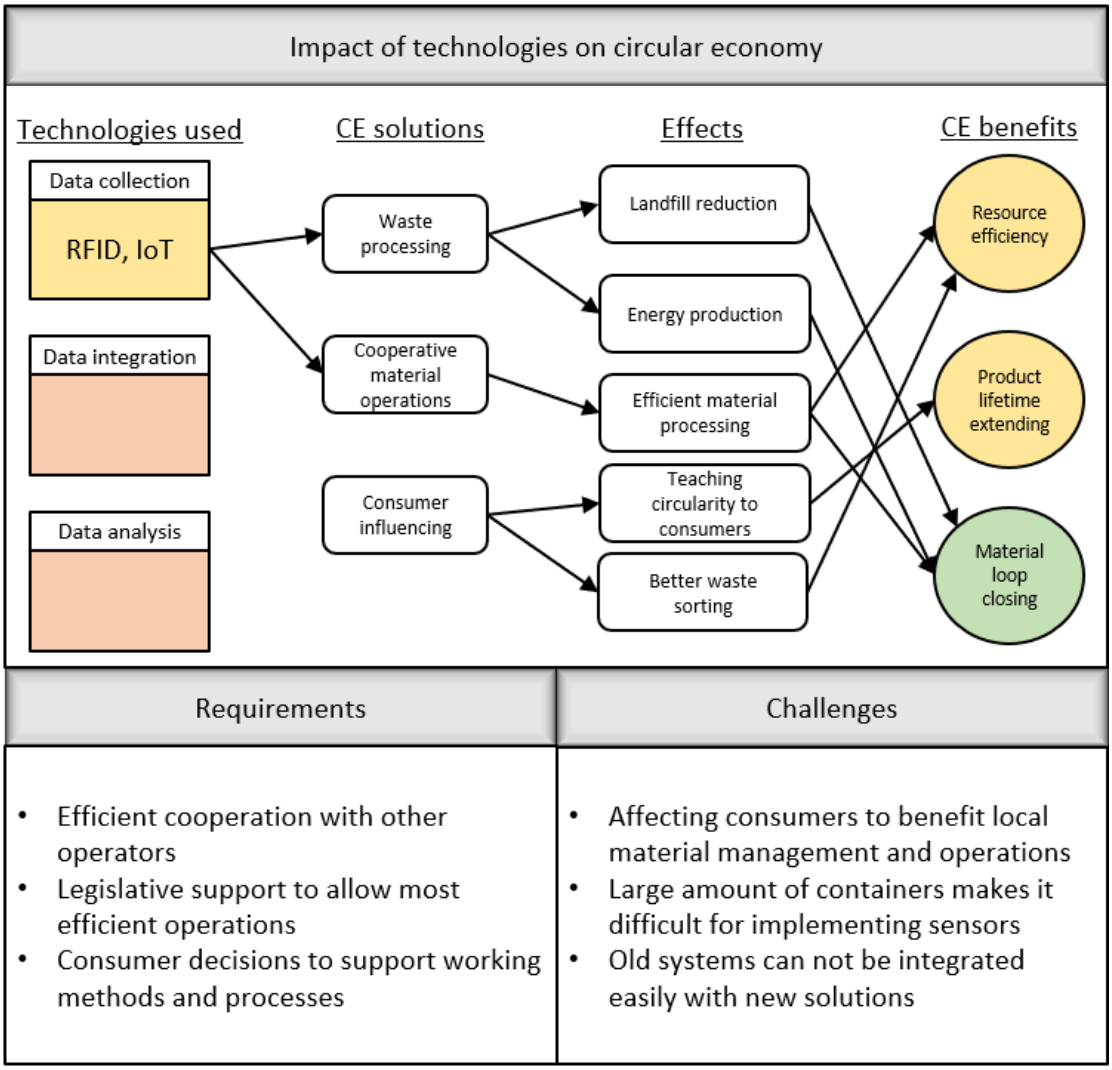


Figure 21. *HSY: Circular economy impacts of digital solutions*

HSY has their digital technology development around data collection technologies, which they are implementing through different pilots. Data integration and data analysis technologies have not yet been implemented, which is why they are colored red. Consumer influencing is an important part of CE development in HSY area, which helps achieve benefits in resource efficiency and product lifetime extending. The main benefits of HSY data collection technologies are in material loop closing, which is presented green.

5.3.5 HSY: Utilization and development of digital solutions

Digital technologies have been a part of HSYs operation for long and on the technological side several pilots and researches have been conducted on how new technologies or innovations could be applied to the material management processes. HSY tells that the organization has seen several RFID pilots and IoT solutions have also been seen in

discussions, but not many Industry 4.0 technologies have yet been implemented. IoT is named as the main technology that is being followed. New IoT software for internal use is being developed for tracking material locations, but experimentally it is still in its early stages. Research has also been done in the form of a master's thesis on dynamic waste collection solutions where IoT technologies were tested in waste containers. The focus on the digital development has been in the area of data collection technologies which would help in organizing the logistics and consumer interaction more efficiently. No development has yet been made on data integration or data analysis technologies. HSY is currently focusing their digital development on customer reporting to make the process more visible and understandable to the customer. With better customer engagement HSY can identify and answer customer needs as well as possible.

On the other hand, a lot has changed in HSYs operations due to different single solutions implemented to the material process. The logistics have been operated semi-automatically since 2008 and digital tags have already been introduced to the trucks that transport the materials as well as to the cargo documents that are today transported digitally. At the gate of the facility, the trucks can be identified based on the truck allowing the tracking of material masses and their origins. Each cargo brought with the trucks are numbered, and the data is stored in the system if backtracking of the material is later needed. According to HSY they can quite easily trace the materials back to their collection sites especially on the public side. On the households' side it may be impossible to trace the single person behind each container, which means that the responsibility of pre-sorting waste to right containers remains with the consumers. In Finland backtracking the material is a legal requirement for waste operators.

Developing the data gathering management technologies related to the processed materials does not necessarily change the operations of HSY and Alpha significantly as currently almost no data is needed from the material. The material is controlled with quality checks and cameras that monitor the process at Alpha, which try to spot enormous differences in the material flow. Altogether the material is crushed to material mass that is sent for incineration where all the processed material is mixed. In the incineration process the qualities of the materials do not need to be known to complete the process. Therefore, HSY has not made large investments to the material related data gathering and management processes as the data does not have clear uses or benefits. Analysis on the composition of incinerated materials is being done, but mainly just on Alphas side, where they can analyse the burning process with sensors in their facility. The output gas from the process gives information on the qualities of the used material, which is used to develop the supply process and fix mistakes. According to HSY, the analysing process

is already well developed with the current tools and does not need new solutions. This means digital technologies can't significantly help to develop the process. HSY says that the main solution digital technologies are used on is to remove the manual work. In the process this can especially bring advantages to the storage controlling, where manual tasks are still a large part of the work.

HSY does not want to be a frontrunner of digital development and they rather want to be the one buying cost efficient and ready solutions. Based on the previous pilots that HSY has had, they have noticed that the implementation of new solutions widely is quite difficult. The operating volume with different containers is approximately 200 000 units, which would require large investment in just hardware for a whole system implementation. Also, in case updates or small changes happen they need to be done to every single container, which can make the maintenance difficult. In the industry, different sensors are used to help in waste sorting, for example in identifying different coloured bags to separate different waste from each other. HSY says that it is still unclear if the sensors can be used to help in more detailed waste identification as the ones currently marketed are based on movement and not measuring material characteristics. If possible, the technology could be used in identifying for example different textiles which would enhance the pre-sorting operations of HSY.

HSY also mentions that there are some old systems, where digitalization could be used to help. The weighting system used in measuring material flows is from the 80s and the integration of the old system can produce difficulties in accounting. If new systems could be implemented easily to replace the old ones, new possibilities would open, but a large system change would need heavy investments, which are not currently needed. Development needs to move from data collection technologies towards data integration to enable combining old and new systems.

5.3.6 HSY: Digitalization in circular economy development

HSY sees that digitalization can have many uses when the technologies are developed further. On their behalf the unit costs of sensors need to sink to enable wide implementation to gathering information from containers. New technologies can be used to develop digital waste containers, which can smartly identify when they are full and inform data systems when they have been emptied. According to HSY this has already been piloted in Sweden. In an ideal situation a container could include sensors that report when its being filled, what it weights and keeps track of times when it is opened. At the same time the sensors would provide information on consumer behaviour. In addition to the smart containers, several other potential solutions in the industry can be identified.

One of the current challenges for HSY is finding out the location of usable and cyclable materials. Currently it is hard to identify what materials are gathered, where are they located and what are their volumes, which all are critical information in helping close the material loops. Digitalization has brought up many new marketplaces for materials, which are a step forward in local material management. HSY is also developing a material register for internal use to know locations of different usable materials and identify circular solutions for them. HSY explains that there have been different workshops to generate a unified material register or market for companies and organizations in the local area, but a clear solution has not yet been decided. It is unclear who has the responsibility in an area to generate the system and how would the management be handled. Development and maintenance of a system produces costs, which some organization would need to handle. To generate a unified system for all local operators, every party needs to cooperate and commit to the system for the implementation and use to be successful. A unified system could help the local material management and close the loops, but someone needs to take responsibility of it. HSY is in a good place to do that as they already are an organization that cooperatively provides services to four cities.

Customer behaviour and affecting the sorting methods, were mentioned earlier as critical challenges for further circular development. Digital technologies and data gathering could provide new answers to consumer interaction by providing information on consumer behaviour and their sorting methods. The gathered information could then be used to teach consumers individually and develop their sorting methods towards more environmental and efficient ways. A challenge in the implementation of smart cycling is that the consumers need to be reached with the smart technologies to teach the new methods to them. Interaction with the solutions needs to be made easily accessible to motivate consumers in trying the solutions. HSY explains that one example, which could be used without new technologies, would be to use QR codes to input recycling information to the products. Consumers could then scan the product with their mobile phones to immediately get information on how the product should be disposed of. A more technological solution would be to give instant feedback to the consumer on how they are sorting their materials, which would need a more developed solution and system. In the discussion HSY also points out that if the measuring of consumer actions is developed more, the responsibility of taking actions in sorting is transferred even more to the customer. Thus, the benefits of focusing in tracking the consumer behaviour might not have the intended outcome. New system implementations done directly to the customers might result increases in the costs, which could have a negative impact on the customers. For the new

solutions it is important to balance between the price and the benefit to make it worthwhile.

As an important note HSY also point out that, even though many of their action revolve around the consumers, they can't always be the center of development. All solutions and their benefits need to be evaluated from a larger perspective as changes might have a negative impact to the process in total. Logistics for example produce a large part of the costs and its environmental effects easily increase on behalf of consumer needs. In this regard the total environmental impact from waste sorting might be negative if the logistic costs are increased a lot to provide easy material management for consumers.

5.4 Case: Neste

5.4.1 Neste: Background

The fourth company included in the research is the Finnish biofuel company Neste, which is a forerunner in digital and circular development in the industry of renewable fuels. Neste has had many successful projects with new digital technologies and have gotten far in the digital development. The core business of Neste also revolves around sustainable values, which makes Neste a good fit for the current research.

Neste produces renewable fuels from waste and residue raw materials, by for example transforming nearly any waste fat or vegetable oil into renewable diesel. Using their chemical processes and material expertise, Neste can increase the value of waste, thus bringing previously worthless materials back to the economic cycle. Operating with fuels makes Neste a close operator to the transportation industry, which has been one of the focus areas of public circular economy discussion. Therefore, Neste is in a significant position to drive the development of circular solutions and innovations in transportation and fuel consumption.

Two interviews were conducted at Neste, which focused around the digitalization and new solutions of the organization. Both interviewees were working in sectors related to digitalization and IT development operations in the company. This means that both interviewees had great expertise related to the research subject and could cover all the important subjects related to the study.

5.4.2 Neste: Circular economy perspective

The values of Neste fit the core ideas of sustainability well and circular economy has an important part in Neste's operations. Neste's purpose is to create a healthier planet for

our children and one of the drivers behind the renewable solutions has been the need to come up with resource efficient solutions to maintain sustainability. This means that the core operations of Neste have a close connection to circular economy. According to Neste they have before been an oil-company, they are now an energy-company and they are on their way to becoming a fully operating circular economy company. Circular values can be seen to be a strong part of the operations and development of Neste as circularity has a strong role in their strategy. Neste explains that renewable innovations have always been a part of their core strategy, but they still have a lot do on the development of their material circularity. Neste sees that publicly circular economy tends to focus on emissions and energy, but material cycle is rarely talked about.

Generating renewable fuels is the most important business of Neste, which is simultaneously the most important circular solution Neste has. According to Neste they have other circular solutions as well for example related to the end-of-life processing of plastic materials, but for Neste renewable fuels are so significant that other circular economy solutions are easily left to their shadow. From the perspective of the circular economy value drivers the solutions of Neste focus in closing the material loops both in their core operations and in separate projects. Neste is constantly identifying and developing possibilities to utilize their knowledge in material flows to create value in the form of renewable energy. Neste explains that product life cycle management is also tracked and enhanced, which can be seen especially in the machines used with Neste's fuels. The machines are provided by Neste's partners, where the responsibility in PLM development is also divided to them.

Neste sees that there are three levels of development in circular economy business that a company can achieve, the levels being linear-, recycled- and circular operating. On a circular operational level, all the material flows of a service or product can be managed and maintained. Neste say that they are practically on the top of the recycling level, but still far on the side of circular economy development as currently there is nothing that can be done on Neste's behalf to cycle the fumes from vehicles. Still circular economy is widely implemented to all units in the organisation and it can be seen in daily operations of the company. Circular economy can be especially seen in the research and development sector and chemistry process development.

5.4.3 Neste: Description of the solutions

The circular solutions of Neste revolve around their expertise in chemistry and material processing. Using their knowledge on different materials for example hydrocarbons,

Neste can utilize their innovative solutions in varying material flows. The solutions revolve around life-cycle extension, where materials can be transformed to usable fuels, and closing the material loops, where materials can be transformed to new usable products. The operations of Neste revolve around different projects, which are constructed from identifying material flows where their expertise could be utilised. Through identifying suitable material streams Neste can develop the material outputs to fit the needs of the target ecosystem.

In lifecycle extension projects Neste aims to generate a manageable material process connected to a supply of waste material that they can use to generate biofuels. Neste then tries to develop the whole supply-chain process from the gathering of materials to the production and use of renewable fuels. In the process Neste gathers the waste materials and generates the chemical process around it, where the material is transformed to a fuel used for consumption. Neste then cooperates with machine operators to get the fuel available for consumers to use.

"*We can give another life to the CO2 (molecules). We take bad quality waste and make them consumable and then they are used and released to the atmosphere. We kind of double the use of a single CO2" – Interviewee 2.*

On the side of material loop closing, Neste names the development of bioplastics as one of the key examples. Similarly to the biofuel process, Neste tries to identify material flows suitable for further processing, where they could generate a circular supply-chain. Through Neste's expertise they focus in transforming the plastics to a reusable material, suitable for production, or new products usable by consumers right away. Neste says that they have the expertise for circular business, but these solutions are still quite new and need to be developed further. In material loop closing, Neste would need to take a continuous part in the circular supply-chain process and find fitting markets or customer needs for the renewable products they can generate.

"I think this is the first time we are actually doing circular economy… I consider the renewable fuels still a part of recycling as we can't affect what comes out of the exhaust pipe (in a car)" – Interviewee 2.

5.4.4 Neste: Circular economy business

Neste's business and circular potential revolves around their knowledge on chemical processes. The company is so far in the chemical development that they can generate high quality materials from pretty much any fat, which is also their largest competitive edge in the renewable material markets. The generating of ideas for renewable solutions

began in a “start-up-style”. At that point the focus of renewable business was around belief and testing of new innovations and ideas, which has afterwards developed to be the core of Neste.

Circular economy has also been implemented to the strategy of Neste, which is also partly driven by the customers. The aim of Neste is to be proactive around the trend and minimize their own as well as their partners’ environmental effects. The solutions of Neste are generating benefits to the whole material chain as they are generating business opportunities that benefit all the cooperative parties. The providers of the waste material get a solution for managing their material outputs, Neste gets a chance to utilize their knowledge by producing renewable materials and fuels, which can be sold to consumers to generate revenue, and 3rd party operators get customers for their fuel pumps and their parts. In addition, all the organizations participating in the process gain a positive brand impact by developing and managing a sustainable solution in the eyes of consumers.

Neste points out that development of waste material businesses also may have a critical downside if the industry develops too much. Currently the business solutions are driven from the value increase generated to materials not needed by the operators who are producing the waste. The business aspect of value generation to waste has the risk to increase the value of waste material. If the value of waste material increases the material markets may introduce new competitors in the field in the form of waste producers. In the development of the circular markets the values of sustainability and environmental development need to be remembered for the development to be environmentally beneficial.

Neste also mentions that the development of circular economy comes partly from legislative pressure. The changes in legislation can force companies to develop their operational processes towards a more sustainable approach. Increased focus in the material flows can result easier identification in the possibilities to close material loops. Neste says that politicians have a great responsibility in affecting the way circular economy develops. Consumers often make decisions based on public discussion and influencers, which give them significant possibilities to affect consumer behaviour. In the end consumers have the power to decide, which solutions succeed, and which fail.

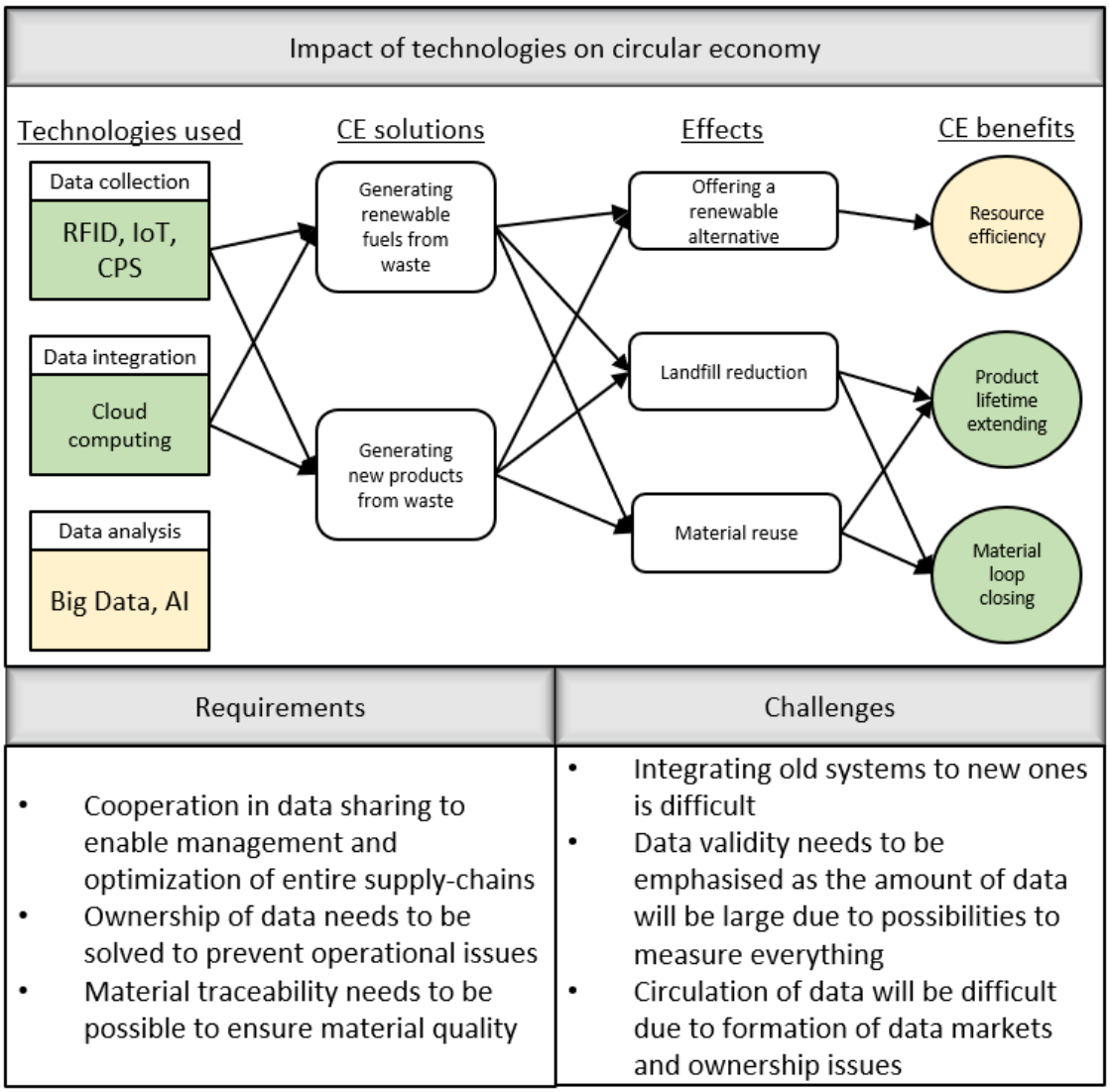


Figure 22. *Neste: Circular economy impacts of digital solutions*

Neste has developed far in utilizing their technologies and are already using data collection and integration technologies. Data analysis solutions are being piloted, but they are not yet fully utilized in circular economy. The solutions benefit all the circular value drivers and according to the results the product lifetime extending, and material loop closing are benefitting the most.

5.4.5 Neste: Utilization and development of digital solutions

As presented earlier, the basis of Neste's solutions is in chemical expertise, which means that digital solutions aren't the real driver behind their operations. Yet, the digital solutions have a significant impact to Neste's business and the development of the company during the recent years. The effect digitalization has in increasing operating efficiency is

important to Neste and they enhance that digitalization enables remarkable possibilities for process optimization.

Neste is quite far in digital development compared to other organizations in the study. On the level of digital technologies Neste is currently widely utilizing the data collection solutions and have shifted their focus towards the development of data integration and analysis technologies. Neste say that they still need to gain more knowledge on the analysis technologies before wider implementation of technologies can be done. Also, the basis for utilizing the data analysis tools need to be available and thoroughly implemented. This is done with the data integration technologies. Neste mentions that cloud technologies, big data and machine learning are constantly discussed, and their development is eagerly followed. Additionally, AI, Blockchain and CPS are still mentioned as technologies that are still in testing and piloting phases and just coming to wider use. Neste says that they see no reason why they would not try new technologies and want to keep up with the digital development.

Neste mentions that cloud computing and the data storing elements it provides are currently the most important technologies for them and provide access to several new solutions. With the technical and digital development, the prices for calculation capacity and data storage have become so low that it is today profitable to use them. Before the prices and need for investments were so high that the technologies weren't worth the costs. Neste said that before the current new solutions, there was no data or any capacity for it – now we have both. Cloud computing provides the capacity needed to utilize the benefits of data gathering technologies by providing platforms to store, integrate and utilize the massive amounts of data gathered. This enables the use of big data analytics and machine learning technologies in large scale. Still Neste points out that this is something no one has still yet done, and the frontrunner implementers are only soon getting there.

As lot of the solutions described earlier include the creation and management of a sustainable supply-chain, the digital solutions bring several solutions to cooperative operating methods. According to Neste the digital technologies are a big help in optimizing and mapping the supply chains. Ultimately the most beneficial goal for Neste in the perspective of business generation as well as circularity, is to be able to manage and optimize whole supply-chains from the beginning of material flows to their end. This requires the utilization of the new technologies to allow the management of the whole process through data gathering, -integration and -analysis. The amounts of information that are needed from production lines are massive and they can only be handled with the cloud technologies. With data solutions, the decisions to optimise maintenance processes can be made and resource efficiency can be increased. Additionally, Neste mentions that in the

future AI solutions will play a big role in helping with process analysis done in the supply-chains.

In the perspective of digital development in the whole supply-chain process, Neste is in a position where they can't necessarily affect the development of the whole process. In the renewable fuels Neste isn't necessarily the manufacturer of all the machines used in their processes as they may be provided by third party operators. If Neste want to implement their solutions to their stations, the development may need to happen from their machine suppliers' side. This means that the requirements to develop new technologies for example in IoT, is on the side of the suppliers. Neste says that the development is also happening on the suppliers' side as they as well want to develop their own products and service possibilities to retain a competitive edge, but Neste can't directly affect it.

5.4.6 Neste: Digitalization in circular economy development

Neste sees that there are several possibilities how digitalization can drive circular economy, but on the other hand there are several global data related issues that need to be solved. Neste says that with the basic methods and technologies we can only gather historical information. Moreover, we should aim to see to the future, which is why AI is also one of the most followed technologies of Neste. We need to be able to combine and utilize data, which allows the use of AI technologies. With the current technologies we have already enabled the availability and capacity to data, which are giving an opportunity for AI development. Through AI development we can model the future and develop optimized data and operative processes, which can change whole working methods radically. The data driven optimization of manufacturing processes allows the cutting of manual work, which Neste says to be one of the most important goals of digitalization. Reducing manual tasks, allows to shift the work capacity and tasks more towards development and analysis focused tasks, generating more value for the organizations in the form of development resources.

Neste implies that through data management, especially closing the material loops will become easier. When we know what we have and what material needs customers have, we can straight away create end-to-end material chains, where both need and demand can dynamically meet. To optimize the whole material closing process information from the whole material chain is needed. According to Neste all discussed technologies are needed for the best result. Neste says that every company should be able to close their own material loop, as that is the way the market of supply and demand can be formed. Digitalization is needed so that all the operators can join the material market and find the partners to cooperate with.

One of the key problems that Neste points out in the discussion will be the circularity of data. The circular solutions and therefore the benefits require open data sharing in co-operation with organizations that try to form closed material loops. When the data technologies develop the data markets and the asset nature of data comes even more into play, the ownership of data needs to be clear. Circular solutions require cooperation in data management, especially to keep up the processing data related to materials in the form of material specifications and quality characteristics. The data markets might produce a problem for the collaborative operation, if the ownership and transaction procedures of data aren't designed clearly. The asset nature of data can also easily introduce payments to the data sharing.

On a circular economy perspective Neste says that material traceability will be important to gain knowledge on the quality of the material. Quality factors can have an important effect in material processing and manufacturing by affecting the end products. Digital development has a clear impact on the traceability as data gathering can allow the quality control to be managed. The functions at the beginning of the material process need to change to utilize the data storing of new used materials and data analysis of incoming renewable materials. Neste acknowledges that in material traceability blockchain is an important technology that allows data sharing in a reliable way.

Neste says that in a world where data can be infinitely gathered, the importance of data validity comes into play. Even though all data can be gathered companies need to identify the important data to be gathered and used for analysis. As an important data type Neste mentions the data on customer behavior, which could give new ideas for research and development. Based on the customer data, the solutions could be designed to fit the customers' needs even better and Neste could also use the data to analyze and teach consumers toward more circular behavior.

Neste notes that the digital solutions are still missing methods to efficiently integrate old systems to new technologies. Many organizations have ancient systems which they use for data management, whose developers may have already retired. The problem is how the new technologies can understand the functions of the old systems and import the most important features to new solutions.

6. SUMMING UP THE RESULTS

This chapter contains the comparison and analysis of the results in the study. The chapter focuses on delivering answers to the research questions presented in the introduction. The subchapters are divided based on the research questions so that questions one and two are answered in chapter 6.1, question three is answered in chapter 6.2, question four is answered in chapter 6.3. Additionally, the themes that were greatly mentioned in the research but were left to a smaller importance in the results of the study, are also discussed.

6.1 Impacts of digital solutions

The study included four organizations that were researched as four different cases. The organizations were chosen so that the results and knowledge gained would cover a wide range of solutions on how digitalization can support circular economy. The four case companies and their characteristics are described in table 3.

	Hilti	**Ponsse**	**HSY**	**Neste**
Most important technologies	Internet of Things	RFID, IoT, Data integrating technologies	Internet of Things	Cloud computing
Level of digitalization	Data collection	Data integration	Data collection (piloting)	Data analysis (piloting)
Circular economy focus area	Resource efficiency	Product lifetime extending	Material loop closing	Product lifetime extending and Material Loop closing
Benefits of solutions	Material and product management	Spare part services and remanufacturing	Effective material processing	Development of material processes

Table 3. *Case company characteristics*

In the interviews the case organizations listed the most different digital technologies that they are using and assigned their organizations to the scale of digital development from implementing data collection technologies to mastering data analysis technologies. All

of the organizations had proceeded with digital development, but the scale of development status was quite large. HSY is in the early stages with their digital development and when compared to the development level of Neste, the gap between the two organizations is large. As many of the organizations are still in quite early stages in digital development, the most important technologies focus around data collection technologies. Most of the applications and new solutions are still being developed in this area and Neste and Ponsse are the only organizations that have developed further solutions. On the perspective of research, the solutions introduced heavily focus around efficient use of data collection technologies as the companies have developed them the most. Data analysis and integration technologies are on the other hand only introduced in 2 organizations.

Neste talks a lot of the importance of cloud technologies and their possibilities especially in enabling the implementation of data analysis technologies. Cloud technologies is a necessity in the digital development and the solutions the technologies provide seem to revolve around enabling new solutions. This means that cloud computing, as an individual technology, does not provide an impactful solution towards circularity.

The organizations are focused on different circular economy drivers, but still the same technologies are brought to discussion in the interviews. Internet of Things can be identified to be a common and most important technology that all the organizations identify to have many solutions and a large impact on circularity development. Therefore, the technology can be seen to enable solutions around the whole circular economy industry. The discussion around the importance of data management and new solutions that data gathering provides, supports the theory of the benefits of digital solutions presented in chapter 3.3.

The impacts of digital technology can already be seen in all different circular economy value drivers. To better understand the connections between technologies and circular economy effects the different impact streams are evaluated in chapters 6.1.1 – 6.1.3. The subchapters also answer research question two on the effects of digital technologies in circular economy.

6.1.1 Digital solutions promoting resource efficiency

Benefits in resource efficiency focused heavily to data collection technologies and include a single benefit provided partly by data integration technologies. There were many benefits that could be identified in the area, which either indicates that the organizations have heavily focused on resource efficiency or the solutions are quite easily imple-

mented. Most of the solutions introduced in the interviews focus around traditional resource efficiency by reducing the material consumption with an aim to reduce material costs. From the cost perspective resource efficiency is already traditionally implemented to common business sense, which can be one of the reasons why there have been many different and easy implementations to enhance resource efficiency. On the other hand, solutions including material choices and using more circular and sustainable materials are not heavily mentioned. The different material choices offered by Neste in the form of fuels are the only solutions that does not focus on efficiency. The data provided solutions seem to be focused on just optimizing resource use and keeping track of them to enable efficient material management. Hilti's solutions are focused around resource efficiency and they can be heavily identified from figure X below as their solutions help customers in material management and cost savings.

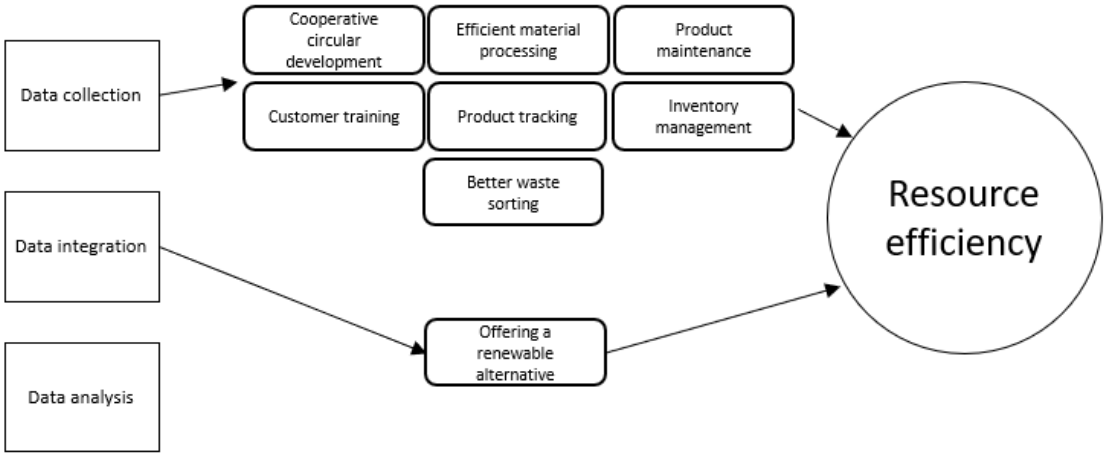


Figure 23. *Sources of resource efficiency benefits*

Customer training is an important method in resource efficiency improvement, and it provides a new look to resource efficiency development in the form of an indirect solution. The customer training is done especially at Ponsse by training their customers to use their machines efficiently. The aim in the training is to teach the drivers to spend less fuel by adjusting their operating habits. Thus, less fuel is consumed, customer has less costs and Ponsse's machines gain a competitive advantage as efficient machines with lower operating costs. Ponsse doesn't reduce its own material consumption but the actions have a large impact on customer resource consumption. The customer training is made possible by data collection on driving habits.

As can be seen above. The resource efficiency solutions focus heavily on the data collection technologies and the amount of different solutions is high. This is due to the large

investments and development on data collection side. Resource efficiency solutions on data integration and analysis side are still to be seen.

6.1.2 Digital solutions promoting product lifetime extending

Solutions benefitting product lifetime extending can be seen to divide among data integration and data collection technologies. Compared to resource efficiency solutions, data integration and cloud technologies have a clear impact on extending product lifetime and create new solutions for circular economy. Material reuse and landfill reduction are related to solutions of Neste, where data integration is an important part of creating the solutions and managing the information flows with several cooperating operators.

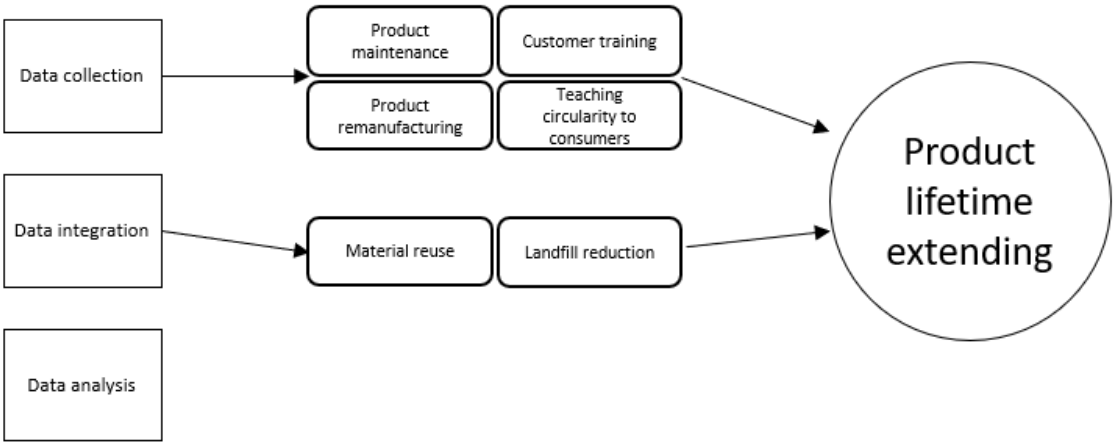


Figure 24. *Sources of product lifetime extending benefits*

The rest of the effects come from product maintenance and remanufacturing. The focus areas and solutions of Ponsse can be identified from the figure as they are the only organization in the research that are applying remanufacturing practices to their operations. Product maintenance and product remanufacturing can be seen as good ways to extend the lifetime of products, but the business models of the solutions need to fit the practices of the company. For Ponsse and their values, the operating model fits them well and they have made it a worthy option both for the organization and their customers. Other organizations need to think the business aspect and profitability in solutions to enable efficient remanufacturing without risking their own operations.

In a similar aspect to resource efficiency, customer training is seen as an important effect promoting circular economy. By affecting the customer in using the products correctly and implement regular maintenance procedures to preserve the good quality of them,

the customers themselves can extend the lifetimes of products. Additionally, the customers perception on circular economy can be affected by showing them the effects and benefits of remanufacturing. This should promote customers to support remanufacturing processes themselves.

The data collection technologies are enabling efficient remanufacturing solutions, which are the first step towards additive manufacturing. Additive manufacturing isn't widely implemented yet and Ponsse for example tells that they are focusing in developing towards additive manufacturing. Achieving additive manufacturing solutions seems to require further development in the level of digitalization and the implementation of integration and analysis technologies. Through digital development additive manufacturing should be seen as an important driver of circular economy through extending lifetime of products.

6.1.3 Digital solutions promoting material loops closing

In effects towards material loop closing, the missing of data analysis can also be seen. This indicates that the data analysis technologies have not yet widely been implemented and the effects of data analysis on circular economy are still unclear. Otherwise, the sources of circular economy benefitting effects are divided similarly to the technologies benefitting product lifetime extending. On data integration side the same effects can be identified, and their role in enabling the material loop closing projects of Neste is crucial. Sharing information and integration the different data sources helps operators to generate material flows from a material provider to a material processor.

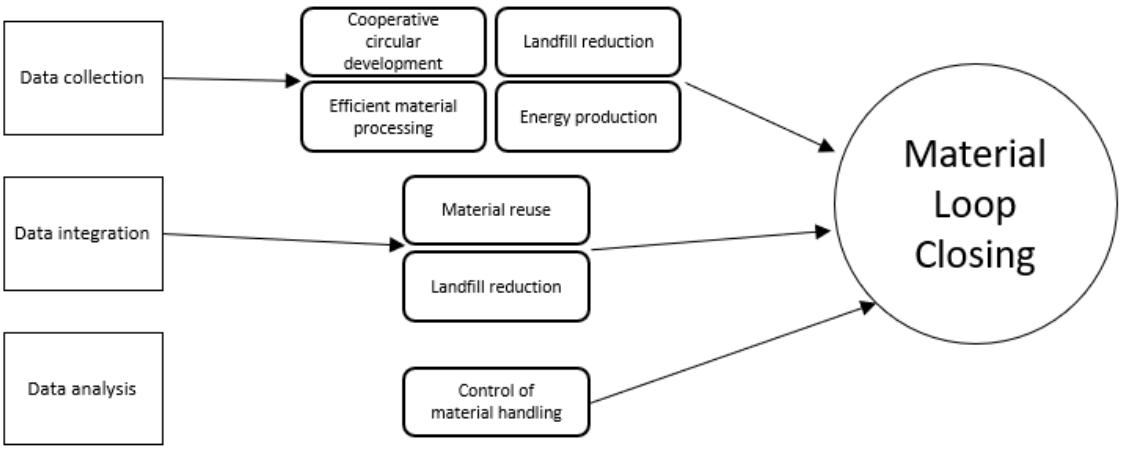


Figure 25. *Sources of Material loop closing benefits*

The other solutions in the area are related to cooperation of different operators, which is enabled by collecting and managing the material related data. The use and importance

of data solutions can be identified as a key component in HSYs solutions where the material is processed between two operators. In HSYs process the volume and operating efficiency need to be measured precisely to manage the material loop closing process with large material volumes.

Additionally, control of material handling is identified as a solution promoting material loop closing, but as seen in the figure, it isn't enabled by any of the digital solutions. The effect is produced by Hilti's asset management solutions, where Hilti rents tools to customers. As the owner of the tools, Hilti can manage the material flows after the tool is being used by customers and decide themselves the next place for the materials. Instead of a digital technology, the solutions are driven by servitization opportunities of Hilti, which on the other hand are driven by digital development.

The amount of loop closing solutions is still quite small and the effect of data analysis technologies still remains unseen. According to Neste's discussion on the wide possibilities of data analysis technologies and the effect they bring to managing large data flows and material chains, the effects of analysis technologies should increase crucially. This indicates that, when further development can be seen in the technologies the three figures and the new solutions should be shifting from resource efficiency even more towards new solutions in material loop closing.

6.2 Requirements and challenges for implementation

This chapter gathers the theory- and interview-based findings on requirements and challenges that were identified in the research. The results are compared by matching the identified factors found on both sides and the analysis is done based on the results of the comparison. The analysis done on figures 26 and 27 aims to answer research question 3 on requirements to implement digital solutions and circular economy.

Figure 26. *Requirements*

Figure 26 includes the requirements that are needed for implementing circular economy driven by digital solutions. The theoretical findings were introduced in figure A and the results gathered from case research were introduced on each framework of the cases. All the results identified in the literature were also introduced in the discussion during the interviews, which indicates that the theoretical background and the interviews have been on the same page of the industry discussion, which strengthens the validity of the information.

Additionally, there are many new findings that were not discussed. The characteristics of the different case companies behind the results can be quite clearly identified as Hilti can be seen in the large transformation process towards servitization, Ponsse in reverse logistics, HSY especially in consumer decisions and Neste in data ownership and material traceability. The different requirements that are shown may not be generalised as they describe the requirements for different types of circular solutions. Yet, they all bring new elements to the discussion of digitalized circular economy implementation. All the identified requirements can be seen as important parts of wide circular economy solution implementation, but for smaller scale solutions the requirements should be evaluated based on the circular economy value driver that the solution supports.

Figure 27. *Challenges*

Figure 27 includes the challenges and barriers for digitally supported circular economy implementation based on the theoretical findings and case research. The theoretical findings are presented in figure B and the results gathered from cases are introduced on each framework together with the case materials. In comparison to the requirement results, the results on challenges and barriers differed heavily between the theoretical and case-based findings. The matching requirements that were found, related to the large amount of investment, old system integration, uncertainty and data ownership. All the factors mentioned above are quite close to each other as overcoming them requires risk taking or development of something entirely new. Large transformation processes are often difficult to manage, which can reduce the interest to pursue circular economy implementation processes.

One of the reasons for uncertainty is that the succession of new solution implementation is hard to be calculated. On the other hand, the technologies that help in investment, decision-making and data analysis are further away in the levels of digital development. If the investments are never made, because of poor basis for decision-making the analysis technologies that support decision-making can be hardly reached. Organizations need to take risks to implement circular solutions and through organizations like Hilti, Ponsse, HSY and Neste others can be encouraged to do the same. It is important that forerunners, who can show that the risks are worth taking, exist.

On the figure, it can be discovered that the theoretical findings and research results differ a lot from each other. Apart from single notices like cybersecurity the theoretical findings are focused on circular economy challenges and the case research results are focused on enabling the digital technologies. The theoretical findings include sources that are specifically interested in the challenges encountered in circular economy processes, which is why the circular economy values easily come up more in the circular economy side. The fact, why the same problems are not discussed on the organizational side is harder to explain. The companies may not see large problems on circular economy implementation, the digital solutions may be seen as the real solution for circular economy, which is why it is emphasized, or the main reason behind circular economy can be seen to result in from the consumers who either drive or don't drive the change.

Some of the challenges and barriers on both sides are factors that the organizations can't solve themselves and are either totally unsolvable, like physical limitations and the laws of nature, or wait for the industry to develop the practices, for example in data ownership and industry working methods. Still most of the challenges are solvable and require new knowledge and technical development. The challenge for finding top experts gives an important perspective to the discussion as when top knowledge is needed for implementation not all organization can acquire it at the same time. This brings a new competitive approach to the discussions as the focus of circularity may shift from a cooperative development towards competitive advantage. The competitive shift might also have a positive impact on the market by forcing the companies to develop their circular capabilities to keep up with the competition. The end results of issue cannot be predicted, but the circular development can clearly have a large impact on the different industry markets.

The challenges differ based on the digital level of development and the resources available for a target organization. Yet, the challenges identified can be overcome and through developing the knowledge both on circular economy and digital solutions the industries can develop their cooperative availabilities at the same time. The circular level that can already be reached without direct solutions to data ownership can already be very high, which gives more time for a wider digital development on the sides of data marketing and cooperative management practices.

6.3 Future implications of digitalized circular economy

The fourth research question of this study focused on the upcoming changes in the areas of circular economy and digitalization and how the companies expect the changes to affect their industries. The subject was discussed as the last part of each case interview

with the aim to find out how the companies perceive the development of digital circular economy to shift and what are the most critical technologies to keep an eye on. The key areas mentioned by each company are gathered in figure 28.

Several repeating themes can be identified from the findings. As a logical finding, the data analysis technologies are pointed out as a key area in future development as companies are trying to develop towards it. Some of the companies have already reached the piloting point of data analysis services, which indicates that larger implementation can be predicted to happen in the upcoming years. The advantages of data analysis technologies have also been pointed out multiple times both in the theoretical and empirical findings, which supports the argument that data analysis solutions will have a radical impact in the field. The analysis services are seen to have large potential, but larger implementation remains to be seen. It is understandable that companies want to keep up to date to interesting technologies as they have a chance to change their operations remarkably.

Customer information is also seen as an important factor, as being able to gather data on customer actions, enables access to more efficient customer interaction and service business operations. At the same time gathering customer data can be used to help customers in operating products more efficient. As mentioned in the interviews, it is difficult to reach and affect consumers, which is why digital technologies and customer data could be one of the pathways to both teaching consumers and affecting their behaviour.

In the field of extending product lifecycles, preventive maintenance is the key technology to greatly increase efficiency and help maintain products in operation. With preventive maintenance companies refer to being able to identify the ending point of product lifetime already beforehand through analysing data on product usage. By predicting the need for spare parts or new products, operators can plan the spare part or product delivery ahead to keep the customer fully operational. Preventive maintenance has increased interest especially in product-based companies, where increasing the quality and efficiency of the products are key factors. Implementing successful preventive maintenance processes can give a company large competitive edge through better customer experience, quality control and material optimization.

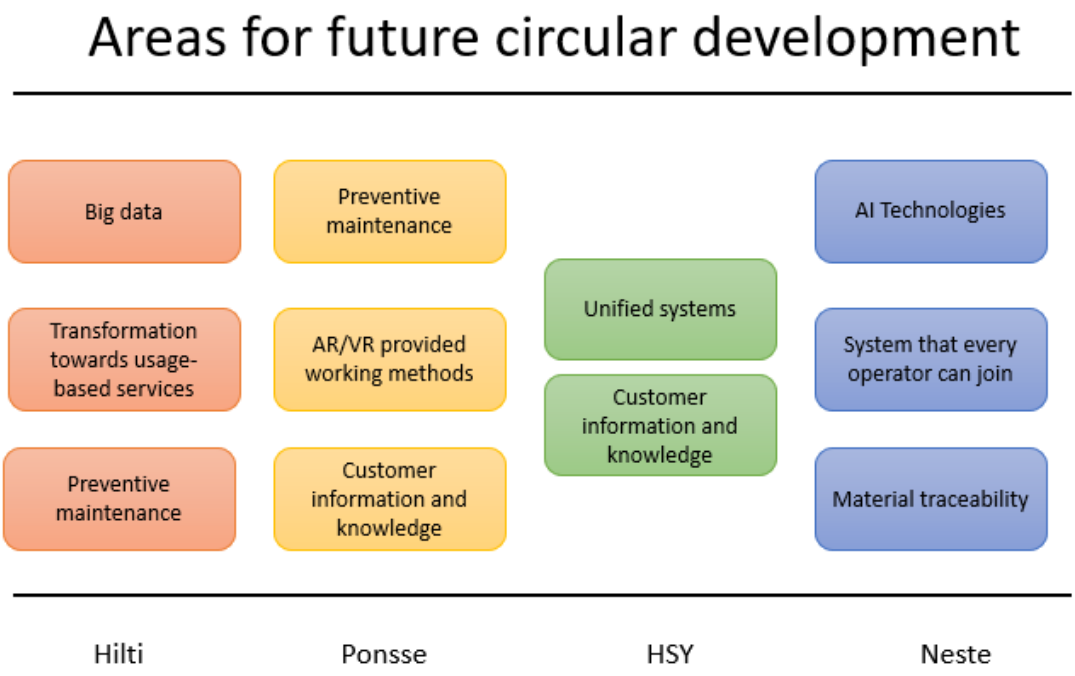


Figure 28. *Key Areas in future circular development*

As the fourth identifiable factor, the unified or cooperatively operable systems can be pointed out from the results. In order to achieve efficient and cooperative operations in controlling material flows, the systems of the process operators need to be easily synchronisable to make cooperative operations an appealing choice for material flow development.

7. DISCUSSION AND CONCLUSION

This chapter evaluates the meeting of the objectives of the study and introduces theoretical and managerial implications that were identified from the research results. The introduced implications are factors that are valuable to be further investigated either from a research perspective or from an organizational development perspective. At the end of the chapter the quality and the limitations of the study are assessed, and future research subjects derived from the current research are introduced.

7.1 Meeting the objectives of the study

To evaluate the success of the study, we evaluate meeting the objectives of each research question separately. The first main question of the study was: "*Which digital solutions and technologies can support circular economy?"* The aim of the question was to be able to identify all the important digital technologies that are used with circular economy solutions. The different technologies were identified from available scientific written material and from the interviews on Finnish organizations working with circular economy. As a result, the identified technologies were gathered to 6, where three main technology categories were identified. Later the interviews confirmed the identified technologies to be the most important ones in the field and supported the introduced categorization. Additionally, the categories could be shown to function as development stages of digitalization. The interviewed organizations could identify their own status of digital development, which is shown in table 3. The objective of the first research question was met well with a clear visual result for the research question.

The second main research question was a continuation to the first research question defined as: *"how can the digital technologies benefit circular economy?"* The aim of the question was to be able to identify clear methods, sectors and effects that the technologies have on circular economy functions and solutions that drive them forward. The benefits were analysed based on the three value drivers of circular economy and how they support them. First the theoretical findings were gathered into figure 9 and the correlation between the technologies and value drivers was used to structure the framework used in analysing data from interviews. The technologies their benefits and their relation to circular economy value drivers were identified and presented visually for each research case and each value driver. The objective of the second research questions was met well with clear indications on which value drivers the different technologies are supporting.

The third main research question was: *"What are the challenges and requirements for implementing digitalization into circular economy processes?"* The objective of the research questions was to identify the most important factors that affect the implementation of digital solutions in order to better understand the barriers, problems and solutions in the process. The challenges and requirements were researched both from theoretical findings and data from interviews. The challenges and requirements had some similarities with both data sources, which confirmed that the organizations and theoretical sources had reliable information. Additionally, the interview data brought up several new findings that were not mentioned in the scientific material related to the subject. The findings and the differences between the data sources are introduced in figures 27 and 28. The objective of the research question was met well, by finding both similarities and new important factors to support the existing research information. The findings are also used in the theoretical and managerial implications of the research.

Additionally, a fourth research question was included in the study to find out the development trends and future directions of the area. The question was defined as: *"What are the expectations for digitalized circular economy development?"* The upcoming changes and directions of the circular economy development were researched only based on the research cases and the interviewees' expertise on the subject. The interviews introduced several focus areas that the organizations believed will be important in the near future either for themselves or for Finnish circular economy solution development. The key focus areas are introduced in figure 28. The presented findings are important for the future research areas on digitalized circular economy and bring an important side to the scientific discussion from the organizational point of view.

Altogether, the research included information from theoretical findings on digitalization in circular economy as well as four interview-based cases from Finnish organizations working on circular economy solutions. All of the questions were answered with results from high expertise on the subjects and new relevant factors were discovered in relation to every research question. Due to finding relevant answers to all research questions, the research can be seen to have been successful.

7.2 Theoretical implications

The research area in the study covers two topical and critical phenomenons that are seeing an increased interest on both the side of researchers as well as organizations. Both topics are critical as individual subjects but the research on the supporting elements between the two is developing constantly. Due to the lately rising interest and potential in the subject, most of the research material on the area have been written during the

last four years. Due to the new rising of the subject, new information, discoveries and theories are introduced constantly as the discussion around the topic evolves.

The importance of the introduced study revolves around the small amount of empirical evidence on digitalized circular economy as the previous studies have heavily focused on theoretical implications. The case interviews on the subject introduce new findings to the scientific discussion by clearing the picture on the mindset of organizations and how they perceive the development of digital solutions and circular economy, or if any correlation between the two even exists. One of the key findings in the research can be seen in the development status of digital technologies from the organizational side. Even though the theoretical evidence highly anticipates different uses and solutions for data analysis technologies to current status of most of the companies is still in the implementation of internet of things. This is a clear difference between theoretical and empirical findings as hypothesis and results don't seem to meet.

This research has developed the understanding on existing findings and discovered new important factors to support several existing researches related to circular economy and digitalization. The categorization and listing of critical digital technologies in circular economy context develops the earlier findings on digitalized circular economy (Lenka, Parida and Wincent, 2017; Pagoropoulos, Pigosso and McAloone, 2017) by introducing the development status of digitalization to the framework. The findings on the important role of public sector and consumer behaviour improve the understanding on the bottom-up model (Lieder and Rashid, 2016). Also, the empirical results on the benefits, requirements and challenges of organizations working with digitalizing circular economy complement the earlier research on the subject (Ellen MacArthur foundation, 2016; Bressanelli *et al.*, 2018b; Jabbour *et al.*, 2018) by confirming their findings, theories and frameworks with interview data.

The research also included several topics and factors that had a large focus on theoretical side, but eventually did not have any impact on the expert discussions or interviews. 3D-printing appeared heavily in the theoretical material (Prendeville *et al.*, 2016; Zhong and Pearce, 2018) as an important technology to develop circular economy. Despite the large amount of research focus around 3D printing in context of circular economy, the technology didn't come up in any of the interviews. This might be due to the issue that it is not easily perceived as a digital technology. Additionally, augmented reality (AR) and virtual reality (VR) technologies were mentioned in the literature several times (Bressanelli *et al.*, 2018a; Nascimento *et al.*, 2018; Stock *et al.*, 2018; Yang *et al.*, 2018), but from the interviews they only appeared to have upcoming uses in the future as implicated by one of the case companies.

7.3 Managerial Implications

The managerial implications include the findings of the researcher that could help the cooperating organizations to develop their operations based on the conducted research. The implications presented have been made on analysing only a small part of the organization and are focused only around the subjects covered in this study. The implications should be only applied in circular economy and digitalization related discussion and development and perceived as a result of a study, without knowing the thorough situation or history of the interviewed organizations. Figure 29 introduces implications for the participating companies for driving the development of digitalized circular economy forward. The implications were formed by the researcher and are based on the operational strengths and competitive edges that the organizations introduced during the interviews.

Hilti

Hilti is a great example of an organization that has taken the potential of digitalization into circular economy and has created a great solution to support circularity through daily operations. Hilti has great access and potential to develop an industry that is critical in the context of circular economy as material management problems are heavily present in construction projects. Currently Hilti has a great view to the industry and is already close to the operators. To further develop the circular approach and utilization of the technologies, there might be further potential to apply the digital solutions to other areas in the construction business for example helping the operators to manage the waste from demolition as part of other operational services.

Ponsse

For Ponsse the most potential for development is in preventive maintenance as the company has great foundations and existing operations that support it. The technologies that are needed for preventive maintenance already exist and are in use with other companies, which means that the development towards the utilization of those technologies is possible. The solutions fit the values of Ponsse and their customers well and might have revolutionary effects on the area of circular economy, if the solutions can be applied efficiently.

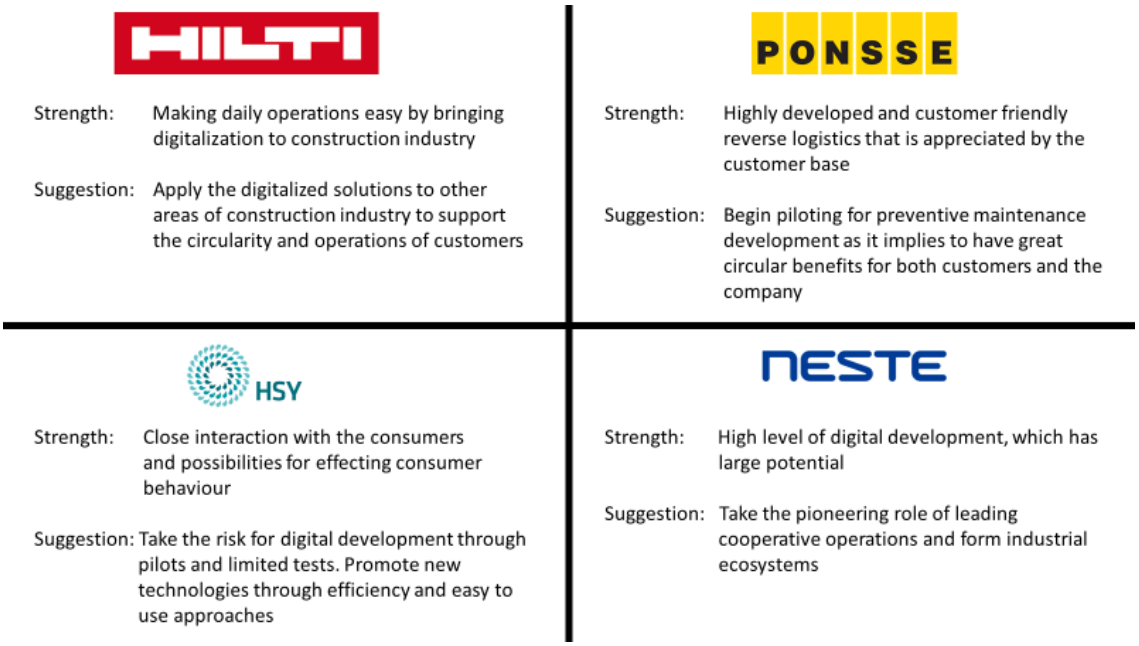


Figure 29. *Managerial implications for case organizations*

HSY

HSY has an important role in developing the circular processes from the consumers side and they have great possibilities for that as they are operating very close to consumers. As said in the interviews, HSY has had several pilots towards utilizing digitalization in their processes, but the wide implementation and constantly developing solutions present large challenges. In order to take steps in digital development the solutions should be applied in a limited test area where they would have the most impactful effect, to see the benefits. Sudden changes in services that are applied to consumers daily routines might have a negative effect and get a bad approach, which is why the change needs to be done with simple steps and by promoting the benefits of new solutions from a consumer-friendly approach. For example by promoting the easiness of new sorting solutions, the consumers might be reached better. The solutions have great potential and they may be easier to implement them through small changes as large transformation process can always be a risk.

Neste

Out of the four case companies Neste is in a quite unique position as they are clearly on the highest level on digital development, which is why they also have the possibility to challenge the theoretical benefits of digital solutions that have already for quite long been pointed out. The development and applying of data analysis technologies must be an

important goal for Neste as the effects of utilizing the potential on technologies that only a few other organizations possess provide a great competitive and operational edge. In a circular economy context, the access to the higher-level technologies can give Neste a good position to promote and apply the solutions to cross-organizational solutions and promote the forming of circularly efficient industrial ecosystems.

Additional implications

The implementation of digital technologies is an implementation process with many challenges and requirements, which leads to competing with many operational risks. Developing operations to the implementation of data analysis technologies can be a good goal with many benefits, but for most of the organizations a data analysis level development is not required to implement digital solutions that benefit circular economy. When developing digital solutions as part of circular economy, organizations need to first identify their current level of development and secondly identify which are the most useful and potential technologies to work towards. Organizations should focus on single technologies that support their cause to develop their digitalization level systematically towards the next stage of development. Doing development on the side of all different available technologies produces an unnecessary financial risk, which can be avoided by clarifying the objectives for development. The development of new technologies should always include a clarified roadmap, where the different steps of development can be identified and processed.

Even though many of the technologies might seem distant and feel like a large risk, the transformation towards a new technology does not necessarily need to be large and the technologies may be even more obtainable than they sound like at the first glance. As can be seen from the case interviews some of the organizations have already implemented especially data collection or data analysis technologies, which indicates that those technologies are already available for applying. For example, in the cases of developing preventive maintenance, companies should research which technologies need to be implemented for the solutions to work and are those technologies already accessible. Due to some organizations already using data integration technologies, the data collection and integration technologies required for the first stages of preventive maintenance could already be developed.

Even though the development of the digital technologies would not seem necessary, all organizations should start to implement digital solutions to their operations even with small and easy steps. The digital development of organizations, operations and markets

is constantly moving forward and the further an organization gets from an industry standard, the larger the transformation process. Also, by implementing small digital development processes, the expertise in the organization grows and the applying of new systems and methods can be done easier. By implementing the early development stages of the technologies already now, foundation for applying data integration and data analysis technologies will already be there when the technologies become more accessible.

The digital transformation and applying new technologies to existent requires courage and big steps from organizations, but as can be seen on the interviewed companies, the risks of the transformation processes are worth taking. The new methods and possibilities provided by digital solutions are more efficient and offer revolutionizing ways for operation. In addition, they are a requirement for continuous development and should be implemented to the long-term development of most organizations who want to stay in the industrial development both competitively and environmentally.

7.4 Assessing the quality and limitations of the study

The conducted research was done with a broad range of material. The ground of the study was done on gathering information on scientific literature on the area. The material focused on publications made during the recent four years, which indicates that the material used was up to date and the questions addressed in the study are important for current research on the area. The empirical focus of the research was on Finland and four organizations with different circular economy focus areas were chosen for the research. The interviews were held in a two months period. The results give a narrow perspective to the circular economy solutions of Finnish organizations and their development through digital solutions. The results are barely generalisable on a wider level, which is typical for a multi-case study (Gable, 1994), but are valuable for the research and understanding of the subject on a local level. All the differing factors should always be considered when applying the results to other organizations.

As the covered subjects can be directly related to the competitive advantages and new research and development opportunities, the interview results can be somewhat seen to include some bias. The organizations might have a strict policy of keeping important development items or expertise as secrets. The same effect can be seen in discussing negative effects or subjects as insight into those matters is hard to be obtained through interviews. Members of an organization rarely want to tell negative facts about their company, which is one of the reasons why most research data gathered gives a positive feeling of the case organization. In addition, the answers from the case companies are

based on only a few experts, which can result in some of the interviews including personal opinions on the covered subjects. To reduce the risk of personal opinions affecting the research data more interviews could have been conducted. The conducted research was done in a limited time frame, which is why the small number of interviews was suitable to fit the schedule of the research.

The interviews were done as semi-structured, where a script was used as a basis for discussion. In order to keep the quality of the research data high and trustworthy, the interviewer must be as objective as possible. The interviewer can guide the interviews, which can result in biased results in the interview data. To reduce the effect of interviewer guiding the answers, the scripts of the interviews were sent to the interviewees beforehand for preparing their thought for the interview. Before the analysis the results of the interviews were written to chapter 5 by the researcher based on notes taken during the interviews and tapes that were recorded from the interviews with the interviewees permission. To improve the quality of the results and reduce the misunderstandings of the researcher based on the interview sessions, the written texts from each case were sent to the interviewees for comments. This way mistakes were corrected from the material.

7.5 Future research

The conducted research concludes a set of empirical findings on the area of digital solutions in circular economy in Finland. Before the research was conducted, the empirical evidence on the field was very limited, and although the researched trends are seeing an increase in popularity, there is a lot more to learn and discover on the subject. This is mainly a result due to the constant evolving of the trends by organizations moving further in digital development and the knowledge and number of innovations on the field of circular economy growing daily. As the current research has only been done in Finland and only for a few selected companies, further evidence is needed to support the generalization of presented findings. For example, in Finland the legislation and participation of the public sector might play a large role in organizational development, which might raise the attention public sector received in the results to higher than it would in other countries. Some of the presented findings need to be analysed, and if possible replicated, in other research environments to improve the research done on the subject.

The amount and industry of analysed organizations needs to be widened, as the current research group focused only on a few organizations. Although the organizations operated with different solutions and in different areas, there are still several target groups with different approaches to digitalized circular economy. In the research conducted,

several companies with a focus on material marketplaces were identified, which have an interesting role in developing local material cycles. As shown in the results, the data integration technologies are said to play a large role in enabling information synchronization, so the effect of data integration technologies in material markets should deepen the knowledge on the benefits of data integration technologies on circular economy.

The conducted study gives a perspective on different organizational operators, where the results mainly focus on internal organizational activities. Apart of a single case on organizational cooperation a wider meso- or macro-level approach remains to be researched as the change in the level, can change the focus areas, requirements and operative challenges critically. By increasing the level of operation, the amount of deciding parties increases, introducing questions on operative responsibility, purpose of cooperation and operating methods. The changes and new factors on macro-level are difficult to even imagine before understanding the core functions of circularity in meso-level.

The results of the study heavily indicate that the development of digital technologies is still in the beginning and larger implementations of data analysis solutions has not yet been seen. Most of the information on data analysis benefits rely on the expectations participating organizations, which means that clear results on the benefits of data analysis technologies and their effect on circular economy requires further research as well as further development on the organizational side.

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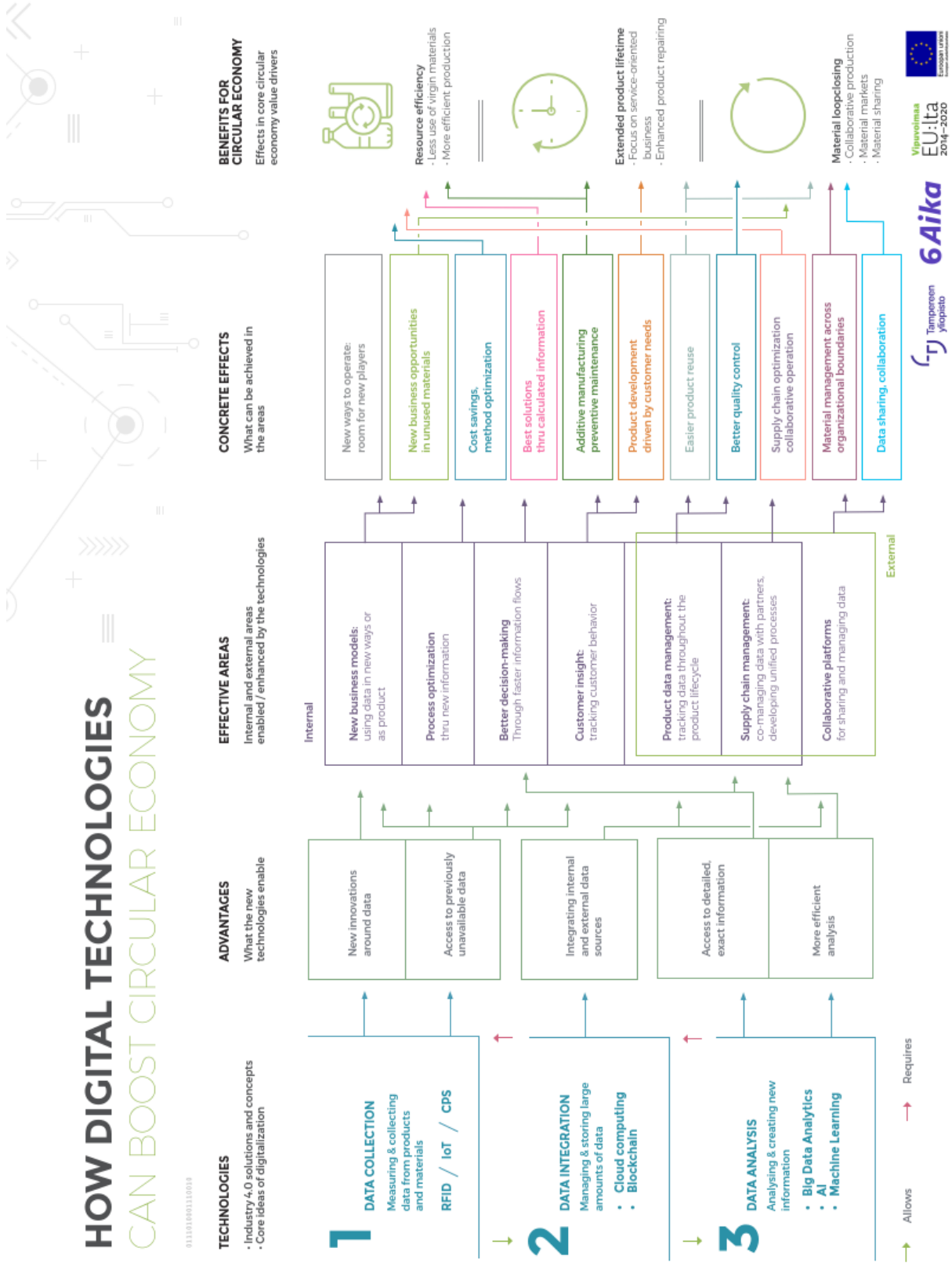
APPENDIX A: FRAMEWORK PROCESS FIGURE



APPENDIX B: STRUCTURE OF THE INTERVIEW

HAASTATTELURUNKO

1. Yleiset kysymykset

- Kuka olet?
- Mitä kautta olet tullut yritykseen?
- Miten urasi on yrityksessä kehittynyt?
- Nykyiset vastuualueet?

2. Kiertotalous käsitteenä

- Mikä on oma käsityksesi ja mitä ajattelet kiertotaloudesta?
- Kiertotalouden tavoitteita on kolme: Resurssitehokkuus materiaalien käytön vähentämisen kautta, Tuotteiden elinkaaren pidentäminen sekä materiaalikiertojen sulkeminen niin, että jätteen sijaan kaikki materiaali palaisi uudestaan omaan tai jonkun muun materiaalikiertoon. Ovatko resurssitehokkuus, elinkaaren pidentäminen ja materiaalikiertojen sulkeminen kaikki osana yrityksen toimintaa vai keskittyykö toiminta selkeästi tiettyyn/tiettyihin osa-alueisiin?
- Miten kiertotalous näkyy yrityksen toiminnassa?
- Kuinka kauan kiertotalous on ollut mukana toiminnassa?
- Mistä kehitys lähti liikkeelle?
- Kuka vastaa kiertotalouden kehittämisestä
- Onko aihe mukana toiminnassa säännöllisesti?
- Miksi kiertotaloutta halutaan toteuttaa?

3. Kiertotalouden toteuttaminen

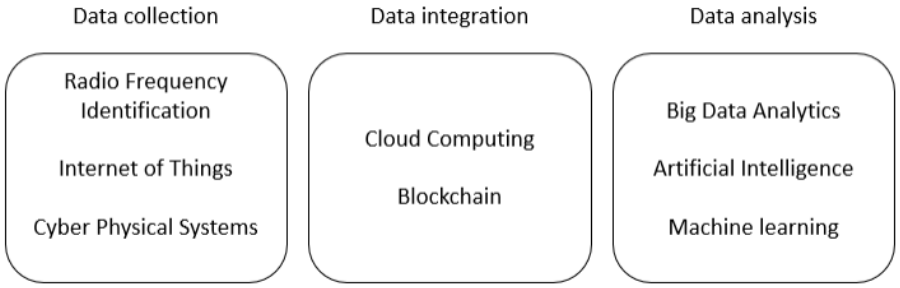
- Miten kiertotalous ratkaisun prosessit toteutuvat?
- Mistä idea ratkaisuihin lähti liikkeelle?
- Onko prosessoitavalla materiaalilla tai sen mittaamismahdollisuuksilla merkitystä?
- Toteutetaanko prosessissa materiaalin analysointia?
- Miten tieto tulevan materiaalin määrästä saadaan? Ennustetaanko sitä?
- Onko materiaalin määrällä merkitystä?
- Mitä edellä mainitun kaltaisten ratkaisujen toteuttaminen vaatii yritykseltä?
- Ketkä ratkaisuista vastaavat?
- Mitä hyötyjä ratkaisut tuovat?
- Onko ratkaisusta ollut haittoja?

4. Digitalisaatio ja teollinen internet

- Kirjallisuudessa teollista internettiä tai Internet 4.0 pidetään neljäntenä teollisena vallankumouksena, jossa esineiden yhdistäminen internettiin muuttaa

koko toimintaperiaatteita radikaalisti. Eri teknologiat voidaan jaotella dataa kerääviin, dataa yhdistäviin ja dataa analysoiviin teknologioihin. Näkyykö kyseinen jaottelu yrityksen teknologioissa ja hyödynnetäänkö joka kategorioiden tekniikoita jo nyt?

- Kirjallisuudessa kiertotalouden yhteydessä on esiintynyt esimerkkejä seuraavien teknologioiden käytöstä kiertotalouden ratkaisuissa:



Herättääkö mikään teknologia erityisiä ajatuksia tai puuttuuko listasta joku olennainen teknologia?

- Miten digitalisoituminen on vaikuttanut yrityksen ja toimialan toimintaan?
- Miten digitalisoituminen on vaikuttanut oman osa-alueesi toimintaan?
- Mitä ”uusia” digitaalisia teknologioita teillä on käytössä? (esim. Esineiden internet, Big data)
- Mistä teknologioista olet erityisen kiinnostunut, miksi?
- Mitkä ovat suurimmat haasteet uusien teknologioiden käyttöön otolle?
- Jos niin miksi ette halua implementoida uusia teknologioita?
- Vaikuttaako, vai miten yritysten välinen yhteistyö vaikuttaa uusien teknologioiden implementointiin?

5. Kiertotalouden kehittäminen digitalisaation avulla

- Mitä mahdollisuuksia näet kehittyvillä digitaalisilla teknologioilla, näätkö niiden muuttavan yrityksesi prosesseja?
- Erityisesti tiedon merkitys korostuu uusissa teknologioissa, niin että lähes mitä tahansa tietoa voidaan kerätä ja analysoida tehokkaasti. Kiertotalouden näkökulmasta, mitä tietoa olisi hyvä saada käyttöön, jota ei vielä ole saatavilla?
- Miten uutta kerättyä tietoa voisi hyödyntää?
- Mitä kiertotalouden kolmesta alueesta digitaaliset ratkaisut voivat edistää?
- Mitkä ovat mielestäsi suurimmat digitalisaation hyödyt keskustelluissa kiertotalousratkaisuissa?
- Onko mielessä muita uusia kiertotalouden ratkaisuja, joita digitalisaatio voisi toiminta-alueellanne mahdollistaa?