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THE ROLE OF ARTIFICIAL INTELLIGENCE, BIG DATA AND THE INTERNET OF THINGS IN THE ACCELERATION OF CIRCULAR ECONOMY

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<p>Abstract</p> <p>Circular economy is the alternative to the current linear (make, use, dispose) model. In business model literature, circular economy has emerged recently, affirming more practical methods to solving business challenges and developing innovative solutions for business processes, directly concerning the climate crisis. Circular business models propose to change the product-oriented business models in which the main objective of firms is maximizing profits by the number of products sold, to a service-based business model in which firms make profits by the services they offer. In this context, business models like Product-Service Systems have been identified as enablers of Circular Economy in companies. As a result of this, data and digital technologies presented by Industry 4.0 or the 4th Industrial Revolution, have proven to be tremendous catalysts of circular economy for industries. But despite this knowledge there is very limited implementation of circular economy processes and of Industry 4.0 tools for its acceleration. Academic literature highlighting the specific co-relation of digital technologies to Circular Economy is also limited. There is still a lot of scope to explore the nexus of these topics, by academicians and industry alike. In an attempt to bridge this gap, this study aims to provide an analysis in the role played by Industry 4.0 tools, especially Artificial Intelligence, Big Data and the Internet of Things, in the implementation and acceleration of Circular Economy. Based on the findings of the empirical research, the role of the selected Industry 4.0 tools is examined and discussed.</p>			
<p>Keywords</p> <p>Circular Economy, PSS, Data, Data Enabled Circular Economy, Industry 4.0, IoT, Big Data, Artificial Intelligence and Circular Economy, Sustainability, Business Models, Business Model Innovation</p>			
<p>Additional information</p> <p><i>Abbreviations</i></p> <p>CE: Circular Economy; BM: Business Model; BMI: Business Model Innovation, PSS: Product-Service Systems; AI: Artificial Intelligence; IoT: Internet of Things;</p>			

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*“The products of today are the materials of tomorrow at
yesterday’s prices”.*

–Walter Stahel

1. INTRODUCTION

Over the past years, the words ‘sustainability’ and ‘circular economy’ have garnered momentum and have become crucial aspects of policy making, industry and academia. Circular economy (CE) is the response to the inefficient management of the resources in the traditional linear model (Michellini et al, 2017). In a linear economy, materials flow in a straight line from resource extraction through manufacturing, to landfill. A linear economy is characterised by two unsustainable processes, resource scarcity and excessive pollution load. Both cause ecosystem degradation, wealth concentrations and social inequities. A circular economy aims to overcome these problems through intelligent design inspired by nature’s genius, which reuses and redevelops resources already operating within the production cycle via renewable means (Thomson et al, 2016). By definition a circular economy is an economy that is restorative by design, aiming to keep resources at their highest utility and value at all times (Ellen MacArthur Foundation, 2012).

According to Schaffartzik et al. 2014, not only has the use of resources grown globally but it has also increased especially in the last decade. The material and energy resources required to extend the current metabolic pattern of the industrial countries to the rest of the world are most likely not available, nor are the capacities of global ecosystems sufficient to absorb the outflows of industrial metabolism (Schaffartzik et al. 2014). There is a general consensus that we are passing through a period of severe resource depletion. Tukker, 2015., Michellini et al, 2017., Nobre et al. 2017., Schaffartzik et al. 2014 and Tseng et al 2018 all show that circular economy is a better alternative to the traditional linear economy (make, use, dispose) because it allows us to keep resources in use for as long as possible, extract the maximum value from them whilst in use, then recover and regenerate products and materials at the end of each service life (Michellini et al, 2017).

The outbreak of COVID-19 in 2020 has been a morbid manifestation of the erroneous nature of the linear model. Thus, the need to transition to circular economy has never been more urgent and imminent.

Figure 1 shown below was developed by Ellen MacArthur Foundation, 2019. It demonstrates the Circular Economy systems:

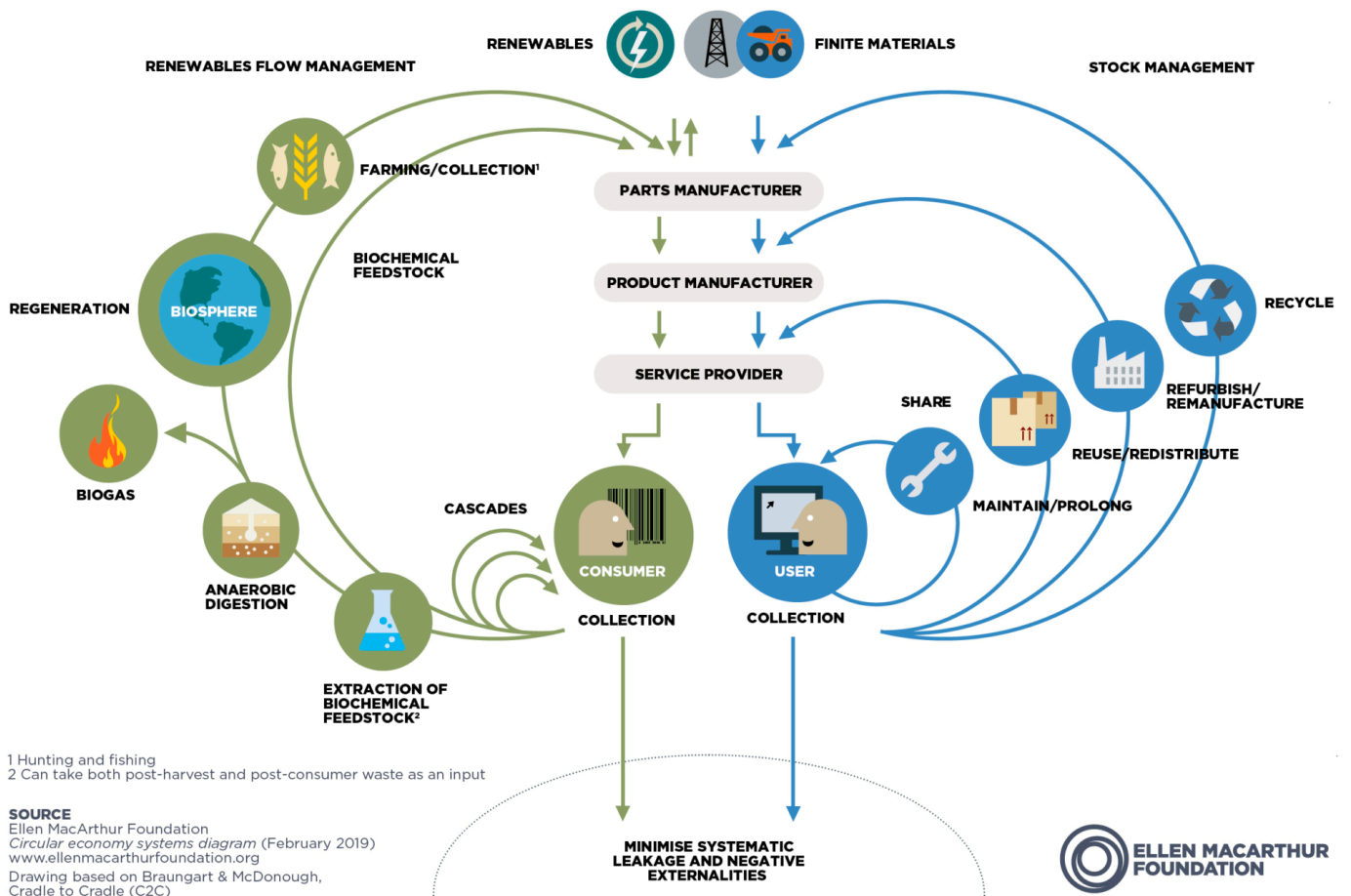


Figure 1. Circular Economy Systems, EMF (2019).

In business model literature, circular economy (CE) has recently emerged, proposing feasible ways to business innovation linked to sustainability concerns (Annarelli et al, 2016). It is an attempt to change the product-oriented business models in which firms have the incentive to maximize the number of products sold, to a service-oriented business model in which firms make money by the service offered (Tukker, A., 2015). In this context, Product-Service Systems (PSS) Business Models (BMs), in which the function or the utilization of the product is sold instead of the product itself, have been recognised as one possible enabling factor of the CE paradigm into companies (Bressanelli et al. 2018). As a consequence of this, digital technologies, exhibited by the 4th Industrial Revolution (Industry 4.0), such as Big Data, Analytics, Artificial Intelligence, IoT, 3D printing and Internet of Things, enrich the introduction of CE into companies (Despeisse, M et al. 2017., Jabbour, CJC et al. 2017., Pagaropolous, A et al. 2017., Bresaanelli, G et al. 2017). With this change, firms will have an incentive to prolong the service life of products, to ensure they are used as intensively as possible, to make them as cost and material-efficient as possible, and to re-use parts as far as possible after the end of the product's life (Tukker, A., 2015).

However, a crucial component for the implementation and acceleration of Circular Economy (CE) also is good policy and governance. A report by the World Business Council for Sustainable Development stated that, "Effective policies can help accelerate and scale up circular actions in the economy. These policies support businesses in overcoming hurdles by stimulating innovative projects and long-term investments in circularity, facilitating collaboration and partnerships, and producing tangible results". According to Ellen McArthur Foundation (2013), good policy offers short and long-term economic, social, and environmental benefits. But success in increasing our overall resilience ultimately depends on the private sector's ability to adopt and profitably develop the relevant, innovative and new business models.

During the nascent stage of this research, very limited literature was discovered highlighting the specific co-relation of digital technologies to Circular Economy (CE). There is still a lot of scope to explore these topics, by academicians and industry alike. In an attempt to bridge this gap, this study aims to provide an analysis in the role played by Industry 4.0 tools, especially Artificial Intelligence (AI), Big Data and the Internet of Things (IoT) in the implementation and acceleration of Circular Economy (CE), by means of qualitative research.

Hence, this thesis is structured as follows. Section 2 explains the background of this study, focusing on Industry 4.0, emphasising on Artificial Intelligence (AI), Big Data and the Internet of Things (IoT) and the role of the selected technologies in furthering circular economy (CE). This section will also highlight the importance of Product-Service Systems (PSS) and Business Model Innovation (BMIs). Section 3 highlights the research gap, research question and methodology applied. Section 4 presents the key concepts necessary for unveiling the role of AI, big data and IoT in the acceleration of CE. Section 5 showcases the data and results of the analysed data. Lastly, section 6 comprises the conclusions, discussion and scope for future research.

2. BACKGROUND

2.1 Circular Economy and Industry 4.0

Circular Economy (CE) can be viewed as the means to make the most out of the triple bottom line (TBL), and could be useful in the initiation of new job opportunities and business models. Triple bottom line (TBL), in economics, believes that companies should commit to focusing as much on social and environmental concerns as they do on profits. TBL theory posits that instead of one bottom line, there should be three: profit, people, and the planet (Žak, A. 2015). CE can also be used to save cost, soften the price volatility of resources, and improve resource security for the supply chain, while reducing the environmental pressure and impact (Kalmykova, Y et al. 2018). Elia, et al. proffer different measures for a CE, such as circular product design and production, business models, cascade/reverse skills, and cross-cycle and cross-sector collaboration. However, for companies, the transition to CE still brings a lot of difficulties, including sustainable production–consumption systems, closed-loop supply chains, and product service system (Tura, N et al. 2019). According to Tseng, M. L et al (2019), CE also faces many unsolved methodologies and limitations, e.g., those concerning the common methods of environmental life cycle assessment and system dynamics (Balanay, R., Halog, A. 2016; Kuo, T.C. 2019). In other words, its implementation is still in the early stages, since few available implementation tools have been developed (Kalmykova et al. 2019; Agarwal, S et al. 2015).

Tseng, M. L et al (2019) state that in order to implement newer technologies in CE, it is important for the barriers to be overcome with emerging technological improvements and concepts, such as Industry 4.0 or the ‘Fourth Industrial Revolution’. Industry 4.0 itself is a set of tools in data management that uses automation and data exchange in the setting of smart manufacturing and production through the use of cloud services, robotics, 3D-printing,

Internet of Things (IoT), Big Data and its analytic tools, and Artificial Intelligence (AI) to reduce over-consumption and production errors (Tseng, M. L et al. 2019). The efficiency gains can contribute to sustainability. In itself, Industry 4.0 brings a new perspective to the industry on how manufacturing can utilize new technologies to create value with maximum output and minimum resource utilization (Tseng, M. L. et al. 2018; Cai, Z. et al. 2017).

According to Schwab K, 2016, 'Industry 4.0' is the ongoing automation of traditional manufacturing and industrial practices, using modern smart technology. AI, IoT and Big Data are amongst the many components of Industry 4.0. When applied to manufactured products, these digital technologies have the capability to provide remote visibility and asset control – enabling the location, use, condition and value of materials to be tracked at every stage of their lifecycle. There are clear benefits here for manufacturers seeking to offer more circular business propositions such as closed-loop processes, remanufacturing or Product Service Systems (PSS) models, *also known as product-as-service* (Reuters Events, July 2016). Research by academicians in the past point us towards the benefits of data-driven Industry 4.0 to solve the problems of CE. They claimed that the benefits of Industry 4.0 are vertical integration, virtualization, automation, traceability, flexibility, and energy management (Tseng, M. L et al. 2019). Kamble et al. (2018) proposed a sustainable Industry 4.0 framework. Rajput and Singh (2019) proposed finding the connection of CE and Industry 4.0 in the context of a supply chain. Stock, et al. (2018) mentioned using Industry 4.0 as an enabler for sustainable development. In this thesis, the specific focus is on AI, Big Data and IoT.

In their paper, Tseng, M. L et al. 2019 state that:

(i) The Internet of Things (IoT) changes the way to create value in the business sector as the information that is generated by the interconnected

devices, machines, and products evolves in a fundamental component in value creation, such as maintenance, re-use, repair, and recycle. Through IoT, there is a capability to foster CE through the connection of people and things by mobile devices, which derives significant economic opportunities for both individuals and businesses in multiple domains.

(ii) Data-driven analysis (Big Data and Analytics) can be used to help enterprises understand their sustainability performance and create value (value proposition, value creation and delivery, and value capture). It refers to all the tools and techniques that analyze the vast and varied business data management to generate useful insights for decision making. The analytical tools include mathematics, optimization, simulation, statistics, and other techniques.

(iii) AI can help unlock circular economy opportunities by improving design, operating business models, and optimising infrastructure (EMF, 2019). AI has been implemented in both renewable energy and electrical energy to achieve better efficiency (Tseng, M. L et al. 2019).

So, given the purpose of circular economy and the wide-scaled benefits of applying data/ digital technologies, the objective of this thesis is to better understand how Industry 4.0 tools, especially AI, Big Data and the IoT, can aid the implementation and acceleration of CE across various industries and organisations.

2.2 Circular Economy oriented Business Model Innovation

A business model (BM) is the “design or architecture of the value creation, delivery, and capture mechanisms” of a business (Teece, 2010). In other words, they are ‘mental constructs’ that can be represented with visualisation

tools to explain how a business work (Magretta, 2002). Business model innovation (BMI) are continuous organizational processes aiming to create, diversify, acquire or transform companies' business models (BMs) (Geissdoerfer et al., 2018) as a consequence of change triggers inside or outside the organizational boundaries (Foss and Saebi, 2017).

Understanding Business Model Innovation (BMI) is imperative to understanding the full scope of CE as well as the challenges in its implementation and the role played by digital technologies in enabling the same. Building capabilities for CE requires as much of organizational innovation as of technological or product innovation (Schulte, 2013). Hence, a growing stream of academic and industrial interest is emerging around the theme of business model innovation (BMI) towards enhanced circularity. (Diaz Lopez et al., 2019; Pieroni et al., 2019). BMI for circularity aims to uncover new ways of providing value to stakeholders (e.g. customers, suppliers) and exploring economic values along the products' life cycle to systemically boost resource efficiency and effectiveness (Den Hollander and Bakker, 2016).

According to Fernandes, S et al. 2020, Business Model Innovation (BMI) enables a systemic perspective on business, while facilitating the structure of the systems beyond the conventional way of creating, delivering and capturing value (Mentink, 2014). Circular business models (BMs) are different from traditional business models of the linear economy model, due to the intentional incorporation of strategies for slowing, closing and narrowing resource loops (Bocken et al., 2016). In accordance with Fernandes, S et al. 2020, this particularly holds for, the BMI towards circular economy because it requires fundamental changes in the value proposition (Lieder et al., 2018). Circular value propositions should be designed to guarantee long-term capacity and preserve the economic and environmental value of resources (Nußholz, 2017) through the deliberate use and

implementation of principles and strategies of circular economy (Aminoff et al. 2017; Nußholz, 2017). Proactive management of stakeholders and their cooperation in a co-innovation process (Aminoff et al., 2017) are also relevant aspects for the design of circular value propositions.

2.3 Circular Economy and Product- Service Systems

Based on service-based value propositions, product-service systems (PSS) are commonly understood as a means to realise circular economy (Fernandes, S et al. 2020). PSS value propositions denote the value that the company may offer to customers and other stakeholders through products and services (Resta et al., 2017). In their work, Fernandes, S et al. 2020 highlight that the circularity of businesses can be enhanced through the implementation of product-service systems (Lieder and Rashid, 2016; Urbinati et al., 2017; Pieroni et al., 2019a), which comprise integrated solutions of products and services in order to fulfil the customers' needs and generate value (Goedkoop et al., 1999; Boehm and Thomas, 2013). Camilleri, M. A. (2019) states that PSS are moving society towards a resource-efficient CE. PSSs shifts the businesses' focus from designing and selling only physical products, to selling a marketable set of products, services, supporting networks, and infrastructures, by including repair and maintenance, updates/upgrades, help desk, training and consultancy, and disposal-services such as recycling and take-back (Gaiardelli et al., 2014). Therefore, PSS consists of tangible products as well as intangible services that are combined so that they are jointly capable of satisfying the consumers' demands (Hockerts & Weaver, 2002). Moreover, PSSs would typically extend beyond purchase, affecting the use and disposal of resources. Hence, these systems could lead to the minimisation of material flows in the economy whilst maximising the businesses' service output and their users' satisfaction (Camilleri, M.A. 2019).

According to Bressanelli et al. 2018, shifting from traditional sales-oriented BMs to servitised ones can incentivise companies in moving towards CE. Moreover, adopting PSS, i.e. integrated bundles of products and services aiming to create customer value (Boehm, M., Thomas, O. 2013), represent an excellent vehicle to foster sustainability (Tukker, A. 2004). Bressanelli et al. 2018 state that the opportunities for improvement with regard to sustainability differ significantly depending on the type of PSS used. Bressanelli et al. 2018 cite Tukker, A (2004), proposing three different categories of PSS, namely *product-oriented, use-oriented and result-oriented*.

In product-oriented BMs, the purpose is to deliver tangible value to the customer (Tukker, A. 2004). The product ownership is transferred to the customer, while the company can sell a combination of single standard products and industrial services, such as maintenance and repair (Bressanelli et al. 2018). Moreover, the company has no responsibility for product lifecycle and the main revenue stream is represented by product sales (Androdegari, F et al. 2017).

In use-oriented BMs, the customer does not buy the product but instead pays a fee to gain access to it (Tukker, A. 2004., Reim, W et al. 2015). Thus, the company takes responsibility for providing lifecycle services such as maintenance, repair and control. Furthermore, the company is incentivised to design products in terms of which elements can be reused after their first life (Androdegari ,F et al. 2017). Thus, the product should be easy to maintain, reuse, upgrade (Bocken, N et al. 2016).

In result-oriented BMs, customers do not buy the product but pay a variable fee that depends on its actual usage or on the achievement of a result or outcome (Tukker, A. 2004). Therefore, the value is generated by an individualised and integrated combination of products and services to produce the expected results (Barquet, A. 2013). Thus, revenues are generally

based on outcome units that are paid for the result (Reim, W et al. 2015). In accordance with Tukker, result-oriented BMs may be the most effective to move towards CE.

2.4 The significance of AI, Big Data and IoT for Circular Economy

2.3.1 Artificial Intelligence

AI is an overarching term for a collection of technologies. It deals with computer models and systems that perform human-like cognitive functions such as reasoning and learning. AI software is capable of learning from experience, differentiating it from more conventional software which is preprogrammed and deterministic in nature (Ellen McArthur Foundation). The circular economy puts a strong focus on design. AI helps to solve problems through performing tasks which involve skills such as pattern recognition, prediction, optimisation, and recommendation generation, based on data from videos, images, audio, numerics, text and more. Designers working with AI can create products, components, and materials which are fit for the circular economy. Employing AI can account for better designs faster, due to the speed with which an AI algorithm can analyse large amounts of data and suggest initial designs or design adjustments. A designer can then review, tweak, and approve adjustments based on that data. AI gives designers a more informed insight into the most effective designs to create and test to make the best use of their time and expertise (Ellen MacArthur Foundation).

According to a 2019 case study by Ellen MacArthur Foundation, in collaboration with Google, AI can enhance and enable circular economy innovation across industries in three main ways:

1. Design circular products, components, and materials. AI can enhance and accelerate the development of new products, components, and materials fit

for a circular economy through iterative machine-learning-assisted design processes that allow for rapid prototyping and testing.

2. Operate circular business models. AI can magnify the competitive strength of circular economy business models, such as product-as-a-service and leasing. By combining realtime and historical data from products and users, AI can help increase product circulation and asset utilisation through pricing and demand prediction, predictive maintenance, and smart inventory management.
3. Optimise circular infrastructure. AI can help build and improve the reverse logistics infrastructure required to ‘close the loop’ on products and materials by improving the processes to sort and disassemble products, remanufacture components, and recycle materials.

2.3.2 The Internet of Things

Cutting-edge technologies such as big data and the Internet of Things (IoT) have the potential to leverage the adoption of Circular Economy concepts by organizations and society, becoming more present in our daily lives (Nobre, G.C., Tavares, E., 2017). The internet of things or IoT simply refers to the overarching network created by billions of internet-compatible devices and machines which share data and information around the world (Nobre, G.C., Tavares, E., 2017). The most commonly associated products are consumer electronics devices such as smartphones and smart speakers, but larger mechanical systems such as cars, household security systems, and even traffic lights are rapidly becoming integrated into this network due to their internet capabilities (Lee, I., Lee, K., 2015). Five IoT technologies are widely and most commonly used for the deployment of successful IoT-based products and services:

1. Radio frequency identification (RFID);
2. Wireless sensor networks (WSN);
3. Middleware;
4. Cloud computing; and

5. IoT application software. (Lee, I., Lee, K., 2015).

The IoT (Internet of Things) can help support a more circular economy by making products easier to maintain and repair. By adding intelligence to a product or device, the Internet of Things technologies can create an asset that can signal problems, determine when it needs to be repaired, and schedule its own maintenance (Smedley, P. 2020). This helps ensure that the product or device is kept in working condition for longer and needs to be replaced less frequently. Another way the IoT can contribute to a circular economy is by enabling a shared-use model. To date, companies like Uber and Airbnb have exploded in popularity in the past decade, because temporarily using other people's cars and holiday homes for a fee makes so much more sense in some cases than the alternatives (Smedley, P. 2020).

Business leaders operating in every industry from financial services to energy and mining are realising the critical importance of IoT within their organizations and acting quickly to invest in the technology (Lee, I., Lee, K., 2015). As per the Statista Research Department Report, Jan 2021, as the sophistication of both hardware and software in the consumer electronics industry skyrockets, an increasing share of the electronic devices produced around the world are manufactured with internet connectivity. Forecasts suggest that by 2030 around 50 billion of these IoT devices will be in use around the world, creating a massive web of interconnected devices spanning everything from smartphones to kitchen appliances (Statista Research Department Report, 2021).

2.3.3 Big Data

Big data is the explosion of digital data generated by the internet and connected objects (McAfee, A., 2012). IoT allows the collection of large amounts of data by companies, which is termed as Big Data (Nobre et al. 2017). Hence, it can be an ally and an accelerator for the circular economy (Tseng et al, 2018). Given their volume, variety, velocity and veracity

(Jabbour CJC et al. 2017), Big Data cannot be analysed using traditional software or database techniques, but require specific Analytics to leverage software and data mining processes, in order to identify patterns in the data and make predictions (Pagoropoulos, A et al. 2017). Thus, Big Data combined with appropriate analytics are usually seen in literature as a valid approach to enable a better decision making (Pagoropoulos, A et al. 2017), which can positively advance management towards CE by feeding sustainability-oriented decision-making processes with the required information (Jabbour CJC et al. 2017). Smart leaders across industries view the usage of big data for what it is — *a management revolution*. But as with any other major change in business, the challenges of becoming a big data-enabled organization can be enormous and require hands-on — or in some cases, hands-off — leadership (McAfee, A., 2012).

2.5 Circular Economy enabled by Industry 4.0

Bonilla, S.H et al. 2018 constructed structural sketch of Industry 4.0 technologies demonstrating the capabilities when applied to the production process. This is showcased in the adapted diagram below in Figure 2. Pham, T.T et al (2019) state that industry 4.0 itself is a set of tools in data management essential to reducing over-consumption and production errors. The efficiency gains can contribute to sustainability.

In itself, Industry 4.0 brings a new perspective to the industry on how manufacturing can utilize new technologies to create value with maximum output and minimum resource utilization. Pham, T.T et al (2019) explicate that with systems thinking, Industry 4.0 could overcome some barriers of CE to promote more sustainability.

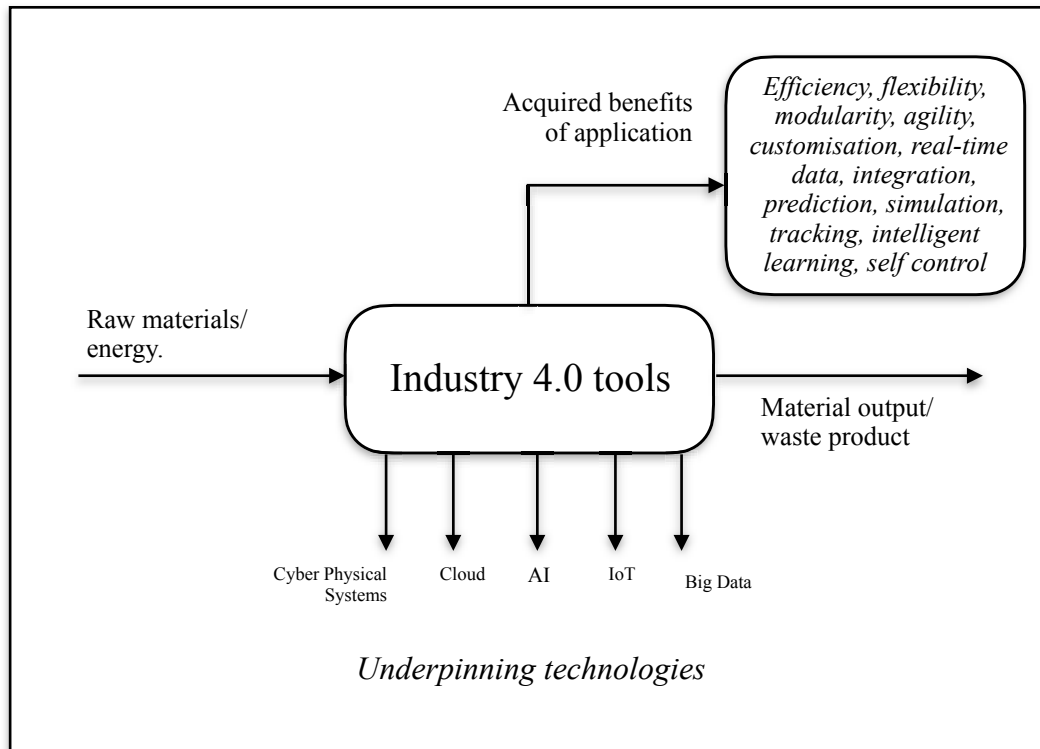


Figure 2. The underpinning technologies of Industry 4.0 and the acquired capabilities that emerge when they are adopted by production processes.

2.6 Artificial Intelligence, The Internet of Things and Big Data for the Acceleration of Circular Economy

As per the 2019 report of Ellen MacArthur Foundation, developed in collaboration with Google, AI, as an emergent ‘Fourth Industrial Revolution’ technology, can support and accelerate the pace of human innovation to design products, bring together aspects of successful circular business models, and optimise the infrastructure needed to loop products and materials back into the economy. Utilising AI capabilities could create a step change which goes beyond realising incremental efficiency gains to help design an effective economic system that is regenerative by design. AI can boost development and design of completely new circular products and businesses. Equally, it can help traditional players in their transition to become more

circular. Across industries, AI technologies can unlock three high potential circular economy opportunities:

- Design circular products, components, and materials;
- Operate circular business models; and
- Optimise infrastructure to ensure circular product and material flows.

The Internet of Things (IoT) technology refers to supplying devices with sensors, which give them the ability to communicate and to become active participants in an information network (Rymaszewska, A. 2017). To this regard, Porter and Heppelmann (Porter, M.E. 2014) showed how the application of the IoT technology turns stand-alone products into smart and connected ones, pointing out the functionalities of monitoring product status and condition. Therefore, thanks to the IoT, companies may obtain real-time remote monitoring of product usage, status, and location (Baines, T., W. Lightfoot H. 2013), thus having the great opportunity to gain knowledge on how customers are using products. When products become smart, companies may upgrade only their digital components, such as the product firmware. Therefore, product upgradability is enhanced (Rymaszewska, A. 2017), which in turn contrasts product obsolescence and its resulting material waste, helping the transition towards CE (Pialet, O. 2017). Finally, Cheng, Barton, and Prabhu (2010) have pointed out the crucial role of sensors like radio frequency identification (RFID) in tracing spare parts. Consequently, the IoT technology may also support material tracking (Lewandowski, M. 2016), contributing to the collection of end-of-life products (Pagoropoulos, A et al. 2017).

Furthermore, Big Data and Analytics are required in the provision of advanced services such as preventive and predictive maintenance (Baines, T.,

W. Lightfoot, H. 2013). Pham, T. T (2019) in their work state that data-driven analysis can be used to help enterprises understand their sustainability performance (Papadopoulos, T et al. 2017., Rehman, MHU. 2016., Song, M et al, 2017) and create value (value proposition, value creation and delivery, and value capture (Whalen, K. 2019., Gupta, S et al. 2018). It refers to all the tools and techniques that analyze the vast and varied business data management to generate useful insights for decision making. The analytical tools include mathematics, optimization, simulation, statistics, and other techniques (Pham, T. T., 2019).

3. THE ROLE OF INDUSTRY 4.0 IN ENABLING PRODUCT-SERVICE SYSTEMS

Despite the crucial role played by data and digital technologies in the transition to CE, there is not enough literature on the specific role of Industry 4.0 tools, especially AI, Big Data and IoT in the implementation and acceleration of CE. This gap is the starting point for this thesis. The aim of this thesis is to explore the role of AI, Big Data and IoT in the implementation and acceleration of circular economy. It also aims to bring to the fore the challenges to digital technologies and data in aiding CE processes, by means of qualitative research. AI, Big Data and the IoT were chosen amongst various other Industry 4.0 tools due to their far-reaching applications across industries and organisations and also due to their relevance with regards to CE and CE related BMs such as PSS.

In business and academic literature, PSS is considered as the means to realising CE. Digitalization enhances PSS operations in a cost-efficient way and enables service quality through better resource allocation and more accurate information sharing inside and outside the boundaries of the firm (Zambetti, M et al. 2020). PSS was chosen for this thesis due to its interconnectedness with digital technologies which is reflective in the resultant digitalization of products and infrastructures, enabling companies to offer Smart PSS. Consequently, product connectivity enables manufacturers to retrieve a large amount of data from Smart Connected Products that, matched with effective data analytics tools, can become a key source of value creation (Rymaszewska, Helo, & Gunasekaran, 2017). In fact, collecting and elaborating data from the installed base has been recognized as a key aspect for manufacturers to servitize as it can enable sophisticated service offerings and new service-oriented business models (Adrodegari & Saccani, 2017). For instance, KONE, one of the largest global elevator companies, developed sophisticated condition

monitoring and predictive maintenance services together with IBM. Both these services are based on the advanced elaboration of data gathered from the connected elevators (Zambetti, M et al. 2020).

Data-driven analysis can potentially be used to optimize the sustainable solutions intended to reduce the resource and emission intensities of industrial systems (Tseng et al, 2018). However, the transition to Circular Economy (CE) and Product-Service Systems (PSS) Business Models (BMs) implies major challenges to companies too. Despite this general agreement, little attention has been paid to how digital technologies may be used to overcome CE challenges (Bressanelli et al, 2018). Though there is a massive volume of scientific work in these areas (e.g., separate queries in Scopus using ‘Industry 4.0’ and ‘Circular Economy’ as keywords yield 4060 and 2452 published documents, respectively), there is plenty of growth potential for groundbreaking research in the nexus of these topics (Tseng et al, 2018). According to Bressanelli et al. 2018, while the enabling role of digital technologies for Product-Service Systems (PSS) has been thoroughly investigated by previous studies (see, for instance, the work of Ardolino et al. 2017), their specific role for CE has been quite under-investigated to date (Nobre et al. 2017).

Therefore, as the purpose of this thesis is to explore the specific role of AI, Big Data and IoT in the acceleration of CE, the research question is two pronged:

- 1. Why is there still limited implementation of data/ digital technologies towards CE efforts?*
- 2. What are the challenges to the above mentioned digital technologies in aiding CE efforts?*

3.1 Methodological approach

Since this is an investigative research and given the limited body of work on the topic, the data for it was collected primarily by performing:

1. *Thematic Literature review*- Thematic reviews of literature are organised around a topic or issue, rather than the progression of time (Library of the University of Alabama, 2019). This method is used in academic research prior to empirical findings. Sections 2 and 3 exhibit the usage of this method. The objective behind conducting this kind of literature review for the thesis was to highlight the existing research in this field as well as to understand and examine the role of data in accelerating the implementation of Circular Economy (CE). Another important reason was identifying relevant studies that lie at the intersection between Circular Economy and data technologies. The literature chosen for this were recent and relevant, between the average date range of 2015 to 2020. Keywords such as ‘Data and Circular Economy’, ‘Data Enabled Circular Economy’, ‘IoT and Big Data in Circular Economy’, ‘Artificial Intelligence and Circular Economy’, ‘Industry 4.0’, ‘Data and Sustainability’ were used on query data bases like Google Scholar, Elsevier, Web of Science and Scopus. Additionally, relevant online reports and articles from Ellen McArthur Foundation, Reuters and UNEP were also accessed.
2. *Secondary data analysis*- According to the definition provided by Oxford Handbooks, “Secondary data analysis refers to the analysis of existing data collected by others. Secondary analysis affords researchers the opportunity to investigate research questions using large-scale data sets that are often inclusive of under-represented groups, while saving time and resources”. For this thesis, secondary data analysis was conducted by selecting three case companies through Ellen MacArthur Foundation’s repository of case studies. The companies chosen belonged to the USA, Netherlands and

Chile, to demonstrate CE initiatives on a global scale. The chosen companies were entirely distinct from one another in their CE systems and products but the common thread was their usage of Industry 4.0 technologies, namely AI, Big Data and IoT, to optimise their CE processes.

3. *Semi structured interviews*- Were chosen to be the primary data collection method for empirical data, because according to Galletta (2013), it is a sufficiently structured method to address specific topics related to the phenomenon or the theme of the study. The semi-structured interview also offers great potential to address complex research topics (Hirsjärvi & Hurme, 2000; Galletta, 2013). Interviews were conducted with five industry professionals, with extensive experience in the field of CE. The interviewees were chosen by the researcher on the basis of their experience either working in CE solutions companies or in CE consulting firms within Finland, as well as having a robust technical understanding of digital technologies valued for Product-Service Systems (PSS) and CE. The interviews were conducted with the assistance of an open-ended questionnaire which aimed at discussing essential aspects of the topic and forecasting the future of this field of work and research. The questionnaire did not pertain specifically to Finland or to the EU at large, rather, it emphasised on the correlation between Industry 4.0 and Circular Economy, Sustainability, Product-Service Systems and on the interviewees' own opinions and experience on the subject. All interviews were video recorded with their permission. The information collected through this was analysed in the form of content analysis.

3.2 Company case presentation

The researcher interviewed five professionals from companies specialising in CE and data technologies. The companies that these industry professionals

belonged to were Finnish and headquartered in Finland. The companies were namely Taival, DAIN Studios and Kamupak. Three of the informants belonged to *Taival* — Maija Maanavilja, Ira Hanf and Reko Lehti. Karri Lehtonen and Majella Clarke belonged to *Kamupak Oy* and *DAIN Studios* respectively.

3.2.1 *Taival*

Founded and headquartered in Helsinki, Finland, Taival is a new type of advisory company working at the intersection of strategy, technology, design and circular economy. Taival collaborates with companies to help them improve their performance and create sustainable value for their stakeholders. Taival has wide roster of international clients along with whom it co-creates innovative strategies and solutions with circular economy, data and digital technologies at the centre of its services.

The researcher was first acquainted with Taival and its expertise in the field of circular economy consulting in 2020. The researcher approached the consultants regarding a thesis project but there were no open positions at the time. However, during the course of writing this thesis research, the researcher contacted four consultants from the company and three of them obliged and provided excellent insights that enhanced this thesis greatly. The consultant who could not participate aided the researcher in finding professionals from other companies who participated and added to the qualitative data in this research.

3.2.2 *DAIN Studios*

DAIN Studios stands for Digital, AI and Insights providing data consultancy, execution, and product development. DAIN Studios also has sustainably and data ethics at its core. Started in March 2016 in Finland and Germany, the company combines a team of highly experienced experts in the field of Big Data, Data Science and Privacy. They currently serve well-known,

international clients in Finland, Germany, Switzerland, and Austria. The DAIN Studios team combines extensive business experience with deep Data and AI skills, gained at multinationals, start-ups and management consulting firms. They have successfully executed digital, data, and data-science transformation programs for several international companies.

(www.dainstudios.com)

3.2.3 Kamupak

Founded in 2019 in Helsinki, Finland, Kamupak is a startup that provides circular takeaway solution for grocery stores and restaurants across top Finnish metros. Kamupak's product innovation, the 'Kamudish' is a returnable non-throw packaging product, that works as a more ecological alternative to disposable packaging within the Kamupak deposit system. At the moment the Kamupak product portfolio comprises of the KamuBox and KamuCup. Kamupak has engineered a 'deposit' system wherein they encourage users to return their non-throw items to a 'Kamu' location where the next user can pick up a clean, washed item. It is important that the products are returned so that the company can keep track of the usage and maintain a high level of hygiene.

Kamupak products are made of different kinds of polypropene plastics. Plastic is a durable, easy-to-modify, inexpensive, reusable, recyclable, and excellent material in all respects when used responsibly throughout the life cycle. Hence, these products can be returned to the manufacturer to be used again as material for new products. This is of great importance for the life cycle impact of the KamuDish, as the carbon footprint of recycled polypropylene is 70% smaller compared to virgin raw materials. Kamupak's partners are popular Finnish cafes, restaurants and food delivery services like Pykälä, Silta, K Supermarket and Wolt. (www.kamupak.fi)

Table 1 below provides the information of the interviews conducted as well as profiles of the interviewees.

Table 1: Interview information and interviewees' profiles.

Interviewee	Company	Industry	Role	Date	Method	Duration
I1	Kamupak	Circular Economy Takeaway Solutions	Co-Founder & CFO	03.05.2021	Video call	39:25
I2	DAIN Studios	Data and AI Strategy Consulting	Senior Data and AI Strategist	03.05.2021	Video call	1:14:18
I3	Taival	Circular Economy, Data Strategies and Digital Technology Consulting	Senior CE Strategist	23.04.2021	Video call	34:01
I4	Taival	Circular Economy, Data Strategies and Digital Technology Consulting	Executive Partner & CTO	26.04.2021	Video call	37:32
I5	Taival	Circular Economy, Data Strategies and Digital Technology Consulting	Senior Advisor and Head of Disruptive Sustainability Services	23.04.2021	Video call	37:18

4. DATA COLLECTION AND ANALYSIS

Section 4.1 contains secondary data analysis conducted via case studies from three companies who have been the forerunners of change towards CE. These case studies were shortlisted from Ellen MacArthur Foundation's online repository. The chosen cases were selected based on the geographical location of the case companies in order to highlight CE efforts globally, the usage of the aforementioned digital technologies, i.e, AI, Big Data, IoT and Product Service Systems (PSS), as well as the business challenges these companies were able to solve by leveraging the digital technologies.

Section 4.2 contains the analysis of qualitative data collected by interviewing professionals in leadership roles in CE companies based in Finland. They are all industry experts not only in CE but also have a thorough understanding of digital technologies. Owing to this, they were able to provide meaningful insights on the symbiotic association between CE and Industry 4.0 tools and the exploitation of these technologies for the furtherance of CE. The analysis of the data content was tabulated by segmenting it

4.1 Case Studies

4.1.1 Case 1- Ahrend, Netherlands

According to Ellen MacArthur Foundation, manufacturing office furniture requires a lot of materials and energy and 80-90% of these valuable resources are lost after a short use period. Ahrend, a Dutch office furniture company, is a fore runner in sustainability and circularity for the last thirty years (www.ahrend.com). Ahrend manufactures office furniture products with modularity, disassembly, and life extension as core design principles. In this way, repairs, upgrades, and modifications are easily achieved so that every single product can have multiple lives. Ahrend offers their customers furniture-as-a-service (FaaS) where customers pay a monthly

fee and return the furniture when they no longer need it (Ellen MacArthur Foundation case studies). As elucidated by the Ellen MacArthur Foundation, most industrial sectors, including office furniture manufacturing, typically adhere to the linear model of production. Many of the materials in products today come from increasingly expensive finite sources. The loss in value and associated negative environmental and social impacts, mean that there is a clear case to rethink office furniture design and delivery mechanisms. As per Ellen MacArthur Foundation, since the early 1990s, Ahrend have designed all of their furniture products with life extension in mind. Innovative manufacturing processes and use of high performance recycled materials are groundbreaking design strategies through which Ahrend has created circular products.

- Furniture as a Service: In the last few years, Ahrend embarked on a journey to reshape their entire business model to ensure that the benefits of life extension can be realised. Under a traditional transactional model, products are sold to other businesses, but there is no way of knowing what happens to them next. By changing the business model to provide the product (furniture) as a service, Ahrend remains the owner and can ensure materials and the embedded resources are conserved (The Ellen MacArthur Foundation). The success of this new model was brought about by the following elements:

1. *Technology* - the inclusion of QR codes on products, which is an important component of IoT technology, along with a new internal database, has allowed Ahrend to continually log, store, and track the history of all assets under their ownership. This ensures a smooth flow of information on the quality and health of their products, and important datasets to enable the scaling and management of the Furniture as a Service model.
2. *Financing* - the creation of an alternative financing model has provided the flexibility and experimental space needed for the PSS model to work.

Ahrend is private equity owned, allowing the business to create a separate financial entity called *Circular Interiors* that owns the products. This allows Ahrend, the furniture company, to free themselves from certain financial constraints, such as the need to generate short-term returns, which can often limit companies from piloting and implementing similar access-over-ownership business models (Sourced from The Ellen MacArthur Foundation).

- Overcoming business challenges: As per the Ellen MacArthur case study on Ahrend, firstly, the potential benefits of capturing value and mitigating supply risks through PSS (in this case Furniture as a Service or FaaS) were not widely appreciated in the Netherlands when Ahrend introduced the new option to customers. Today, the company has witnessed far more awareness about circular economy and material reuse advantages at various levels. Ahrend have found that as the key players in the value chain have come to understand the rationale of the PSS model, the easier it has become to form the necessary partnerships, contract new customers, and bring the model to scale. The second challenge to overcome was deficiency in infrastructure for furniture as a service. *Reverse logistics* infrastructure was needed for the business model to be successful. As reverse logistics systems have matured over the last decade in the Netherlands, the viability of the model has increased. The final barrier that Ahrend needed to overcome, was the significant internal resistance in bringing the FaaS model to life. Convincing various departments that the company's future direction lay in leasing furniture rather than selling it outright, took considerable time and effort, including developing the business case that such an approach would work in the long term. During a 30 year period, including periodic upgrades of wheels, control mechanisms, textiles, and other components, the potential material savings from keeping such furniture in use, compared to the manufacture, use and disposal of three 'standard' desk chairs, could total more than 4.000 tonnes. or the return of products from customers (*Sourced from The Ellen MacArthur Foundation*).

4.1.2. Case 2- Winnow, U.S.A

Winnow was setup in 2013 with the objective of reducing food waste. Winnow devised a simple way of collecting data on food waste in commercial kitchens, leading to better decision making in food preparation and increasing awareness in kitchen staff. Winnow's data analytics correlates food waste to sales directly by connecting behaviour changes to increased profits.

The insight that led the founders of Winnow to develop the platform was that up to a third of all food that is produced in the world is lost or wasted, with an estimated value of USD1 trillion discarded each year. Furthermore, greenhouse gas emanating from decomposition of post-consumer organic waste is responsible for 5% of global emissions (Ellen MacArthur Foundation). Winnow chose to focus on the hospitality industry, a challenging business sector due its small profit margins, which wastes about USD 100 billion each year. In recent years things have got more difficult, due to competition from new emerging business models (e.g. Uber Eats, Deliveroo) and rising food prices estimated at +7% since 2016 (UN Food agency). This combination of factors makes the hospitality industry very receptive to ways of becoming more efficient. This is where Winnow comes in, offering a simple and novel technology package that helps commercial kitchens manage their food resources in a smarter way.

- Managing the system: Winnow is particularly interested in businesses where food is prepared in advance, for example hotels with daily buffets and universities or companies with staff canteens. In these kinds of catering operations, it was found that over 70% of food waste by value is lost before it reaches the customer's plate, so there is huge potential in just cutting down overproduction. To help tackle this, Winnow has developed a simple system, The Winnow Waste Monitor, comprising a weighing scale and a data recording terminal. Each time a kitchen employee discards food into a bin, the scale under the bin records the weight and the employee is prompted to enter basic information about the type and origin of the food waste (e.g. lasagne, lunch buffet) using large pre-programmed buttons for

speed and practicality. The benefits of the Winnow Waste monitor were realised immediately through increased staff awareness, particularly as the costs of discarded food were displayed by the terminal after each 'transaction'. This is possible as the system assigns cost/kg for every food type or dish offered on the menu. However, the true value of the system lies in the **analytics** generated on a daily and weekly intervals and, for larger companies, across multiple sites. Winnow's revenue model is based on sending out these regular reports, for which it charges a monthly service fee tiered according to the size (in terms of total food costs) of the kitchen. In the first few weeks of the analysis period, clients are requested to collect data without modifying behaviour, to establish a baseline for future comparison. The key outputs are a function of the weight of the food type and the timestamp when this weight was recorded. To add more meaning to this basic measurement, Winnow requests information on food sales during the same time period, so that waste can be normalised against sales, creating a more powerful metric that can be related to ROI and profits. The analysis also provides other useful estimates including the volume of avoided carbon emissions (*Sourced from The Ellen MacArthur Foundation*).

- Using insights for growth: According to the Ellen MacArthur case study on Winnow, the first insight experienced by many customers during the baselining period is that food waste is typically underestimated. This leads to imprecise forecasting and financial planning that use profit and loss accounting methods that are underpinned by this data. Once the baseline is established and the analysis period begins, a typical customer can expect to reduce waste by 40 - 70%, with an average reduction of about 50%. Low margins in the industry mean that this scale of reduction could lead to a doubling of profits in many businesses. Today, Winnow is installed or scheduled in over 1,000 kitchens saving its customers around GBP 9m every year. In the near future, Winnow plans to further develop the technology by improving analytics and reporting and setting up a network for its clients allowing the sharing of insights and knowledge. Once established, this network could be opened up to external stakeholders such as bio-refineries and

other enterprises that require organic feedstock (*Sourced from The Ellen MacArthur Foundation*).

4.1.3 Case 3- NotCo, Chile

NotCo is a Chilean food-tech company producing plant-based alternatives to animal-based food products. NotCo was founded in 2015 and used AI and machine learning to create plant-based alternatives to replicate the taste and flavour of many different types of foods including milk and meat products. It has an AI that it calls “Giuseppe” that is used to create initial recipes. NotCo’s first product was an egg-free alternative to mayonnaise, and the company aspires to launch five additional products in the near future.

- Contributing to a circular economy: NotCo provides plant-based substitutes so that people can rely less on animals for protein, which require a lot more natural resources such as soil and water to grow than their plant counterparts, without needing to change their dietary habits. The machine learning algorithm, ‘Giuseppe’, identifies new plant-based foods and composes food formulas by detecting patterns at a molecular level and analysing flavour molecules. Food scientists then test and taste the formulas and provide feedback to the algorithm to ensure the final product tastes as good as the original one. The scientists also evaluate the feasibility of the algorithm’s output with regards to economics and availability.
- Capturing value: NotCo is positioned advantageously due to the rising sentiment for sustainable food systems. It has a range of food options which adds to its competitive edge, should NotCo decide to venture into overseas markets. While plant-based was already experiencing a boom at the start of 2020, the Covid-19 pandemic has escalated this further. For those who have concerns about the trustworthiness of their meat sources, the most failsafe route is to avoid meat altogether and choose plant based. Couple this with potential meat shortages owing

to meat plant closures and also the longer shelf-life of plant-based products, it's easy to see why plant based companies such as NotCo have experienced such growth.

- Solving business challenges: The solution improves the cost effectiveness of R&D by increasing the speed with which new food sources and ingredient combinations can be identified, tested and iterated. For customers it offers the opportunity to eat healthy and delicious plant-based foods, while satisfying dietary preferences and avoiding a significant price premium. The company has expanded to Brazil and Argentina but each market has its own set of challenges either in the form of taxation or policy and some markets are more open to plant based products while others are not. In September 2020, NotCo raised \$85m in a Series C funding round. Its investors include challenger brand VC fund The Craftory, Jeff Bezos' Bezos Expeditions and others. This funding has likely been used to fund NotCo's US debut in November 2020 (*Sourced from Ellen MacArthur Foundation and HBS Digital Initiative*).

4.1.4 Takeaways from the case studies

An underlying fact from the above mentioned case studies, that is also well articulated by the EMF, 2019 report is that if the current linear model is to be transformed into a circular one, feedback loops need to be established at several stages of product life.

1. Companies like Ahrend are using digital technologies to help keep products in use by managing reverse logistics, creating new consumption models and processes, testing, repairing and refurbishing used products and creating a new pathway for more business to follow.
2. According to the EMF 2019 report, developed in collaboration with Google, reliably knowing the condition of a product (whether electronic devices or

furniture), can be key for consumers to accept a used device. At the moment, where infrastructure, systems and processes that support reverse cycles for consumer electronics, including collection, disassembly, sorting and recycling, are available, they are cumbersome, fragmented and labour intensive.

3. Digital technologies like IoT, Big Data, AI and Analytics can not only be used to make production and existing processes smarter and more efficient, but is also tremendously useful in creating new production processes and new types of products altogether. This, however, requires high amounts of investment in technology and research but there is a payoff, as seen in the case of the above mentioned companies.
4. In the case of organic materials like food and agricultural produce, digital technologies like AI, Big Data Analytics and IoT can improve the information about the makeup of these organic streams that can then make use of valuable nutrients that can be used for a range of other purposes.

4.2 Interview Data Analysis

Table 2. Causes for limited implementation of data in realising circular economy

A common theme among all the interviews was that CE is still a fairly new concept in economics. According to Interviewee 2 (I2), “Until COVID, there was a very slow impetus for CE and digital initiatives. It took a year of work-from-home for digital technologies to rise to a higher dimension and for policy to support that.” There was a strong consensus that for CE, strong policy needs to be in place to encourage circulation. Interviewee 2 (I2) also expounded from experience that in order to implement CE effectively, one needs to be able to make good decisions, *not* backed by intuition. For this, data is needed. In summary, policy needs to catch up to the technological shift and education needs to catch up to it as well.

Causes	Description	Quotes
Perception about CE	<ul style="list-style-type: none"> • Perceived as mere ‘recycling’. • Education about CE itself is lacking. This precedes data awareness. 	<i>“Look beyond recycling.”</i>
Dearth of awareness	<ul style="list-style-type: none"> • Lack of familiarity among people about digital technologies and their usage. • Those who specialise in CE and those who specialise in digital technologies are not necessarily working together • There are silos within companies as well. 	<i>“Education of stakeholders and their cooperation.”</i>
Lack of cooperation	<ul style="list-style-type: none"> • CE requires broad cooperation between parties that are often competitors. • Data sharing in such a value chain might be difficult due to the market positioning of these companies. • There’s an inherent distrust about data sharing 	<i>“Lack of cooperation stemming from mistrust and competition.”</i>
Lack of good quality data	<ul style="list-style-type: none"> • To be able to execute CE effectively, one needs to be able to make sharp decisions. • Data is needed make these decisions • Policies do not fully support it as they should 	<i>“Important to have an infrastructure for data.”</i>

Requires many stakeholders	<ul style="list-style-type: none"> • Implementation is not within the scope of a single company or entity. • Requires many stakeholders to solve the problem and collect data that's efficient enough to make a difference. 	<i>"The onus is not on one single entity alone."</i>
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Table 3. Challenges to circular economy

According to Interviewee 4 (I4), there is a lack of understanding of how to operate in a circular environment. A key challenge is also that there's very little historical interpretation of such a model so there is no viable precedent for industries to follow. This, according to the interviewees, causes companies to view CE BMs as high risk. Therefore, it causes those in leadership roles to gravitate more towards traditional models of logistics, supply chain and the likes.

Causes	Description	Quotes
Barriers to business	<ul style="list-style-type: none"> • Not considered as a viable business opportunity as yet. • Viewed as a tool for marketing campaigns and brand imagery. 	<i>"CE generates revenue streams."</i>
Momentous changes	<ul style="list-style-type: none"> • Too many big changes required from companies, business models, ecosystems and structures. 	<i>"Lot of very big changes need to be made by companies."</i>
Leadership challenges	<ul style="list-style-type: none"> • There still exists a traditional view of business operations in the board and leadership. 	<i>"There is still a limited perception of possibilities."</i>

Lack of data	<ul style="list-style-type: none"> • There is not enough data about businesses that have already successfully moved to a circular model. • The data could build a strong business case that can be provided to companies, which could set a precedent for them. 	<p><i>“Need for a precedent in order to inspire more companies.”</i></p>
Lack of initiative	<ul style="list-style-type: none"> • There’s very little actions towards the actual execution of CE initiatives. • There is not enough understanding of ‘how’ to implement CE in practice. 	<p><i>“More talk, less work.”</i></p>

Table 4. Importance of an open culture around AI, knowledge and data sharing

According to Interviewee 1 (I1), an open culture around data sharing is crucial for CE but some data is sensitive. Hence, there has to be an element of anonymity that will incentivise companies to share the data. All interviewees identified misuse of personal and company data as a possible threat to data sharing and having an open culture around AI. One of the interviewees identified bias in AI algorithm as one of the other possible negative outcomes of this. According to I2, this bias could lead us to enter a new era of inequality. For example, if the AI algorithm used for job recruitment is biased, only certain types of profiles will be given preference over others. I2 stated that, “The implication of this with regards to CE is that there must be fairness for CE to be effective. This should not be only a first world paradigm.”

Reasons	Description	Quotes
<p>Transparency in sharing</p> <p><i>*Negative implication</i></p>	<ul style="list-style-type: none"> Imperative for knowledge, communication and solution sharing. <p><i>*Data safety/misuse of data. Data misuse will make it arduous to regain public trust.</i></p>	<p><i>“Openness in information sharing is at the core of CE.”</i></p>
<p>Effective implementation</p>	<ul style="list-style-type: none"> Having an open culture around data sharing and AI is crucial for implementing CE effectively 	<p><i>“Essential for CE and PSS.”</i></p>
<p>Monetization</p>	<ul style="list-style-type: none"> An open culture around data sharing and AI is very important but the companies developing the algorithms for open source AI should monetise on the development and sharing of the algorithms. For example if a company has developed an algorithm for identifying what’s plastic and what’s not, it should be open but they should charge a fee for it. This is the basis of the API economy (Application Programming Interface) which is a crucial piece of the puzzle in using data to accelerate CE. 	<p><i>“The model must be understood thoroughly for monetization.”</i></p>

Shared cognisance	<ul style="list-style-type: none"> • Outside of CE, there are a fairly good amount of digital processes that are open. For eg GitHub, OpenAi, AWS & TensorFlow. • Culture around sharing is changing. Young researchers today don't believe in hiding or hoarding code/information. • More education processes are needed that make AI accessible to people 	<p><i>“The attitudes towards knowledge sharing is definitely changing.”</i></p>
Business viability	<ul style="list-style-type: none"> • Creating data infrastructure is meticulous work & currently there exists a challenge in finding a business logic around open source infrastructure. • For the sake of data safety, systems need to be partially open and partially closed. 	<p><i>“If any data/information has the potential of adding value, then it must be shared.”</i></p>

Table 5. Key drivers of the transition to CE

All the interviewees highlighted that policy, industry and public opinion/ consumers are the most crucial drivers of the transition towards CE. Over and above these, cultural factors and climate change we identified as the other drivers of change. Interviewee 5 (I5) explained that, “At present, industries and government are shifting their responsibility on consumers and consumers in turn are shifting the responsibility of transition to industries and government. So no one is really taking on the responsibility.” Interviewee 5 also stated that nowadays there are a lot of

companies that are moving towards sustainability because their customers are demanding it. Many companies, especially new startups are sincerely engaging in activism as well. Through observation and industry experience I5 summarised that in the current scheme of things, it can be said that there is also some resistance from consumers because they fear change. However, political willingness can impel people to make a change by means of regulation. Except, said I5, political willingness is still lacking.

Elements	Description	Quotes
1. Policy-making/ regulatory bodies/ government 2. Industry/ company responsibilities 3. Consumers	<ul style="list-style-type: none"> • Regulation may be radical for consumers, especially with regards to fast moving goods (eg. Clothing etc). • Change for companies is completely reliant on policy and regulation (so that there is transparency in production and supply chains). • Public opinion has to be driven by consumer behaviour and right action, which is influenced by the above. 	<p><i>“Policy, industries and consumers together drive the change.”</i></p>
Climate change	<ul style="list-style-type: none"> • Rapid speed in implementation needed to meet the climate target. • There should be a need for a radical shift amongst all the stakeholders, i.e, policy makers, industries as well as consumers. 	<p><i>“There needs to be a sense of urgency amongst all the stakeholders.”</i></p>

Public opinion and education	<ul style="list-style-type: none"> • Consumers must see a pay-off. • Public opinion and consumer choices demand action from industries and government bodies. • However, there is certainly a need to educate consumers to make informed choices so that they are not fooled by green washing. Rather, they understand real impacts, which is hard even for industry insiders. 	<p><i>“There has to be a visible pay-off for consumers.”</i></p>
Cultural factors	<ul style="list-style-type: none"> • The radicalness of the transition to CE depends on the culture one belongs to. For example, it will be harder for the USA compared to the Nordics and most Asian countries. • The importance or value placed on CE, as a matter of priority, also depends on the generation one belongs to. • CE is also something that all social classes must be on board with. Unrealistic aspirations created by some sections go against CE efforts by destroying community values. Hence, there has to be a right marketing of CE, its branding and segmentation for everyone to be on board with. 	<p><i>“For the current generation, who grew up very much aware and sensitised about climate change, there is an urgency about the matter.”</i></p>
Adherence to policies	<ul style="list-style-type: none"> • Policy makers must set rules that companies must abide by. • Even giving out an indication about making any transition towards CE efforts can compel industries to adopt CE. 	<p><i>“The role of policy is most crucial.”</i></p>

Table 6. Key stakeholders in implementing Industry 4.0 for driving the success of CE

Interviewee 4 (I4) mentioned that their experience in the the field of CE and technology led them to discover that one of the crucial stakeholders for accelerating CE is designers in production companies. According to I4, designers in production companies are key for the following reasons-

1. They need to accept that industries need to use more circulated materials as the basis for their products.
2. They also need to realise that the needs of consumers are actively changing towards more environmentally friendly/ circulated products.
3. The way products are designed and produced has a huge impact on how they can be circulated.

I4 also pointed out that companies that provide data to the designers or the companies that these designers works for, must understand the real impact of goods production. I4 shared the example of L&T Finland, which has been influential in creating data essential for circulation itself. Apart from this, there was an overall consensus amongst the interviewees that policy makers/ regulators, industry and consumers are the most important stakeholders for the implementation of Industry 4.0 for driving the success of CE. All the interviewees emphasised that the state and municipality have a much higher responsibility upon them because they have to create the infrastructure for CE and the basis for data sharing across the board. It is the responsibility of the state and municipality to make laws that require industry to share data, as also, laws that consumers are required to abide by. I2 elaborated that in addition to the above stakeholders, early childhood education could be the key that unlocks the challenge. I2 used Finnish education as the perfect example for this stating that schools in Finland begin educating children from early childhood, up to

tertiary education about sustainability, also stating that educational institutions play a crucial role in paving the path for Industry 4.0 towards CE for the younger generations.

Entities	Description	Quotes
1. Policy-making/ regulatory bodies/ government	<ul style="list-style-type: none"> Government bodies are responsible for funding innovation and important research projects and plans. 	<p><i>All the interviewees emphasised that the state and municipality have a much higher responsibility upon them because they have to create the infrastructure for CE and the basis for data sharing across the board.</i></p>
2. Industry/ company responsibilities	<ul style="list-style-type: none"> It is the responsibility of companies to educate people to make a shift in their actions. They must do so themselves first by reducing their carbon footprint and showcasing their actions. 	
3. Data companies		
4. Consumers and public opinion	<ul style="list-style-type: none"> Data companies providing data to industries must understand the impact of goods production. 	
5. Educational institutions	<ul style="list-style-type: none"> Public opinion has to be driven by consumer behaviour and right action, which is influenced by the above. Early childhood and tertiary education paves the way for Industry 4.0 towards CE. 	

4.3 Managerial implications

Based on the secondary data accessed through the case studies and primary data gathered through qualitative research, the researcher developed a diagrammatic representation below (Figure 3) of the use of AI, Big Data and IoT for the

implementation of CE. The diagram has been adapted based on author Americana Chen's work on the business potential of using AI for CE, in 2019 and 'CE Activities Value Chain', developed by Michael Hanf, Executive Partner at Taival, in 2017.

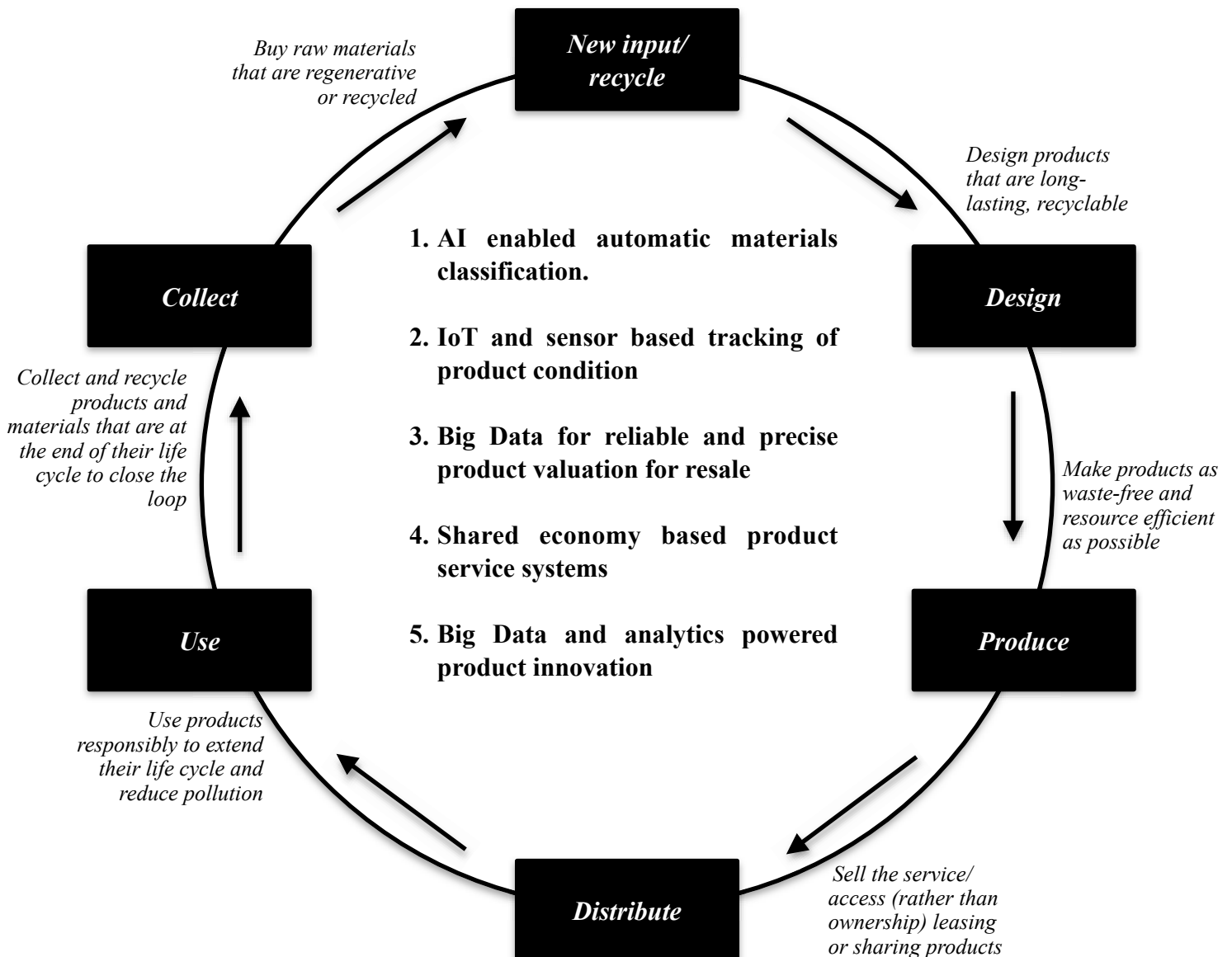


Figure 3. The role AI, Big Data and IoT in the implementation and acceleration of

Sections 4.1 and 4.2 both place high emphasis on the role of data as an enabler of CE. But in order to leverage data and digital technologies optimally, there needs to be a strong infrastructure in place. According to Interviewee 1, the realisation of a circular economy requires a better understanding of where the raw materials of products come from, how the products are utilized and what happens to them after use. The product must be accompanied by information that can be followed. This is precisely where the expedient role of digital technologies especially AI, Big Data and IoT comes in because in a circular economy, knowledge is power.

Data from the case companies, i.e, Ahrend, Winnow and NotCo as well as the qualitative data demonstrate this inference. This coupled with the interviewees' accentuation on data sharing and having an open culture around it, corroborate that information must be decentralised because it leads to knowledge and solution sharing. All the interviewees unanimously agreed that any entity having a requirement of intelligence necessary for addressing particular set of challenges should be able access it. But they also emphasized that there have got to be policies and regulations that fully support CE and digital technology in order for this to occur. By combining the take key takeaways from the case studies and the interview data, the researcher was able to identify that digital technologies like AI, Big Data, Analytics and IoT can unravel three promising prospects for CE which are in complete alignment to the thematic literature in section 2.6.

1. Designing of circular products, components, and materials

2. Operation of circular business models

3. Optimization of infrastructure to ensure circular product and material flows

According to Interviewee 1, a better understanding of the product life cycle will make procurement more sustainable, facilitate the construction of resource-efficient service models and facilitate the recycling of product materials. The case study of Ahrend and interview data also reflect that raw materials can be utilized more

efficiently when material flows are better known. In an article authored by Interviewee 1, it was expounded that in knowing the currents, it is possible to close the material circuits/ loops (www.peryritys.fi). Sharing knowledge enables the emergence of local ecosystems and the formation of entirely new value chains. In summary, the advancement and usage of digital technologies like AI, Big Data and IoT can not only help in making processes more efficient, but it can also help in creating a valuable market for the exploitation of material flows.

5. DISCUSSION AND CONCLUSION

5.1 Discussion

At the crux of the research findings is the fact that there is *not enough data available* for effective CE implementation. Quality data needs to be generated and gathered by industries and data companies. As per the interviewees, solid processes for gathering data at currently still lacking. An example of this, as shared by Interviewee 4, is a need for data models that track material flows, for instance plastic. Organisations responsible for collecting this data must collate it in a manner that is shareable and usable for the other entities involved as well. Interviewee 5 mentioned that since no single body possesses all the data required to carry out CE operations, there must also be cooperation in data sharing from different organisation within the ecosystem. Under the current scheme of things, data companies are not willing to share this information with public organisations. Companies don't want to share their data because it could imply a competitive disadvantage for them (Lehtonen & Esono, 2018). Even so, since the past year, COVID-19 has brought about an unprecedented acceleration in the adoption of digital and data technologies. This has enunciated further the need for a decisive and fundamental structural change in the dynamics of how we live.

As per Interviewee 2, at present, data collected by most companies cannot be termed as good quality, usable data. Dalenogare et al. 2018, concluded that Industry 4.0 innovations tend to be cherry-picked by enterprises, especially in developing countries. Businesses in those countries prefer the use of low-end technologies (e.g., tracking and management technology), and not the full suite of support tools (e.g., data analytics) that comes with Industry 4.0. This reluctance creates situations where data is collected but not optimally used to support decisions. In the EU, the implementation of big data infrastructure played an important role in the readiness of big data analytics and the implementation of Industry 4.0; differences in

infrastructure quality (e.g., internet connection speed) directly affect the capacity to utilise Industry 4.0 (Pham, T.T et al).

During the interview, Interviewee 2 observed that data has CE to it as well. Meaning, if data can be reused, it is worth a lot more. Therefore, we can infer that it is essential to derive such kind of data in order to develop a good business case around it and sell it to industries and policy makers, since, as underlined in section 4.2, Table 3, there is no historical precedent of circular and PSS models for them to refer to. Interviewee 2 (I2) also stated that outside of northern Europe and UK, Circular Economy is still somewhat of a buzzword. Hence, according to I2, the key question, *“What great things can be achieved with digital transformation trends, apart from making money?”*, is still conspicuously missing in the business realm. According to the interviewees, there is also a general misconception that CE won’t bring a business profits or generate revenues and that needs to change because, according to them, that is far from the truth.

5.2 A radical shift

The need to shift to a CE should be radical for all the stakeholders involved, including consumers. However, as substantiated by Bressanelli et al. 2018, the transition to CE also implies adapting to the new way of closing product loops, which will affect all the stakeholders involved. The analysed data in sections 4.1 and 4.2 indicate that consumers stand to benefit the most from the transition to a CE because of the various new kinds of services that are to emerge. According to Interviewee 5 (I5), consumers are already adapting to sustainability driven changes because of the ongoing shift in mindset. I5 said from experience and personal observation that more than consumers, companies are bound to face a challenge in terms of transitioning to CE due to the upheaval/shift in operations, processes and business models.

During one of the interview sessions, it was Interviewee 4 (I4) who said that consumers can be trained by industries to adapt to CE but the issue with training consumers is that it implies, by default, that the industry/company is trying to create a market, which, in hindsight, has been proven to be counterproductive. Therefore, it is more so the role of regulatory bodies and municipalities to ease consumers into adopting CE. I4 also added that consumers do, however, have upon them the onus of behaving responsibly so that they ultimately make informed choices based on what best suits their consumption needs. But overall, it must be a joint effort between the regulator/ municipalities and industries to transform the products and production methods so that the impact on consumers is not extreme. In doing so, it will become a natural choice for consumers to be more circular. Through observations from sections 4.1, 4.2 and in tandem with Bressanelli et al. 2018, this process naturally becomes much more efficient once combined with data. So, it can be said that efficient use of data could also lead to better informed consumers who are able to grasp the full extent of the impact of the manner in which products are produced and aren't fooled by greenwashing. As per Interviewee 2 there is also a need for 'disruptors'. Disruptor, according to I2, are not what's known as 'mainstream' industry. These companies are born with a shared economy mindset which is essential for participating fully in a circular economy. Herein, stakeholders within the ecosystem make use of the externalities of each other as sustainable resources for 'new' products for their own production cycles, which closes material loops.

5.3 Industry 4.0 for PSS

In accordance with Camilleri, M. A. (2019), PSS is a business model for CE. There are enormous possibilities for the use of data in this business model to enhance CE. Based on the use of data, there might be opportunities to develop many more business models. According to Interviewee 5 (I5), more data implies more possibilities, depending on the industry/ field. I5 mentioned that if data is collected

effectively, better services can be provided to consumers; very individualised services. Services that can be made so smart that they can predict one's decisions. In connection to CE this implies that data and PSS are the very essence of moving to a CE. I2 mentioned during the interview that it is old-fashioned to sell products and services. *“What we are selling is outcome and experience and Industry 4.0 tools, especially AI, Big Data & analytics, IoT and Cloud based systems play an enormous role in enabling that”*, I2 stated. According to the report developed by Ellen MacArthur Foundation, in collaboration with Google in 2019, developing successful and profitable circular business models requires the organisation of business functions such as marketing, pricing, and sales, after sales services, customer support, logistics, and reverse logistics, underpinned by circular economy principles. It involves introducing new business propositions such as asset sharing and product-as-a-service, but also making existing circular products compete successfully with linear ones. The report also highlights that dynamic pricing and matching algorithms have unlocked the potential for sharing and access models for things like cars and bicycles – other industries are ripe for innovative circular business models, too. Making reverse logistics and remanufacturing work requires solving several problems, including the fluctuating demand and supply of used products and components, and the widely varying condition of the returned components (Ellen MacArthur Foundation, 2019).

5.4 Challenges to companies moving towards a circular model

One of the main challenges, especially from the point of view of industrial production companies is their high investment on a certain type of supply chain that carries huge volumes. Hence, as per I4, changing existing processes abruptly and making investments in new models (circular systems), is problematic for them. Since business cases around CE are few and far between, there's a combination of *big investment, unknown risk* and *somewhat unknown rewards* for these companies, that

are key deterrents for them in adopting circular systems. According to I5, nowadays, however, there is a genuine desire amongst most multinational companies to take affirmative action in the direction of CE. With regards to this, I4 observed that while greenwashing still persists, the affirmative action of companies towards CE is not so much based on their desire as it is on the recent ramping up of *regulation* and *policies* that require them to adhere. Their knowledge in industry experience inspired I2 and I4 to highlight that the leadership of these companies also pose a stumbling block to CE. The leadership doesn't fully grasp the concept of CE and typically, the management belongs to a different generation. A generation that was indoctrinated in the linear system, that only views the bottom line bottom line profits and dividends as the determinants of success.

On the supply chain side, the 'want' to source the lowest priced inputs is a detriment for CE too. According to I2, while the transition to CE must ideally be driven by regulation and policy, it has become a political issue in most regions. The reasons for this vary from region to region. I2 shared that amongst companies who are making sincere efforts towards CE and paving the way for others are Adidas, IKEA and H&M (to name a few). Adidas has been using ocean waste to design its clothing line by sponsoring communities that live on coastlines to collect ocean plastic. H&M has been making serious efforts as well to redeem itself from its 'fast fashion' persona by producing clothes from recycled yarn manufactured from pre-owned clothes. Another example is IKEA's online platform for second-hand furniture that stemmed from the insight that people tend to upgrade their furniture as they go up in life.

5.5 Challenges to new companies that circular from inception

According to I2, companies that are circular from inception are enablers of circulation of products. In this context I2 provided the example of **Tori.fi**, a leading online buying and selling marketplace in Finland and explained that these are the type of companies that are termed as 'disruptors'. A major roadblock for such

companies is changing the mindset of people. In this context, I4 said that another challenge for platform operators such as Tori.fi is managing to get more private individuals to share more and more resources/ used materials on their platform. “For companies who are trying to get rid of their waste, (produced by them as a part of their business/ production processes), the challenge is identifying companies that will buy their waste materials from them”, I4 said. An issue for recycling/ refurbishing companies, as seen in the case of Ahrend, is the monetary challenge. Compared to other business, the monetary investment for recycling/ refurbishing companies is far higher. I4 explicated that in order to offset this, these companies need to create a premium product with the refurbishment that is comparable to a brand new product, while keeping the raw/ new materials needed to create that ‘new’ product, as low as possible. Alternatively, they need to be able to amass major volumes of materials in the market so that it offsets the low cost per item on the basis of the volume. The challenges to these companies also vary according to the market/ industry of the companies.

In accordance with Ellen MacArthur Foundation (2019), for a company to choose the next use cycle for each returned product – such as reuse, recovering components through parts harvesting for remanufacture, or recycling – it would have to take into consideration a combination of factors regarding the product’s condition, as well as the current market situation. Only with the ability to collect large quantities of product and customer data, and a powerful AI-based analytical model to make sense of it, does such a decision-making model become feasible. Using an AI technology creates the potential to cut inventory levels, without compromising the ability to meet customer demand. This could lead to a big reduction in waste from unsold products, as well as a reduction in cost (Ellen MacArthur Foundation, 2019).

According to I2, another key challenge to new, circular companies is branding. Companies like Adidas, H&M and IKEA have an advantage because they are well established brands. Unknown/ new companies struggle with branding. I1 shared from experience that for new companies that are circular from inception, such as Kamupak

Oy, there is the added challenge of training both consumers and companies (Kamupak's clientele) about circularity and the usage of their circular products. According to I1, the task at hand for a company like Kamupak is to train both these partners simultaneously. But I1 also expounded that while the challenges to new, circular businesses are many, it also presents many opportunities and revenue streams. All the interviewees shared the sentiment that when companies only see the superficial benefits of CE, they reduce CE to a mere marketing gimmick. "In today's era, being circular gives businesses a definite competitive edge over the rest of their linear counterparts", said I1.

5.6 Challenges to data in aiding CE

The main challenge, as outlined previously, is the openness around data. According to I5, companies and people operating in and around the field of CE are often reluctant or do not possess an understanding of digital technologies so they are unable to identify the opportunities when they arise. As per I4, an essential aspect of digital technology or Industry 4.0 is the API economy. API stands for Application Programming Interface. It necessitates the need for cloud computing. *"API economy creates standardised, open and easy integration points between companies"*, explained I4. The inference here is that there have to be proper platforms that use all the Industry 4.0 tools like AI, IoT, Big Data and Analytics to enable data sharing. This requires a strong digital and data infrastructure, which, according to the five interviewees, is not fully there yet. As per Lehtonen & Esono (2018), amongst the many things that need to change for CE to thrive, is the need for companies to open up culturally. I4 said that once this happens, there must be an API economy type sharing system where companies learn to capitalise on their (now) open data channels.

Through experience I2 stated that on the user interface side, it is challenging to make the concepts of data as well as CE understandable to people. For this, I2 explained,

smaller companies must find their own path to create a UI/UX that adds value to both, the CE system as well as the users. There was a consensus amongst the interviewees about the fact that in order to make sound decisions on CE, it is essential to understand how users are behaving which can be brought about only by effective policy. I2 also said that, “A state’s GDPR must also incorporate and serve CE”. For this, it must also lay emphasis on how the acquisition of data can support CE. Policies must clearly outline rules to ensure ethical practices for the acquisition of data, collected via digital tools like IoT, cloud computing and platform services, Big Data and AI. Pham, T.T et al. 2019 state that in the case of data, especially from IoT (sensors), (which is used a lot nowadays to collect data within our economies), converting it into a *standardised, shareable format*, proves to be a setback. According to I4, companies are very protective of this data because by sharing it, they risk losing their competitive edge over their industry rivals. But sharing it is extremely essential for CE processes. Therefore, we can infer that there must be a balance between competition, cooperation, finding good quality data and having policies that support data sets.

To sum up, the challenge of transition and the need to accommodate the rapidly growing population in a world of finite resources is so enormous that no actor can address it alone. It will require collaboration within and between all sectors of society: governments, the private sector, academia, non-government organizations and the public. *Powering the circular economy by providing digital solutions and closing the information gap is probably the best investment that technology companies of our time can make (Ellen MacArthur Foundation, 2019).*

5.7 Pressure on the service systems

For PSS, data is at the core of the business model (Bressanelli et al. 2018). But, according to Bressanelli et al (2018), one possible risk of servitisation models is that consumption possibilities may go higher because it expands one’s options to

consume more. This could possibly prove to be an issue in the long run. According to I2, in the current scheme of things, PSS and rental models have done well in certain regions and haven't done well in some others. I4 stated that overuse of the PSS system is something that companies must learn to anticipate to be able to cleverly limit overuse and disallow misuse of the system. For example, according to I4, an effective method to deploy in order to avoid over consumption, is to charge a fee to consumers if they wish to order more and more products from the rental services. Thus, in accordance with section 4.2, Table 4, it is all about understanding the business model thoroughly and monetising it. On the other hand, in the same context, I2 elaborated that if a company possesses personal data of individuals and companies, they have a responsibility to use it ethically and acquire it through ethical and justifiable means.

Even though this is also something that has to be policy driven, I1 and I2 stated that industries should not wait around for legislations and policies to be put in place first because that would be pernicious to the climate crisis and the UN Sustainable Development Goals (UN SDGs 2030). The initiative or the push for change should come from the industry since it affects their production and profitability directly. There are specific industries that require policies and regulations to enable their actions towards CE, whereas there are some other industries where the companies themselves are the driving force. In accordance with Bressanelli, Perona and Sacconi (2017), when companies make their products smarter and start generating data from them, they are able to manage logistics, maintenance and other aspects of the product's lifecycle efficiently. By using data, they also eliminate the need to re-order the product because it is monitored and well maintained. Thus, it was deduced, in tandem with sections 3, 4.1 and 4.2 that the circular economy model, enriched with the synergies of technology is a powerful and potentially highly productive combination.

5.8 Limitations and scope for future research

This study was designed to have a broad scope. Hence, it does not limit the course of its findings by viewing it through the lens of any specific business theory. Previous research in this topic has been developed by researchers in relation to specific products/ industries (for instance electronics), a specific digital technology, or a specific business model. By referring to these papers, this study encompasses and correlates all these elements by discussing fundamental concepts and exploring key factors that influence the transition to CE.

This study is set against the backdrop of a global pandemic, COVID-19. While the role of the pandemic in accelerating the adoption of digital technologies has been acknowledged, this research does not fully delve into the implications, challenges and opportunities of CE in relation to the pandemic. The topic of CE and Industry 4.0 is as deep as it is wide. Hence there is a lot of scope to explore and broaden each sub-topic within the ambit of CE and data technologies mentioned herein. Owing to the limitless possibilities in the nexus of these topics, this thesis is an effort in the direction of scratching its surface. Within Industry 4.0 itself, there are barriers and problems that still require extensive research. These barriers include the role of regulation and policies and cultural feasibility of business models such as Product Service Systems. The role of legislation and effective policies for the implementation and furtherance of CE and digital technology is huge topic in itself that needs to be explored. Moreover, this paper does not examine all the other digital technologies within Industry 4.0. The chosen technologies, i.e AI, Big Data and IoT, were selected based on their far reaching usage across industries. However, the specific functions of other technologies within Industry 4.0 such as cloud computing, Robotics, Cyber Physical Systems (CPS), Application Programming Interface (API), and 3D modelling for CE must also be extensively assessed.

APPENDIX

INTERVIEW PROTOCOL

1. It is widely known that data/digital technologies can help in the acceleration of CE. But why do you think that there is still very limited implementation?
2. What according to you are the true challenges to CE today?
3. From your experience, what are the main challenges faced by companies who wanted move to a more circular model in the various operations?
 - Do you think there is a genuine desire among companies or are they just joining the bandwagon because it's a 'trendy' thing to do (read greenwashing) ?
4. What are the challenges for companies who are circular from inception, for eg, electric vehicle companies, recycled/refurbished furniture companies, etc?
5. What are the challenges to data/digital technologies for aiding CE?
6. What would you say is the most important component for the acceleration of CE amongst the various components of Industry 4.0 (such as Big Data, API, Analytics, Ai, Cloud Computing, IoT, Robotics). Why?
7. What would you say about the need to establish digital processes for an open culture around AI?
 - How imperative is it to aiding CE efforts?
 - What could be the negative outcomes of this especially with regards to CE?

8. In your opinion, how radical would the transition to CE be for consumers? How much time do you estimate it will take for consumers to fully adapt?
9. Do you think industries can train consumers to make this shift in their way consumption? Are we ready for it?
10. Who, in your opinion, are the crucial stakeholders in implementing industry 4.0 and its success for driving and accelerating CE?
11. The transition to CE for smart cities, electronics and fashion industry is well known. How can CE be applied to industries like agriculture?
12. How much can data help the process?
13. How, according to you, can data/ industry 4.0 tools better implement Product service Systems?
 - Will adopting Product Service Systems place an added pressure on the service system/provider?

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