Digital circular economy

a cornerstone of a sustainable European industry transformation

White Paper - ECERA European Circular Economy Research Alliance

ECERA

Research and Technology for Circular Economy in Europe

Digital circular economy as a cornerstone of a sustainable European industry transformation

White Paper - ECERA European Circular Economy Research Alliance - 20 October 2020

Authors:
Holger Berg (Wuppertal Institute)
Kévin Le Blévennec (VITO)
Eivind Kristoffersen (SINTEF)
Bernard Strée (CEA)
Arnaud Witomski (CEA)
Nicole Stein (Wuppertal Institute)
Ton Bastein (TNO)
Stephan Ramesohl (Wuppertal Institute)
Karl Vrancken (VITO)

ECERA is a voluntary collaboration network between European RTO's, with the aim to strengthen and integrate scientific knowledge and expertise in the field of Circular Economy from an interdisciplinary perspective. We bring together 10 leading European research and technology organisations with high relevance in the R&I field for Circular Economy in Europe: CEA (FR), ENEA (IT), IETU (PL), IVL (SE), SINTEF (NO), Tecnalia (ES), TNO (NL) VITO (BE), VTT (FI), Wuppertal institute (DE).

Table of Contents

Introduction

This white paper explores the role of the digital transformation in the development of a circular economy. We argue that the use of digital technologies represents a major opportunity to scale up the circular economy and provide ideal types of solutions with a special focus on industrial settings. We also show some risks that need to be carefully assessed in this development. The paper provides a vocabulary for the digital circular economy and provides insights to industry players on how the digital technologies can generate added value if put in a circular perspective.

The circular economy is one of the key elements in the European Green Deal. It aims at renewing the existing production and consumption system. Its goal is to optimise the functionality of products and materials, and to maintain this functionality for as long as possible, while minimising the production of waste and residues.

Digital technologies are an enabler for the upscaling of the circular economy as they allow to create and process data and information required for circular business models and the complex demands of circular supply chains. The circular goals of optimising functionality on the one hand and developing products-as-a-service on the other, call directly upon digital technologies such as functional electronics, distributed ledger and Internet of Things. The aim of dematerialisation can be closely related to the development of digital twins, artificial intelligence and virtual reality. At the same time circular economy provides the necessary long-term sustainability vision for the upscaling of the digital industry.

In the following chapters we will show how digital technologies can scale up circular business models and close the information and transparency gaps that currently slow down the scale-up of the circular economy. Chapter 1 provides a closer look at the nexus of circular economy and digitalisation. It is specifically aimed at readers who are not familiar with the concepts. Chapter 2 will provide insights into focal points where such improvements can take place. We begin with the role of data and how data can be created as the basis of information processes towards a circular economy (section 2.1). 2.2 addresses the need to transfer and process data for circular purposes. It showcases how this can be done by the use of functional electronics. To understand patterns better, to create matches for circular supply and demand, and to even discover new opportunities, requires fast and precise analysis of an ever-increasing database. How this can be achieved by the use of artificial intelligence is discussed in section 2.3. Chapter 3 will then turn to the sustainability and circular aspect of digital technologies and explore the opportunities provided by the circular economy to the digital transformation. Until now, digitalisation has mostly ignored sustainability issues. Therefore, many digital technologies and processes in the digital economy are far from sustainable. They result in high resource and energy demand; some also accelerate negative effects in other industries, for instance, due to increased consumption and difficulties in waste management because of the low viability of recycling, whereas other strategies to reuse, repair, remanufacture are at still at very early stage in this domain. We argue that the principles of the circular economy offer direct ways to make digitalisation more sustainable and thus show that the circular economy and digitalisation may indeed become self-reinforcing developments. Chapter 4 discusses the findings made. It provides specific opportunities and suggestions for the regulatory, investment and innovation context.

1 Enabling the Circular Economy by Digital Technologies

1.1 Making the circular economy digital and the digital economy circular

The circular economy aims to reduce resource use by recycling of materials, reusing products, extending their lifespan and maximizing and maintaining their economic value. This has both economic and environmental benefits (EEA, 2016). All this contributes to limiting the material related greenhouse gas emissions and to decreasing the material intensity and environmental footprint of the economy. It is important to realise that the implementation of a circular economy is a necessary step towards reaching the climate goals and increasing the resource and energy efficiency of Europe.

Creating a circular economy requires fundamental changes throughout the value chain, from product design and technology to new business models, new ways of preserving natural resources (extending product lifetimes) and turning waste into a resource (recycling), new modes of consumer behaviour, new norms and practices, and education and finance (EEA, 2019). From a business perspective, several circular strategies can be followed, as displayed in Figure 1.

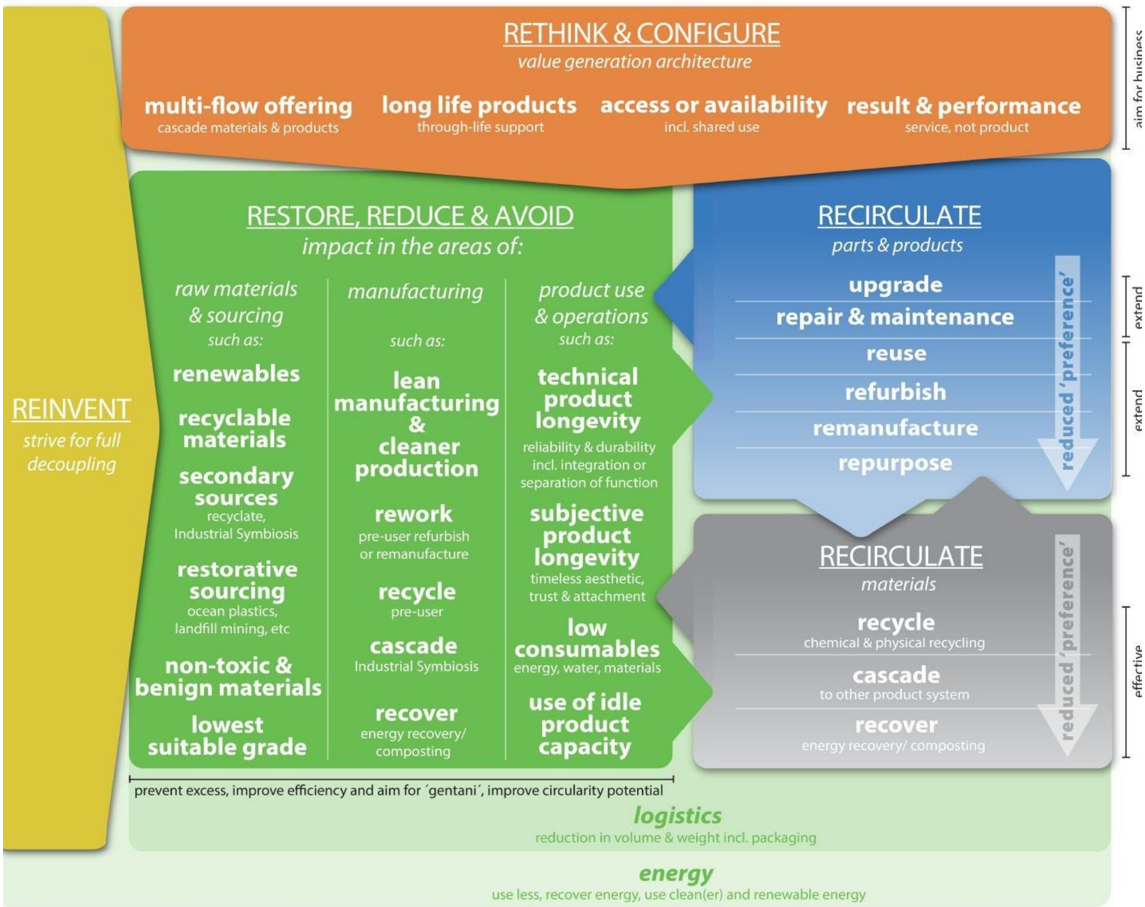

Figure 1: Circular Strategies (Blomsma et al., 2020)

Circular economy has found implementation in a variety of **sectors and companies** (Circulator, 2020). After an initial phase of experimentation by start-ups and SME's, we can now also see large companies and multinationals stepping into circular approaches. Whereas large companies tend to focus on optimizing their waste flows and internal processes, small companies integrate entirely new business approaches (WBCSD, 2018). Also, many digital circular business innovations are not only initiated by companies within a certain sector but are driven by start-ups that do not have a legacy of existing customers, shareholders, employees, capabilities, etc. (Rizos et al., 2016). The current challenge is to scale-up the circular economy and make it move beyond initiatives that are merely focused on the recycling of material, towards new sustainable consumption/usage and production models.

1.2 Towards a digital circular economy

However, the circular economy is based on a strong integration and connection of the value chain as quality and predictability gain in importance. Higher degrees of transparency and information are required, while information deficits currently need to be overcome to further develop and to scale the circular economy (Wilts and Berg 2017). As producers seek to manage their products and materials throughout their lifetimes, not just until the exit gate of their own factory, they need to know the suppliers of their suppliers, the customers of their customers. Hence, also new concepts of product and material ownership emerge which demand new ways of transactions, monitoring and control.

All this interaction requires connectivity and data integration. When also data analytics (e.g., machine learning) is added, new services can be developed (Kristoffersen et al., 2019, 2020a). Therefore, digital technologies provide the basis for the development of circular business models. As shown above, circular entrepreneurs want to have and need to have intelligence about their products and their users. In a circular business model such as the sharing of machines, tools or cars, quality of the service and customer satisfaction is determined not only by the quality of the physical product (e.g., the car), but even more so by the quality of the digital service, e.g. the app through which the user can make a reservation, book, make a last-minute change or see where the product can be found. The digital part of the business determines feasibility, usability and customer (or rather user) satisfaction. If we want to strengthen and scale up the circular economy, there is a need to further integrate digital technologies like the Internet of Things, big data and artificial intelligence into existing circular business approaches to provide such services and information. More generally, digital transformation offers opportunities to the European industry for building competitive and innovative business models based on circular economy principles (Futuring, 2018).

The use of digital technologies can benefit all circular strategies displayed in Figure 1, three main application levels are thus distinguished:

- **Processes**: technologies that allow higher efficiency and circularity in **processing** of materials and **manufacturing** of products: *robotisation, additive manufacturing, digital design, sensor technologies, machine learning,..*

- **Products**: technologies that allow **tracking** and **tracing** of products and components, value chain optimisation, development of products as a service, increase reuse, repair, refurbishment: *IoT, blockchain, digital twins…*
- **Platforms**: technologies that **connect** consumers and producers, allow development of services and **dematerialisation**, industrial symbiosis: *apps, websites,..*

Digitalisation is the key enabler for **upscaling** the circular economy. This involves stimulating the growth of existing small businesses as well as circular business approaches in large companies. Both aspects can be supported by the broader implementation of the Internet of Things, big data and data analytics.

In line with the emphasis given to the role of digital technologies for accelerating the transition towards a circular economy within the new Circular Economy Action Plan, being a building block of the European Green Deal, a Strategic Research and Innovation Agenda for circular economy has been recently published in the framework of the H2020 project CICERONE that puts digital technologies at the core of many key innovation fields (waste management, industrial symbiosis, products traceability) (CICERONE, 2020). Still at a policy level, the EC's President stressed in her Political Guidelines "the need for Europe to lead the transition to a healthy planet and a new digital world" explaining that this twin challenge of a green and digital transformation has to go hand-in-hand. To turn those ambitions into reality, in March 2020 the EC released a New Industrial Strategy for Europe, stressing the leading role that European industry must play in this transition towards a more climate neutral and circular economy. The digital circular economy thus provides the link between the New Industrial Strategy for Europe (European Commission, 2020a) and the European Green Deal (European Commission, 2019). It is the culmination point and field of action to create a greener and prosperous EU, as it is this area where activities take place.

It needs to be stated that digitalisation can lead to unsustainable practices. As it is largely technologically-driven and turnover-driven following linear production and consumption levels, the introduction of smart technologies and automation may lead to increased consumption behaviour, energy use and environmental impacts. The digital industry in itself has a large environmental footprint and energy intensity. Its development needs to be coupled to the introduction of renewable energy sources. IT products typically have a relatively short in-use lifetime, although the hardware may provide for longer use. Therefore, the environmental and societal impacts of the digital technologies themselves must be carefully assessed, and circular principles must be embedded in the digital products, as a condition to their deployment in the economy, to ensure a global net positive balance. Digitalisation can use circular economy as a guiding principle, a target to reach a sustainable end-point.

At present, the Critical Raw Materials Action Plan (European Commission, 2020b) raises the issue of European import dependence for key elements that enable renewable energy and climate-proof technologies. Materials such as Lithium, Cobalt, Platinum, Rare Earth Elements feature on the CRM list. The digital technologies are also dependent on the availability of critical raw materials.[1] The challenge will hence also be to develop the digital circular economy in such a way that the digital technologies compensate for the need for materials that they are made of. This is a strong call for the introduction of principles of dematerialization, life time

[1] CRMs used in digital technologies are typically: In, Ga, Ge, Sb, Sc, W, Pt, Ru, Co, Ta, Hf

extension and recycling into the digital systems that build the circular economy. Therefore, it is important to realise that we will not build a circular economy next to the new digital economy. We need to make sure that the real digital economy becomes circular.

2 From Data to Intelligence

2.1 Creating the basis – The need and opportunities for data

2.1.1 The Data Economy

We are living in the 'Age of Data' with an unprecedented amount of data available and produced at a constantly growing rate (McAfee et al., 2012). Data has never been as important for enterprises, and other entities, as it is today and may even become the biggest trading commodity of the future (Xiao et al., 2014). In fact, in recent study from the Confederation of Norwegian Enterprise, Norway's value creation potential from data is estimated to surpass that of oil and gas by 2030 for a total of EUR 30 billion each year (Skogli et al., 2019).

As a result, data analytics have rocketed to the top of firms' and governments' agendas along with claims that 'data is the new oil' that is to be refined to extract unprecedented value (Brown et al., 2011). The capacity to gather, process, structure, and use data in decision-making is increasingly seen as a source of competitive advantage for firms (Mortenson et al., 2015; Provost and Fawcett, 2013). Figure 2 shows that there is a strong interrelation between four core digital technologies: the Internet of Things (IoT), big data, artificial intelligence (AI), and Distributed Ledger Technologies (DLT). However, in order to be able to explore the integration of these digital technologies with the circular economy, it is important to first understand and appreciate the underlying ICT processes, principles and culture. Moving from the outer side of the sphere towards the centre (blue) provides increased structuring and production of information, whereas the central spots (green) represent knowledge building.

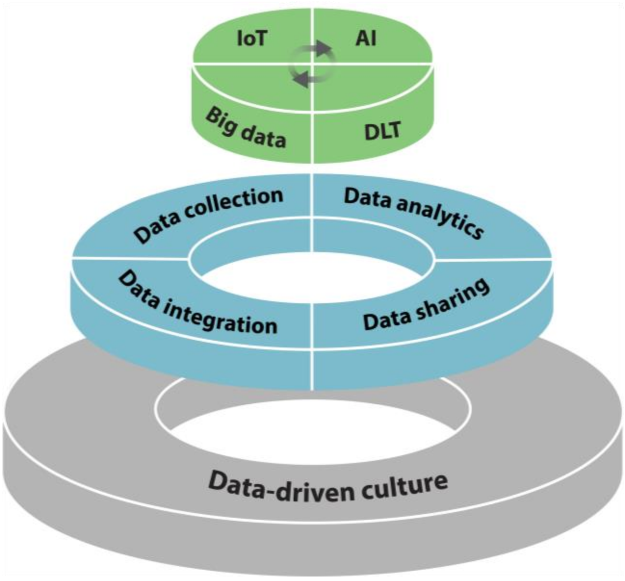

Figure 2: Structural view of the data economy

Circular business approaches need information pertinent to the location, availability, composition and condition of products, components, and materials that allow for the effective cascading or extension of its lifecycle (EMF, 2016). The transition towards a circular economy will require enhanced and supply chain-wide coordination of material- and information flows. Consequently, data and analytics are expected to leverage circular economy adoption to a level of transformation never before achieved.

2.1.2 The Smart Circular Economy Framework

The smart circular economy framework (see Figure 3) establishes a link between digital technologies and resource management, using an integrative maturity approach. The framework provides a detailed understanding of the relationships and underlying technical mechanisms of a digital circular economy. It couples increasing levels of data integration and analysis to higher resource optimization capabilities, and therefore circularity.

The framework allows assessment of different digital circular economy strategies with their associated level of maturity, providing guidance on how to leverage data and analytics to maximize circularity (i.e. optimizing functionality and resource intensity).

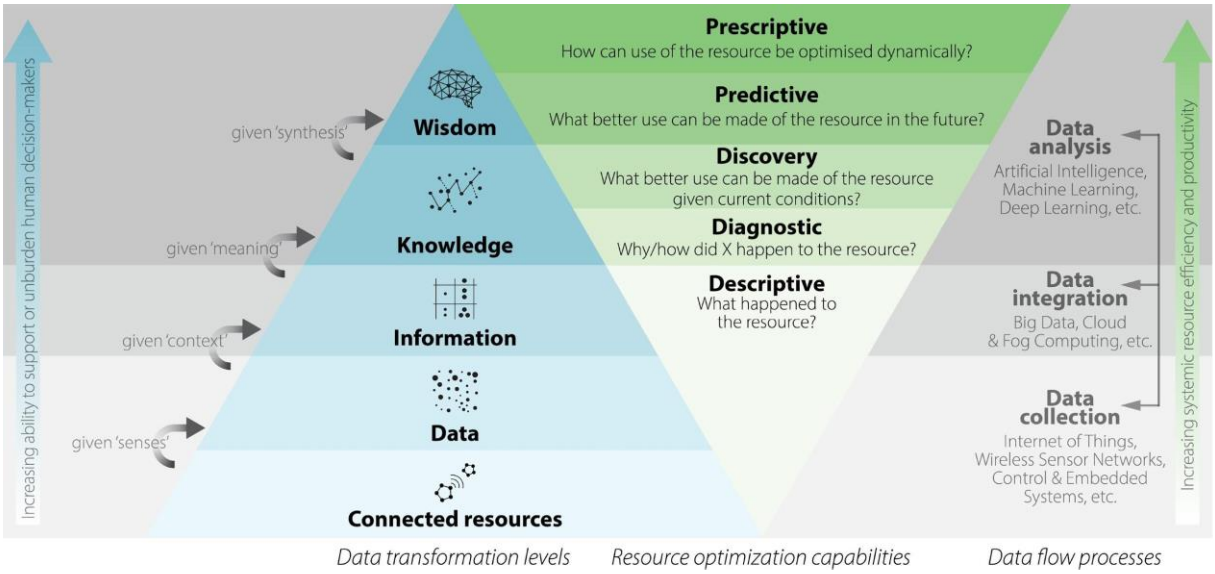

Figure 3: The smart circular economy framework (Kristoffersen et al., 2020a)

Digital circular practice in the manufacturing industry

A survey among 70 companies from the equipment manufacturing industry in The Netherlands has revealed that many technological and business model innovations could be framed as being circular, often without the companies themselves being aware of that framing. The circular innovations that were identified in these cases were related to advanced refurbishment and re-use, smart maintenance, upgrading and repair activities (extending lifetime of assets) and business model innovations known as as-a-service concepts. Moreover, among these innovations many were driven by the ICT driven collection and subsequent analysis of data. Here, we will introduce briefly some of these archetypical innovations.

A producer of milking robots set up a web-based marketplace for used equipment. The quality and related warranties of these assets could only be given on the basis of the continuous monitoring of the performance of the assets during their functional lifetime.

A producer of e-bikes for people with a disability connects the data of the batteries to a central database thereby enabling them to warn users in time for possible catastrophic unloading of their batteries, thereby extending the functional lifetime of these batteries.

The use of sensors to enable remote monitoring of performance and offer improved maintenance schemes was introduced by all suppliers of capital goods. We will name a few examples here.

A producer of compressors offers complete on-line monitoring of their industrial compressors leading to condition based maintenance. Of course, this service can only be offered if clients agree to continuous sharing of data such as temperatures, operating hours, pressures, vibrations, etc.

A similar concept was introduced by a producer of LED-based industrial lighting solutions: remote monitoring of performance loss led to an offering including predictive maintenance.

Numerous as-a-service business concepts are being developed, all of them enabled by the intense use of sensor data, in some cases also leading to partial or radical design changes of the assets. Examples included bedside monitoring-as-a-service, luggage logistics-as-a-service and road maintenance-as-a-service.

A producer of underground waste containers equipped these containers with sensors enabling optimization of waste collection efforts. These innovations enabled the company to experiment with new business models in which the proposition to municipalities was based on the service of collection instead of selling the containers. In the process of developing this proposition, the company also decided to re-design the containers in order to strengthen the failure modes of the current design.

A producer of speedgates developed the speedgate-as-a-service concept. The innovation was based on the already well-developed use of sensors in existing speedgates (including cameras, weight sensors, sensors preventing damages, etc.). The value of such data and the uptime guarantee led to the new proposition, that also led to re-design of the electronic 'heart' of the speedgate leading to more speedy repair operations.

The barriers for introducing sensor-based innovations included worries about data collection, security and ownership, hiring the right competences and changing mindsets and financing the transition (especially in the case of as-a-service offerings).

The maturity levels of Figure 3 can be transposed to the circular economy strategies that have been identified in Figure 1. As indicated in Figure 4, the upper levels represent a greater potential of circular economy strategies to support or unburden human decision makers (blue arrow) and increase the efficiency and productivity (green arrow) of the material use. Moreover, the hierarchical structure of increasing maturity also indicates the aggregation of DTs as “Lego” blocks for the application of autonomous functions. Hence, when a company matures and implements more advanced DTs (IoT, cloud computing, big data, and analytics, respectively), it can leverage self-sensing, self-adaptive, self-organizing, and self-deciding functions (Kristoffersen et al., 2020a, 2020b).

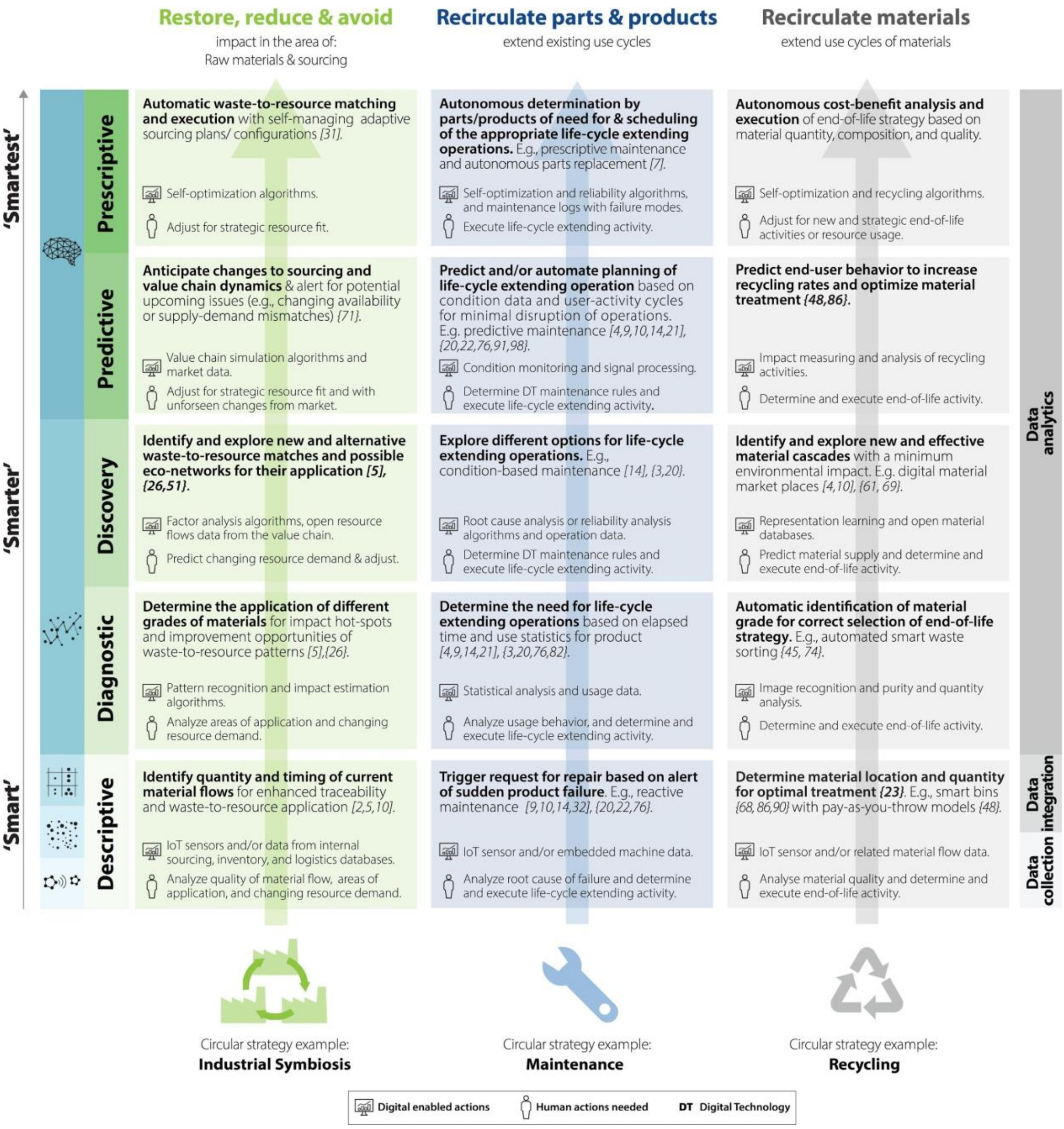

Figure 4: The smart circular framework applied to 3 circular strategies (Kristoffersen et al., 2020a)

2.2 From data production to integration, managing materials for increased circularity

In the previous chapter we established the connection between data science and circularity, based on the initial observation that circular economy needs data from the tracking and tracing of materials along the value chain. Besides this data need, circularity also aims to keep the functionality of a material at a maximum level throughout the entire life cycle. Therefore, material stocks and flows need to be managed in a sustainable way.

When discussing the management of material flows it is important to make a distinction between the following levels of complexity (Parchomenko, 2020):

- **Substance**: single type of matter, which consists of element or compounds (e.g., Al, PP)
- **Material**: a substance or a mixture of substances (e.g., Al, Al alloy, PP with additives)
- **Component**: part of a product that is used as a direct input in the final assembly of the product that is built with the intention to provide a functionality (e.g., engine, wheel)
- **Product**: object that is assembled from components and is produced as a final output of a production process, with the intention to provide functionality to its user (e.g., car)

Components and products typically have a fixed physical shape. They can be repaired, re-used. Components can be re-assembled. Products can be re-manufactured. In order to track components and products, they can be tagged (e.g., linear barcode, QR code, radio-frequency identification tags, …). Additionally, the functionality of components and products can be reset through repair, but it may also be improved by introducing electronics capabilities.

Materials and substances typically have no fixed physical shape. They are blended, mixed, granulated, sieved, separated, etc. It is therefore not possible to attach a physical tracer to materials and substances. Tracing will involve the setup of a digital twin or a model, that provides a digital analogue of the material flow. In view of materials management (and circularity) the challenge is to maintain the link between the physical substance and the digital twin.

2.2.1 Products and components - Functional electronics amalgamate digital and physical

Thanks to sensing and actuating capabilities the integration of electronics into products and components allows them to be traceable, connected, smart or to increase their functionality. A market research estimates that 9.15 billion IoT devices were installed in 2018, with a projected increase to 41.6 billion in 2025 (IDC, 2019). Driven by continuous technological innovation and to support the digital transformation, the electronics industry is continuously looking to penetrate new market opportunities and niches. Trends such as the Internet of Everything, where every physical object can be a connected “thing” are thus emerging. Today electronics ecosystems such as Nano-Electronics, Electronics Smart Systems and Flexible, Organic & Printed Electronics are considered as transversal enablers and differentiators of European digital transformation:

- Nano-Electronics: methodologies for integrating functions at high structural density on a single chip or device
- Flexible, Organic & Printed Electronics: solutions enabling the production of flexible and large-area electronic components, opening up new functionalities and areas of application using a novel approach to manufacturing electronics
- Electronic Smart Systems: Concepts for combining cognitive functions with sensing, actuation, data communication and energy management.

Providing an increasing capability to integrate digital technologies with cognitive functions, shifting from purely physical integration to functional integration, the term 'functional electronics' has recently been introduced for referring to those three ecosystems (5E project, 2020).

Those electronic solutions allow more than ever, the generation and gathering of data along the resource life cycle. Translated into information and knowledge, those data can provide the basis for circular business strategies, if they are used with an aim to maintain or increase the functionality of the product or component, and/or to increase its lifetime.

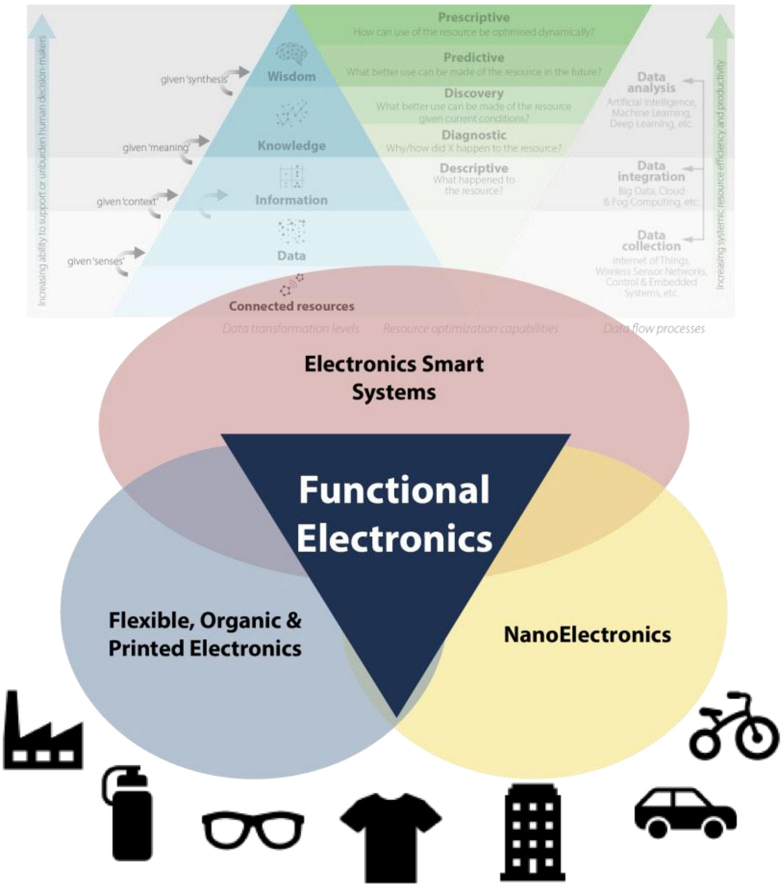

Figure 5: functional electronics turning single object into a smart device and enabling circularity

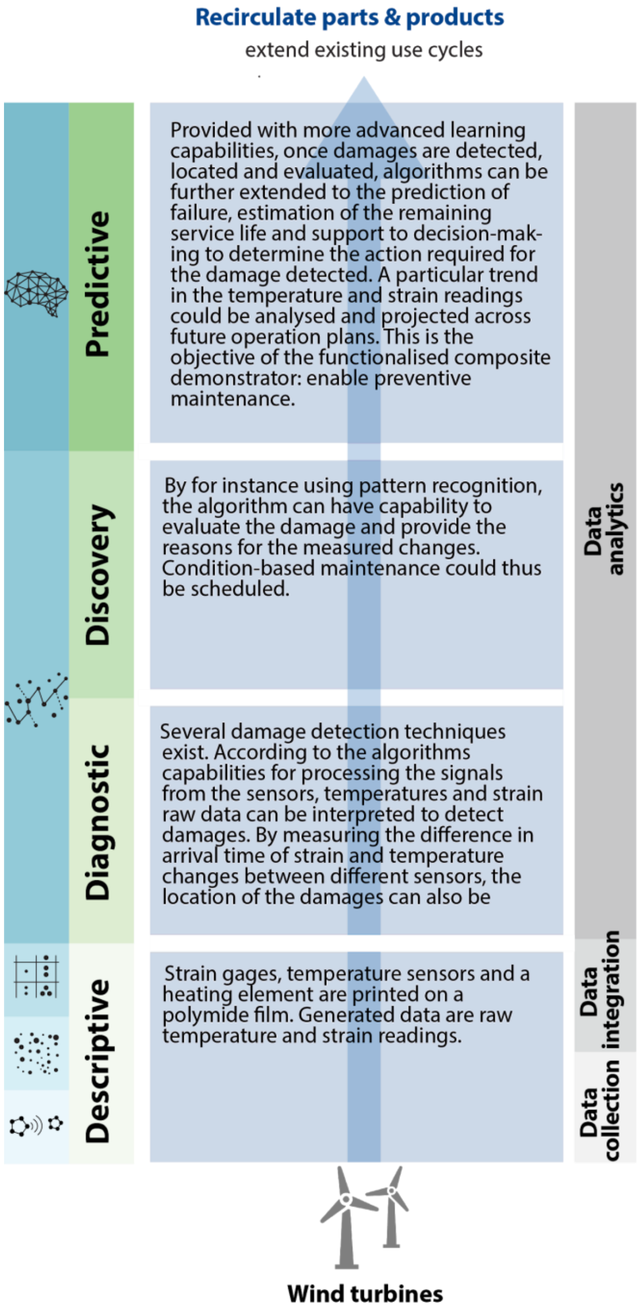

Figure 6: Smart composite for wind turbine safe and efficient operations

Example Case: Smart composite for safe and efficient wind turbine operations

The integration of printed electronics in composite structures is currently being investigated, with the aim to integrate new functionalities. Functionality is incorporated in fibre-reinforced composites for sensor technology, energy storage and energy harvesting among others. Printed electronic active/passive sensors are used for structural control and real-time monitoring of structural behaviour of fibre reinforced polymer composite materials. This will increase their exploitation extending operational lifetime, reliability and robustness (LEE-Bed, 2020).

Based on a collaboration between French RTOs, a small-scale demonstrator (one-meter-long) for ‘smart composites’ in wind turbine blades has for instance already been developed. This demonstrator investigates the functional integration of Structural Health Monitoring (SHM) and de-icing in a wind turbine blade. The turbine blade demonstrator is functionalized with printed organic electronics (namely: strain gauges, temperature sensors and heaters). The strain and temperature sensors are able to detect potential damage occurring on the blade structure beforehand, making it possible to carry out preventive repairs, while the heaters allow the de-icing of the blade preserving its functionality in harsh environment and increasing its lifetime thanks to an optimized usage. The small-scale blade demonstrator received the Public Choice Award at the LOPEC Award Show of the OE-A Competition in 2019.

To understand the potential role of this functional integration in a transition towards circular economy, the Smart Circular Economy Framework more generically applied to some circular strategies in Figure 4 is used and specified in Figure 6.

Integrating functional electronics in material parts and using digital resource optimisation capabilities for extending a component use cycle with better maintenance and repairs actions has been introduced in Figure 6. Taking a more systemic perspective, more efficient wind turbine operations is leading to a higher amount of generated renewable energy. This operational data-driven approach could lead to 15% decrease in inspection activities and thus maintenance costs (LEE Bed, 2020). Utility companies being driven by performance i.e. wind turbine power capabilities, better and more tailored maintenance services can enable wind turbine manufacturers to adjust and rethink their current business models. Condition-based and/or predictive maintenance schemes can provide the necessary knowledge and wisdom for transitioning towards more performance-based business models. Ultimately, obtained data can be used to improve designs for the next generation of wind turbines.

While the above-mentioned electronics ecosystems will provide the necessary technological basis for turning every material, component or product into a smart device, coordinated research and innovation actions based on collaborations between (and among others) digital, materials and circular economy experts are needed for steering an effective electronics functional integration in the right market segments and demonstrates on a use case-basis its potential in a transition towards a circular economy. Supported by ECERA, those research needs have been expressed in a vision paper on the role and impact of functional electronics in a transition towards a circular economy (5E project, 2020).

2.2.2 Making sense of information - Following materials, substances and products over their lifetime to create circular opportunities

To create an effective circular economy for materials and substances, their way through the lifecycle from production to recycling needs to be understood so that their composition, specificities and therefore their lifetime expectation (wearout) and their ability for various recycling purposes (recycling, cascades etc.) can be determined. This is not just a technical issue; information asymmetry currently is a major source of market failure and distrust that hinders the emergence of recycling systems in many instances. The creation of trustworthy information by digital means is hence a major enabler for circular economy markets (Wilts and Berg, 2017).

Digital technologies offer three functionalities at this point to tackle these tasks:

- tracing and tracking of the materials/substances and products,
- safe storage and distribution of data and information,
- execution of transactions.

Several options for tracing and tracking exist and have been described above. This is more difficult for materials and substances since information needs to be created and transferred e.g. via tags as well but cannot be ubiquitously applied to every single particle. The implementation of tracers on the molecular level is therefore currently also tested.

Technologies for safe storage and transfer of information

Information and data also need to be stored safely and incorruptibly to be trustworthy and to enable the safe circular markets delineated. Also, information and data need to be transferred in a way that ensures both reliability and allows a filtering that provides an entity only with those parts of the data stored that is meaningful to it and that it is entitled to obtain by the access rights defined for it- and not more.

For the purpose of safe storage sophisticated database systems and Decentral Ledger Technologies (DLT) - most prominently represented by blockchain technology - provide solutions. Distributed Ledger in general denotes all decentralized data storage systems of the same data records. Blockchain is a DLT with the special feature of chain-like connection of data records (Natarajan et al., 2017). DLT can be understood as "[...] a system of electronic records that enables independent entities to establish a consensus around a shared 'ledger' - without relying on a central coordinator to provide the authoritative version of the records." (Rauchs et al. 2018, p. 23). Providing a single point of truth to the participants records are created to persist in a non-forgeable, non-compressible way (ibid.).

For representation in a DLT, products and materials also require a digital identity. The technologies described here provide means for information creation (functional electronics, tracing and tracking) and systematic information embodiment (digital twins and passports) in Cyber Physical Production Systems.

Digital Twins

The concept of digital twins as the “virtual mirror image” of a product is at the heart of Industry 4.0 (Uhlemann et al., 2017). Such digital twins can accompany a product and material throughout its lifetime and store data on composition, use and abuse, maintenance, multiple forms of utilization and - ultimately - chances and requirements for recycling and disposal. When they provide information on materials used, components assembled as well as maintenance and upgrades during product lifetime, digital twins will also be a decisive ingredient to circular business models and to the closing of product and material loops. However, they require constant tracing and tracking technologies to work.

Introduction of material and product passports

Products and materials can also be accompanied by a digital passport that provides information on the product or material itself, the ingredients used, its ecological footprint as well as its social impact (positive and negative) (BMU, 2020). Such a passport would not be perpetually updated like a digital twin but could be on certain instances. It would especially serve as an easily usable information system for customers and consumers on the product's or material’s abilities and requirements with regard to a resource efficient circular economy.

Enabling transactions through platforms and smart contracts

Another step in the creation of a digital circular economy system is the enablement of transactions through dedicated platforms and safe contractual constructions. Platforms can be used to exchange products and materials between companies in a value creation network to enable reuse, remanufacturing, recycling or proper waste treatment (Berg and Wilts, 2019). Provided that easy access can be achieved, such platforms can then reduce search and transaction costs to improve e.g. recyclate markets.

A further step of enabling safe transactions can be smart contracts. Such contracts resemble a programmed chain of decisions and actions where each consecutive step is triggered by fulfilment of the preceding one (McAfee and Brynjolfsson, 2017). With regards to a circular economy, smart contracts can enable “trustless” transactions which ensures that a transaction is only finalized when all requirements e.g. in terms of recyclate quality have been fulfilled.

2.3 Unveiling patterns, making needs match – the role of Artificial Intelligence

The third level of maturity, after data collection and data integration consist in the smart analysis of the data. Inconsistency of data leads to inefficient and opaque processes and thus, barriers for a large-scale implementation of circular principles. In the context of data acquisition and data analysis, Artificial Intelligence can serve as a panacea. Artificial intelligence describes self-learning and self-correcting computational processes that mimic human-like reasoning and problem-solving (Kok et al., 2009). AI comprises various approaches and principles but at its current core, machine learning and its dynamic algorithms are used to digitize learning (Knox et al., 2020). Machine learning applications range from Natural Language Processing, i.e. the ability to communicate and understand language (Young et al, 2018), to visual recognition, where images are processed, and contextually classified, e.g. in the field of medical analysis (Hosny et al., 2018).

The main benefit of AI lies in its capacity to analyse large quantities of data in short and up to real-time. Apart from handling superior quantities of data, AI detects and unveils patterns that were not visible before, to suggest relations humans are not aware of. Further, AI automatically deducts consequences based on its analysis and matches data input to a connected task. These capacities make use cases in the context of CE evident. AI can support CE throughout the entire value chain: starting from predicting demand, over intelligent design, monitoring to enablement/enhancement of remanufacturing (see Fig. 3).

As can be deducted from Figure 3 various applications of AI in the context of CE exist. Its ability to analyse high quantities of data and act automatically and self-correcting on basis of the outcome allow for increased efficiency throughout the value chain. Often neglected, the benefits of AI are also observable in use cases in customer service and support. The acquired data can be used to shape activities in design, utilization and waste management accordingly.

Starting off with demand prediction, Blunck and Werthmann state that assessing the demand via AI enables optimized decisions regarding material reusability (2017). Banks et al. emphasize this point further, affirming that AI supports CE implementation by improving reverse logistics and associated decision making processes in sorting and disassembling and by utilizing both historical and real-time data to predict demand and thus, optimize inventory and production management (Banks et.al., 2019).

Figure 3 Role of AI in Circular Activities - based on Ghoreishi & Happonen (2020)

Focusing on the expected return, in terms of significantly decreased maintenance cost through a self-managing and self-correcting system and increased revenues through maximized efficiency, sustainability goals usually play a minor role when considering investments into AI applications. However, their impact goes hand in hand, making AI a crucial tool to support circular principles throughout industries and activities.

Further, AI can assist sorting and monitoring, and thus, facilitate material collection for secondary use. In this context especially, successful practice examples prove the benefits of machine vision throughout the waste management processes. Experiments of scholars have shown up to 93 per cent accuracy in sorting achieved with AI applications in computer vision (Costa et al., 2018). This field is in rapid development and higher efficiencies are within reach for industrial implementation. Real-life applications in sorting also employ principles of image recognition and computer vision to automatically identify incoming waste, classify it, detect flaws in quality and provide feedback. These AI applications in the context of sorting are extremely beneficial not only to mitigate risks, e.g. in recognizing and splitting off contaminated waste as early and thoroughly as possible but also in terms of regulations. AI-enhanced sorting can support quality standards and thus, help in avoiding legal actions and fines.

3 The Circular Digital Economy

While the digital transformation is a prerequisite to the successful creation of a circular economy, digitalisation also has huge implications for sustainability itself. The digital/ICT industry has a significant environmental footprint. Data centres, digital devices and digital infrastructures require (often critical) levels of energy and materials. ICT accounts for 5 to 9% of the total electricity demand (associated with GHG emissions) with a potential increase to 20% by 2030, as the demand for data centres, cloud computing and other energy-intensive technologies (e.g., blockchain) increases. Considering the amount of energy digitalisation requires, these developments must be coupled with a transition in our energy system (e.g., increasing energy efficiency and share of renewables) (Hedberg, 2019).

Simultaneously, resource use and waste are a problem. The world produces annually over 50 million tonnes of e-waste, and the amount is increasing due to rapid technical development. Much of this material is directly linked to the digital transformation since hardly any electrical appliance - and in effect many other devices - comes without digital functionalities. Recycling of all this equipment is expensive, complex and still underdeveloped. This is a missed economic opportunity, as enormous amounts of valuable, critical materials are thrown away. (Hedberg, 2019).

In its report on Mineral for Climate Action (World Bank, 2020), the World Bank states that current recycling rates could reduce the required primary demand for the critical raw materials involved in the low-carbon transition (see Chapter 2). Future increases in recycling rates can play an important role in mitigating increases in demand for primary minerals, as can reuse of components for energy storage technologies, such as Li-ion batteries, although commercial application of such reuse is currently limited. Incentivizing recycling, reuse, and refurbishment is a vital part of the low-carbon transition. Meanwhile, the World Bank recognizes that there is likely still a strong demand for primary materials.

The European Action Plan on Critical Raw Materials (European Commission, 2020b) announced the launch of the European Raw Materials Alliance. In a first phase it will focus on the most pressing needs, which is to increase EU resilience in the rare earths and magnets value chain, as this is vital to most EU industrial ecosystems (including renewable energy, defence and space). The alliance can expand to address other critical raw material and base metal needs over time. This can include a focus on the collection, sorting and recycling of WEEE and IT equipment.

Data centre equipment is largely (greater than 99 percent) composed of “common” metals (e.g., steel, copper, aluminium) and polymers (e.g., ABS, PVC, PBT), while 10 critical raw materials typically make up 0.2 per cent of components (ITU and WEEE Forum, 2020). The current focus of the equipment suppliers is largely on energy use and energy efficiency. Together with the fast pace of software development, this makes material obsolete before its end of life. In addition, and as electronics will keep penetrating different market segments, it is clear that the role of product design will be essential. It will be key for ICT designers and developers to be guided in the identification and selection of the right and compatible ecodesign levers. The introduction of modular systems can enable the replacement of components. Wireless infrastructures, data centers and IoT devices need to be designed with a view on dematerialisation and reuse. Modularization and standardization of components will continue to play a key role in making refurbishment and recycling more feasible, including reducing the use of critical raw materials and hazardous substances. Additionally, more research and development in recycling is needed, especially to make this more economically viable (ITU and WEEE Forum, 2020).

The challenge of recycling is increased by the increasing miniaturisation and therefore decreasing amounts of valuable metals per device. Through the growing worldwide market, devices containing critical raw materials are increasingly distributed over the world. The combination of both effects leads to a major dissipation of small amounts of critical materials over an increasing geographical range. A major issue in closing material loops therefore is the collection of the products as well as the logistics to bring them back to the recycling plants. Digitalisation can play a determining role in enabling better and more efficient waste collection, through the use of sensors, tags, digital twins, machine learning and other technologies.

Indirect effects regard impact created by the use of ICT. e.g. electronically enabled commerce can lead to a (massive) increase in consumption, transportation and packaging. Intensification of ICT use demands a consequential extension and build-up of enabling infrastructure especially electricity generation and networks as well as communication networks.

4 Discussion and Recommendations - Creating the digital circular economy

This white paper has elicited how from the viewpoint of leading European research technology organisations a more sustainable circular economy can be enabled, improved and scaled-up by the application of digital technologies. The focus has been on the application of digital technologies to industrial settings. However, there are steps to be taken to reach this goal.

The digital and circular communities need to develop a better understanding, through the use of a common vocabulary. The digital maturity levels of data collection, data integration and data analytics can be coupled to progressive maturity levels of circular activities being descriptive, preventive and prescriptive. The understanding of these parallels will allow an easier integration of digital expertise into circular business development.

The challenge posed by the increase of digital technologies requires the application of circular economy principles to the digital infrastructure. In this regard, the circular digital economy needs to make sure that the material needs of the digital infrastructure can be met in a sustainable way. While the focus of the sector is mainly on energy efficiency, security of supply of critical raw materials will enter the agenda in the coming years. The digital technologies face the challenge of opening the urban mine by enabling the tracing and collection of valuable products and materials. But they also should enable a dematerialisation that prevents a net balance where it enables more material utilization than it actually uses.

Politically, the European Industry Strategy and the European Green Deal including the Circular Economy Action Plan find common ground in the development of the digital circular economy. It is important that the digital circular economy will also be introduced to the European Digital Strategy. European research and innovation programmes as well as investment agendas should focus more attention on the chances that a closer linkage of these strategies can bring for the development of a sustainable society.

The aforementioned technologies - and others - provide the tools and instruments to enable circular economy practices. However, a full-fledged approach has to enable a circular economy by creating markets, reducing information asymmetry and enabling businesses and consumers to make use of the emerging opportunities. Hence, in this section we delineate and recommend ingredients we see as vital to such an encompassing approach.

1. A safe circular data space

Data is the essential prerequisite for circular economy. However, this data needs to be created, stored and transferred safely including protection of intellectual property rights and know-how. The creation of a European data space has been announced in the EU Commission’s Industry Strategy. However, it still needs to be substantiated. A key ingredient for storage could be the new European GAIA X cloud infrastructure. This European system could allow the storage and processing of data in a safe European-controlled data environment.

An alternative could be the creation of a decentralized ledger (DLT) system, which might create more security in terms of fraud resistant data storage, but may also prove to be more complex and more difficult to operate.

Safe access and processing could in both cases be enabled by identifier systems that determine and allow access to specific pieces of information regarding a product or material based on the access rights of a specific user. The ownership of and access to data (also for data stored in digital twins and passports see below) needs to be considered with due regards of privacy issues, during their development. The use of pod-technology allows development of a system in which distributed ownership can be combined with authorised access to data. It allows citizens to control permissions to all data related to the assets and products in their ownership or use.

2. Creation of common standards within an adjustable long-term approach

The creation of standards for digital circular economy tools and instruments such as data formats, protocols, and data processing is paramount to enable circular business models on a large and ubiquitous scale. Such standards should be set as an agreement within and - preferably - overarching supply chains. If and where necessary, industry association, and standardization bodies and EU institutions should develop such standards. Technology standards should also enable the circularity of digital appliances themselves. We must realise however that no current development is as fast as the digital transformation. Technologies, business models, processes etc. move at an extremely fast pace, which makes standardisation very difficult.

3. An information uptake, transfer and analysis system working on the basis of the data space

Digitally tracing and tracking information during a product's or material's lifetime from production, through diverse cycles and, finally, disposal, can enable and improve many business models in the circular economy. From indicating the right point in time for predictive maintenance to high value recycling at the end of lifetime such data can ubiquitously be used.

Digital twins and digital passports are two important levers here. They are deeply intertwined with the industrial transformation to Industry 4.0 and could be easily utilized for circular economy purposes. Upgrading Industry 4.0 principles to a circular economy should be a major R&D and investment goal now and is extremely important given current investment cycles.

4. Modular and standardised devices, enabling product-as-a-service models

Product design is the key enabler and basis for circular consumption and use systems. Products need to be modular in order to allow easy repair, remanufacturing and upgrading, and therefore longer lifetime. It is clear that standardisation can play a role in that direction. Such a modular design may also provide the necessary basis for service based business models that can e.g. provide prescriptive maintenance and autonomous parts replacement. This could be applied for electronic consumer products such as mobile phones, fridges or televisions, but also holds for all IT infrastructure hardware that forms the backbone of the Internet of Everything.

5. Collection and Recycling of materials from the urban mine

Whereas the current sustainability actions in the digital industry are mainly driven by energy efficiency and reduction of greenhouse gas emissions, the availability of (critical raw) materials will become an issue in the near future. The security of supply is already on the European agenda and besides re-mining in Europe, it urges for an increase in recovery of materials from the urban mine. The key bottleneck is the collection and concentration of the widely dispersed electronic materials into the available recycling plants.

Tracking and tracing of products, components and materials through sensors, digital twins and DLT provide important contributions, but a further proliferation of leasing concepts and service models will also allow a better control and management of the material flows. Additionally, the introduction of product service systems, digital services and virtual reality will add to the dematerialisation of our consumption system.

6. Creation of an accompanying monitoring and learning system for a safe circular economy

Data and information obtained can also be used to improve and enable circular economy from an administrative vantage point. It can serve to monitor the degree of circularity in given supply chains, in managing sharing of goods and circular processes, and be used for the adherence to recycling and disposal regulations, including the prevention of illegal exports. It can also allow macro-economic analysis of circular systems to inform policy making. Effectiveness of regulation can be monitored almost instantly and lessons can be drawn quickly and effectively, e.g. informed by artificial intelligence. Environmental effects can be measured and predicted. In sum, digital technologies can also be the key to a highly effective political enablement of the circular economy.

References

5E Project (2020). *Vision paper functional electronics for a circular economy*, (https://5e-project.eu/wp-content/uploads/2020/05/Vision-Paper_Functional-electronics-for-a-circular-economy-1.pdf), accessed on 15 October 20.

Banks, I., Vos, J., Iles, J., Young, P., van Merkestein, R., Guerrini, S & Slough S.C. (2019). *Artificial intelligence and the circular economy - AI as a tool to accelerate the transition*. Ellen MacArthur Foundation, 39.

Berg, H., & Wilts, H. (2019). *Digital platforms as market places for the circular economy—requirements and challenges*. In NachhaltigkeitsManagementForum | Sustainability Management Forum (Vol. 27, No. 1, pp. 1-9). Springer Berlin Heidelberg.

Blunck, E. & Werthmann, H. (2017). *Industry 4.0 - An Opportunity to Realize Sustainable Manufacturing and its Potential for a Circular Economy*, *Microeconomics*, 645-666.

Blomsma, F., Pieroni, M., Kravchenko, M., Pigosso, D.C., Hildenbrand, J., Kristinsdottir, A.R., Kristoffersen, E., Shahbazi, S., Nielsen, K.D., Jönbrink, A.K. and Li, J. (2019). *Developing a circular strategies framework for manufacturing companies to support circular economy-oriented innovation*. Journal of Cleaner Production, 241, p.118271.

BMU (2020). BMU Digital Policy Agenda for the Environment: Digital Product Passport, https://www.bmu.de/en/service/haeufige-fragen-faq/details-cluster/bmu-digital-policy-agenda-for-the-environment-digital-product-passport/, accessed on 15 October 20.

Brown, D.E., Famili, F., Paass, G., Smith-Miles, K., Thomas, L.C., Weber, R., Baeza-Yates, R., Bravo, C., L'Huillier, G., Maldonado, S. (2011). *Future trends in business analytics and optimization*. Intell. Data Anal. 15, 1001–1017.

CICERONE. (2020). *Strategic Research and Innovation Agenda on Circular Economy*, (http://cicerone-h2020.eu/wp-content/uploads/2020/09/Circular-Economy-SRIA-2020.pdf) accessed 15 October 2020.

Circulator (2020). Circulator the circular business model mixer, (https://circulator.eu) accessed 24 *September 2020.*

Costa, B., Bernardes, A., Pereira, J., Zampa, V., Pereira, V., Matos, G., Soares, E., Soares, C. & Silva, A. (2018). *Artificial Intelligence in Automated Sorting in Trash Recycling*. 198-205. 10.5753/eniac.2018.4416.

EEA (2016). *Circular economy in Europe — Developing the knowledge base*, EEA Report No 2/2016. European Environment Agency.

EEA (2019). *Paving the way for a circular economy: insights on status and potentials*, EEA Report No 11/2019. European Environment Agency.

(EMF) Ellen MacArthur Foundation (2016). *Intelligent Assets: Unlocking the circular economy potential*. Ellen MacArthur Foundation.

European Commission (2019). *The European Green Deal*, COM (2019) 640 final.

European Commission (2020a). *A New industrial Strategy for Europe*, COM(2020) 102 final.

European Commission (2020b). *Critical Raw Materials Resilience: Charting a Path towards greater Security and Sustainability*, COM (2020) 474 final.

Futuring (2018). *Policy recommendations and strategy to re-industrialise Europe*, (http://www.futuring-project.eu/static/deliverables/FUTURING-D4.2.pdf), accessed 15 October 2020.

Ghoreishi, M. & Happonen A. (2020). *Key enablers for deploying artificial intelligence for circular economy embracing sustainable product design: Three case studies*. AIP Conference Proceedings. doi: 10.1063/5.0001339.

Hedberg, A., Sipka S., Bjerkem, J. (2019). *Creating a digital roadmap for a circular economy*, EPC European Policy Centre, Brussels.

Hosny, A., Parmar, C., Quackenbush, J. *et al.* (2018). *Artificial intelligence in radiology*. *Nat Rev Cancer*, 18, 500–510, doi:10.1038/s41568-018-0016-5.

IDC: The premier global market intelligence company (2019). (https://www.idc.com/getdoc.jsp?containerId=prUS45213219), accessed Jun. 24, 2020.

ITU and WEEE forum (2020). *Internet Waste, a thought paper for international E-waste day 2020*, *(https://weee-forum.org/wp-content/uploads/2020/10/Internet-Waste-2020_FINAL.pdf), accessed 19 October 2020.*

Kok, J.N., Joost, Boers, E.J.W., Kosters, W.A., Van der Putten, P. & Poel, M. (2009). *Artificial Intelligence: Definition, Trends, Techniques, and Cases,* Encyclopedia of Life Support Systems.

Knox, J., Williamson, B. & Bayne, S. (2020). *Machine behaviourism: future visions of 'learnification' and 'datafication' across humans and digital technologies*, Learning, Media and Technology, 451, 31-45, doi:10.1080/17439884.2019.1623251

Kristoffersen, E., Aremu, O. O., Blomsma, F., Mikalef, P., & Li, J. (2019). *Exploring the Relationship Between Data Science and Circular Economy: An Enhanced CRISP-DM Process Model. In Conference on e-Business, e-Services and e-Society* (pp. 177-189). Springer, Cham.

Kristoffersen, E., Blomsma, F., Mikalef, P., & Li, J. (2020a). *The smart circular economy: A digital-enabled circular strategies framework for manufacturing companies*. Journal of Business Research, 120, 241-261.

Kristoffersen, E., Li, Z., Li, J., Jensen, T. H., Pigosso, D. C. A., & McAloone, T. C. (2020b). *Smart Circular Economy: CIRCit Workbook 4*.LEE-Bed, 2020, (https://lee-bed.eu/cases/autonomous-structural-monitoring-systems), accessed 15 October 2020.

McAfee, A., Brynjolfsson, E., Davenport, T.H., Patil, D.J., Barton, D. (2012). *Big data: the management revolution*. Harv. Bus. Rev. 90, 60–68.

McAfee, A., & Brynjolfsson, E. (2017). *Machine, platform, crowd: Harnessing our digital future*. WW Norton & Company.

Mortenson, M.J., Doherty, N.F., Robinson, S. (2015). *Operational research from Taylorism to Terabytes: A research agenda for the analytics age*. Eur. J. Oper. Res. 241, 583–595.

Natarajan, H., Krause, S., & Gradstein, H. (2017). *Distributed ledger technology and blockchain*. World Bank.

Provost, F., Fawcett, T. (2013). *Data Science for Business: What you need to know about data mining and data-analytic thinking*. O'Reilly Media, Inc.

Parchomenko, A., Nelen, D., Gillabel, J., Vrancken, K.C., Rechberger, H. (2020). *Evaluation of the resource effectiveness of circular economy strategies through multilevel statistical entropy analysis*, Res. Conserv. Rec., 161, 104925.

Rizos, V., et al. (2016). *Implementation of circular economy business models by small and medium-sized enterprises (SMEs): Barriers and enablers*. Sustainability 8(11), p. 1212 (DOI: 10.3390/su8111212).

Skogli, A.E., Stokke, O.M., Hveem, E.B., Aamo, A.W., Scheffer, M., Jakobsen, E.W. (2019). *Er verdiskapning med data noe Norge kan leve av?* Menon Econ.

Uhlemann, T. H. J., Lehmann, C., & Steinhilper, R. (2017). *The digital twin: Realizing the cyber-physical production system for industry 4.0*. Procedia Cirp, 61, 335-340.

WBCSD (2018). *Circular metrics — Landscape analysis*, World Business Council for Sustainable Development (https://www.wbcsd.org/Programs/Circular-Economy/Factor-10/Metrics-Measurement/Resources/Landscape-analysis) accessed 24 September 2020.

Wilts, C. H., & Berg, H. (2017). *The digital circular economy: can the digital transformation pave the way for resource-efficient materials cycles?*.

World Bank (2020). *Minerals for Climate Action: the minerals intensity of the clean energy transition*, http://pubdocs.worldbank.org/en/961711588875536384/Minerals-for-Climate-Action-The-Mineral-Intensity-of-the-Clean-Energy-Transition.pdf, accessed on 15 October 20.

Xiao, Y., Lu, L.Y.Y., Liu, J.S., Zhou, Z. (2014). *Knowledge diffusion path analysis of data quality literature: A main path analysis*. J. Informetr. 8, 594–605.

Young, T., Hazarika, D., Poria, S. & Cambria, E. (2018). *Recent Trends in Deep Learning Based Natural Language Processing*. IEEE Computational Intelligence Magazine, 13 (3), 55-75, doi: 10.1109/MCI.2018.2840738.