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Green and digital "twin" transitions: process of structuration and evolution of circular economy and industrial digitalisation

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Abstract

Over past decades concepts like sustainability and industrial development are slowly coming to the same operational logic. This is indicated by a growing interest to explore and describe the synergy between developments in the Circular Economy (ID) and Industrial Digitalization (ID). There is agreement on their complementarity evolution paths, but no outlook is available regarding the co-evolution staging and structuring. This paper based on desk and empirical research presents an approach to outline the likely path of evolution. So far, the notion of transitions to sustainability has been applied in single sector studies while reality indicates that systemic change required cuts across thematic technologies and sectors. The approach taken can be useful to enrich current analyses but also facilitate the description of complex paths for strategy and policy in companies and governments. The outlook proposed helps situate where we currently are in the long process of institutionalizing change and innovation towards a twin transition in the CE and ID supporting sustainability.

Highlights

- The paper offers a stylized structuration staging for the twin transitions of the circular economy and industrial digitalization
- It presents three scenarios of the possible outcomes of the twin transition process, outlining the role of different stakeholders in the process of institutional, technological, organizational, behavioral and environmental change.
- Building on foresight concepts it offers a detailed process of structuration to help policymakers and business to locate their initiatives in a long-term transition landscape
- Offers a rich and complex description of the multiple activities and implicit actors involved in a long-term structuration process for the twin digital and green transitions
- Twin digital and green transitions call for a strong role for supranational policies to guide and support change at the level of detail required

1 Introduction

Over past decades there has been an effort to bring concepts like sustainability and industrial development into the same operational logic (see e.g. Díaz López and Montalvo, 2015; Baldwin, et al 2005). Over the last five years there have been a growing interest to explore and describe the synergy between developments in the Circular Economy (CE) and Industrial Digitalization (ID). This is indicated by the growing number of academic publishing and policy documents.[1]

Recent developments in the European policy landscape and in industrial innovation have achieved agreements reflected in the new agenda for research and innovation. This is reflected in initiatives under the current agenda of Horizon Europe were ID and sustainability -in particular CE - are very salient. Announced as a flagship initiative of the European Green Deal (European Commission, 2019a), the EU industrial strategy proposes that the “twin transition” (green and digital) is a unique opportunity for the EU to “affirm its voice, uphold its values and fight for a level playing field”, emphasizing that this “is about Europe’s sovereignty” (European Commission, 2020a, p.1). Similar messages can be identified in the new Circular Economy Action plan (European Commission, 2020b), the Zero Pollution action Plan (European Commission, 2021), and the communications Sustainable Products in a Circular Economy (European Commission, 2019) and ERA for research and innovation (European Commission, 2020d). There is a general positive expectation from the development of breakthrough, digitally-enabled circular industrial technologies as key enablers of global leadership, competitiveness and strategic autonomy of the European industry. Recent European industry roadmaps that reflect on such expectations include the automotive sector (Holst et al, 2020), batteries (Edström, K et al 2020), electronics (CEP, 2020), energy (InnoEnergy, 2020), machine tool sector (CECIMO, 2019), plastics (WRAP, 2020), and marine and transportation (SITRA, 20202).

Most of available documentation has focused on describing complementarities, the role that ID specific technologies might play enabling CE and the directionality that CE gives to ID beyond improving efficiency and productivity in industrial processes. Despite such interest there is still a lack of a general outlook of the structuration process of a twin transition that involves technologies, new skills requirements, markets, standards, business models and policy.

This paper aims to contribute to fill this gap by proposing an approach that can help to describe the structuration process of multi-transitions taking ID+CE as a case. The paper is organized as follows, first the overall contours of circular economy and industrial digitalization are described. This description is done in a brief stylized form as this has been the focus of most literature available to date (see for example the review of Romero et al., 2021). Second, the relevance of this approach in the context of transitions studies is highlighted. Third, the approach to develop the description of the structuration process via a scenario method is described, this is followed by a section summarizing the key attributes of the structuration stages driving the European twin transition. A final section in the document is included to provide general conclusions, limitations and avenues for future research

1.1 Circular economy

Heavily influenced by the propositions of the Ellen McArthur Foundation (EMF)[2], the Circular Economy concept has been extensively discussed in academic, policy and industry circles. Yet, there is still a

[1] For recent reviews see Antikainen, et al. (2018), Rosa et al. (2020), Romero et al (2021).

[2] See: https://www.ellenmacarthurfoundation.org/circular-economy/what-is-the-circular-economy

concern that the notion of CE still means different things to different stakeholders (OCED, 2017). Different models of circularity have been proposed for guiding policy and practice, including biological and technical cycles (e.g. the " butterfly" model by the EMF), its sectors/ value chains / product groups of influence and its implications on critical raw material extraction, resource efficiency and growth (e.g. in the new Circular Economy Action Plan), and its life cycle orientation (from resource extraction to end of life, e.g. by UNEP and the International Resource Panel).

The definition of circular economy varies but usually involves reduced demand for natural resources, which can be addressed with three main mechanisms for reduced demand - creating material loops, slowing material flows (leaving materials longer in the economy) and the broadest mechanism of narrowing material flows which relates to efficient use of resources through either new production technologies or/and modified consumer behaviour (Kirchherr, Reike, and Hekkert, 2018). Circular Economy is the latest embodiment of sustainability in the context of business operations and industrial systems.[3]

The CE proponents argue that to achieve sustainability economic growth must be decoupled from resource constraints. In turn, such decoupling enabled by innovation will bring opportunities for business creating new ways of creating value and revenues, reducing costs, creating legitimacy, etc. (Manninen et al., 2018). Despite such promises the willingness of business to invest in CE over the years has been rather limited (Hartley et al., 2020). Many barriers hamper such progress, amongst these barriers, high cost of replacing current production processes across the whole supply chain, lack of radical technological opportunities, high complexity of product to be disassembly or remanufacture. All these with a major effect in companies' productivity and profitability have played a major role (Kummar et al., 2021; Kirchherr et al., 2018).

Traditionally, circular economy in industry is often equaled to closing loops in manufacturing processes in the production phase (e.g. enabled by industrial symbiosis), waste strategies in the end of life phase (e.g. enabled by waste valorization strategies), and eco-designed products (c.f. enabled by cradle-to-cradle design) (c.f. Lieder & Rashid, 2016). Circular business models are considered another critical element for the emergence and deployment of sustainability-oriented solutions that hold the promise of high transformation potential in manufacturing and industrial systems (Ludeke-Freund, et al, 2019; Diaz Lopez et al. 2019). More and more, several key enabling and digitally-enabled technologies are commonly cited in the realm of industry and circular economy across all stages of the life cycle of products and technologies. As introduced in the following section, industry 4.0 and its related technologies like IoT, artificial intelligence and big data analytics are considered some of the most salient examples of digitally-enabled circularity in industry (Massato, et al., 2020).

1.2 Industrial digitalization

Industrial Digitization (ID) (e.g., Industry 4.0, smart industry, etc.) denotes a trend of industrial restructuring based in the implementation of new advanced manufacturing technologies in combination with data connectivity of discrete elements of complex productions process (i.e., sensors, machinery, systems, inventories, etc.) through digitalization at the factory level connecting suppliers

3 Other concepts used in the literature and in policy reports in the recent past include cleaner production, eco-innovation, sustainable innovation, cradle to cradle, industrial symbiosis, sustainable production, etc.

and customers along the whole value chain.[4] ID aims to increase efficiency and flexibility to production operations while enabling new business models. Technological advancements, especially solutions related to ID are considered as an enabler for the Circular Economy. Developments in the areas like robotization, additive manufacturing, simulation and rapid prototyping, augmented reality, data analytics and digital platforms (managing edge-to-cloud data) are only some of the technologies in which industry is developing and deploying. Such technologies have the potential to greatly improve efficiency in materials and resources as well as to track-and-trace and end of product reclaiming by companies. Thus, they can (indirectly) contribute to achieving CE goals and possibly the adoption of CE strategies in companies.

While adoption of advanced digital technologies does not necessarily correspond to a greener, more sustainable or circular economy (Best, et. al. 2020; Khosravani, et al., 2020), it has been argued that with clear and continuous policy framework, digital solutions can accelerate the transition to a more sustainable economy (Hedberg & Šipka, 2020). This has also been recognized by policy-makers as demonstrated by the recent Green Deal and the focus on the twin transition seen also in the Digital Europe Program and the upcoming Horizon Europe.[5] Support towards the development and deployment of greener digital technologies has also been offered recently with the Ministerial Declaration on 'A Green and Digital Transformation of the EU' during the Digital Day 2021 (19 March) and the 26 CEOs joining the European Green Digital Coalition. At the same time, digitization of industry is seen as key to support the innovation and competitiveness of EU industry and programs such as the Digital Europe Program aim to provide strategic funding to build capacities in key areas such as HPC, cyber-security, artificial intelligence, and advanced digital skills and thereby support the digital transformation in Europe, and in particular SMEs.

What is recently acknowledged is that companies are more willing to invest in new digital technologies for advanced manufacturing than to invest directly into CE goals. As technical developments and upscaling of ID are strongly supported by European and national research and innovations policy and integrated in a number of implementation roadmaps, these are implicitly contributing to the deployment of CE strategies. However, further support is needed to develop strategies and guidance for businesses on how advanced digital technologies can be used to support circular strategies for supporting resource efficiency (Eivind Kristoffersen, et al, 2020).

The connection of CE into ID is also seen implicit in the creation competences on systems integration of circular and sustainable business models (e.g. product-service system, remanufacturing, etc.), thus paying an unintended second dividend for the benefit of CE and sustainability in terms of increased efficiencies in energy and raw materials (Romero et al., 2021). While CE proponents strongly highlight ID technological contributions, such benefits brought by ID are not yet widely connected by stakeholders. As an example, the Gartner's Future of Supply Chain Survey in 2020 revealed that while 70% of supply chain leaders had plans to invest in the circular economy, only a small portion had linked

[4] For a thorough description of industrial digitalization see: COM 2021, Ghobakhloo, 2018; and Santos et al., 2017.

[5] See for instance the Horizon Europe strategic plan 2021-2024 which calls for "promoting an open strategic autonomy by leading the development of key digital, enabling and emerging technologies, sectors and value chains to accelerate and steer the digital and green transitions".

these plans to their digital strategies (Garner, 2020). Despite the advancements and promotion of applications of new industrial digital technologies to CE at the EU level, generally speaking, awareness of experts in innovation in specific technologies considered part of ID is still limited regarding environmental impacts and costs of the inventions to the environment and society.

2 Approach

The structuration process towards sustainability has been described in socio-technical transitions theory intending to describe and guide the governance process (for a review see Coenen and Diaz Lopez, 2010). The most salient propositions include frameworks like: Multi-Level Perspective (Geels, 2002), Technological Innovation Systems framework (Hekkert et al., 2007; Bergek et al., 2008), Strategic Niche Management perspective (Kemp et al., 2007; Schot & Geels, 2008); and Transition Management (Loorbach, 2010). More recently the mission-oriented innovation policy approach provides focus in specific and achievable goals (Diercks et al., 2019). Despite these advances, the normative and stylized constructs of these approaches limit their capacity to describe with more nuance the industrial structuration process happening in twin transitions supported by the European green deal and ID. In order to explore with more nuance of the structuration and evolution process of such twin transitions this paper suggests a new approach and structuring process.

Taking a positive approach, the ongoing green and digital twin transition process is described by considering the model of a transition structuration stages as proposed by Montalvo and Leijten (2015). Such model describes a new rationale for innovation and industrial policy guided and legitimized by the grand challenges. This new rationale is moving European policy from international competitiveness to reorient towards the solution of the grand human challenges (e.g., mission oriented policy). The stages suggested in the ongoing structuration process are outlined as follows:

a. definition of the societal challenge (i.e., DI connected factories and the circular economy implementation);
b. development and accumulation of a critical mass across different type of actors that recognize the issue as important and is willing to generate visions and contribute to the solution;
c. appearance of lobbying groups (pro and against) and increased public debate;
d. emergence of institutions advocating, hosting and proposing approaches to address the issue;
e. development of technical and managerial approaches to address the issue;
f. adoption of the issue in the policy agenda by government and multilateral organizations;
g. investment flows to develop and test solutions while patenting and IPRs are settled;
h. early adoption sprout niche markets supported by policy instruments (e.g., taxes and subsidies), regulation and standards start to consolidate markets;
i. investments for production up-scaling often backed by sectoral policy and regulation and wider diffusion takes place;
j. mass markets growth, competition and distribution of production locations become issues for industrial policy.

Such staging of change provides insights into what could be the structuration process of the twin transition. The sequential character of each stage of societal structuration most likely has overlaps between stages, but the progression of complexity and occurrence is likely to hold a sequence and path as described above. It can be expected for example to see a swap in sequence between immediate stages like *b* and *c*, but the sequence in time for stages *c* and *f* is likely to hold. Elements of the available roadmaps for the circular economy (e.g., Domenech and Bahn-Walkowiak (2019) and industrial digitalization (e.g., COM 2021, Ghobakhloo, 2018; and Santos et al., 2017) are organized along two axis: one describing the stages from ideation and challenge identification to markets deployment of new digital and sustainable solutions and development of new sustainable and circular business models. The second axis is described as levels of evolution across time in the form of cumulative scenarios. The structuration stages proposed might present some degree of permutation in the order presented but all stages have a progressive and cumulative character (i.e., ideation of potential solutions gain legitimation before markets creation). The same logic is applied to the evolution stages (marginal change, moderate change and institutionalized change). These scenarios offer the likely pathways of a wide deployment and upscaling ID and CE.

Previous experiences in scenario making has revealed that the exclusive character of scenarios is rather artificial and reality in the long term happens to be a mixt of the apparently mutually exclusive scenarios (for a review see Popper 2008; Ammer et al,, 2013). What is presented in this paper are the necessary minimal steps for a Europe wide implementation of the CE in a context of ID. That is, scenario one progresses to scenario two and three in a buildup sequence, the stages of evolution are clear. Saying this, these scenarios can be seen as complementary stages of an intertwined process of ID-CE co-evolution across time. Such scenarios aim to support ideation, discussions facilitating policymaking supporting ID and CE.

The scenarios were developed based on the analysis of literature, interviews and the author's expertise. The identification of synergies, structuration scenarios and limitations of the European sustainable green and digital strategies are based in the revision of policy documents related to the road maps of ID (industry 4.0) and CE. The empirical stage included interviews with experts. The experts were identified and selected from a selection of 250 EU projects active on digital technologies found to be contributing to the Circular Economy. The interviewed projects included those in higher TRL thus closed to market exploitation. The results of the empirical stage were discussed and validated in an expert workshop including about 20 participants from industry and academia.[6]

In the following sections we present the main concepts in the twin transition scenarios: 1) a pessimistic describing events that very closely resembles what is the current status quo of implementation of the circular economy in a context of digital manufacturing; 2) a conservatively positive scenario whereby some changes have occurred in the innovation systems and an optimistic one where the circular economy is legitimized and in full process of implementation: 3) The third scenario takes an optimistic stand that should not be seen as a culmination of the circular economy and digital industry agendas but as the Europe-wide consolidation and institutionalization of an ongoing process of change. The scenarios are not predictions of the future but describe possibilities and possible stages, aiming to support further (policy) analysis and discussion. We deliberately chose to distinguish among 3 scenarios to present two extremes plus a moderate option.

The elements (concepts, events and activities) considered in each scenario lead to a stylized description of how such cumulative scenarios could conform the structuration stages evolving up to 2035 (which is the time span expected for the deployment of industry 4.0). The content of each

[6] A list of projects included in the process of interviews is provided in the Annex of the paper (respondents have been anonymized).

scenario was elaborated as follow: The first scenario considered information found in the literature reporting roadmaps as they are currently implemented. In this sense scenario one describes the current status of the twin transition in Europe. As next step, the structuration stage was elaborated with the activities and goals described in CE and ID roadmaps running up to 2035. With the two extreme scenarios and the collected information describing the processes of each transition (i.e. CE and ID), a middle scenario was developed back-casting form goals in 2035 and responding to the question: What else needs to happen to achieve such goals?

3 Structuration Scenarios

3.1.1 Pessimistic scenario: Marginal evolution of circular economy and industrial digitalization

Within scenario 1, the current *status quo* follows its natural inertia whereby there is only a marginal evolution of connected digital factories towards a Circular Economy. The emphasis on policy and industry level remains on the economic growth, potentially leading to an over exploitation and thus scarcity resources and environmental crisis. The concept of the Circular Economy (CE) has gained some political, industry, and societal interest. Following developments and roadmaps on topics related to sustainability, and Industry 4.0 (i4.0), the CE concept has been explored in a number of pioneering research and demonstration projects. Thus creating generating seed capacity, knowledge and examples of implementations in different business. While the concept has been defined by the Commission and policy documents such as the Green Deal package have been adopted, the academic and policy debate still lacks a common definition especially when looked from a value chain perspective. In the academic literature, the concept encompasses a broad range of actors and is not always discussed as systemic solution but often refers to only reuse, recycle and reduce activities rather than including design and reduction of resource use as well. Nonetheless, there are some similarities: in general definitions refer to the difference with the linear model and share the concept of increased resource efficiency (OECD, 2017).

Technological advancements, especially solutions related to (i4.0) are considered as an enabler for the Circular Economy. Developments in the areas of IoT, data analytics, robotization, and Additive Manufacturing are only some of the technologies which industry is now busy with and attempting to deploy and which can contribute to the adoption of CE strategies. Technical developments and upscaling of i4.0 are being supported by EU policy and integrated in a number of implementation roadmaps, thus also contributing (at least implicitly) to the deployment of CE strategies.

The connection between CE and i4.0 is also seen implicit in the programs of i4.0 aiming to create competences on systems integration of product-service systems, thus paying an unintended second dividend for the benefit of CE and sustainability in terms of increased efficiencies. While CE proponents refer to technological and i4.0 contributions, the benefits to i4.0 (purpose and justification) are not yet widely acknowledged or seen relevant by i4.0 stakeholders. Generally speaking, awareness of experts in innovation in specific technologies considered part of i4.0 is still limited regarding environmental impacts and costs of the inventions to the environment and society. This lack of awareness is mirrored by a culture of consumption were longer lifetime for product-service systems occurs only for the very high-end products but not for low and medium -cost products.

Change and innovation inspired in CE is patchy and scattered. The pioneering of R&D projects enables the creation of key enabling knowledge are embedded in the projects but the CE developments are and will continue to be in isolated pockets/islands of change. That is, innovations occur at the level of individual project or specific stages of production processes or specific product features within a business but not swiping and radical system changes in the organisation and planning of production and manufacturing within a factory or across a value chain. In general, knowledge is embedded and captured in a limited number of experts working on the related projects. Concepts like Zero Waste in production and services are known but not close to be implemented, most of new manufacturing technologies, at their core, come with inherent challenges of residuals and wastes.[7]

There are a number of positive developments though. One of them is that education in sustainability and CE principles is picking up speed in recent years.[8] As more lobbying organizations and forums[9] started spreading the CE idea and the academic attention increased, public debate on the topic has increased. This has also been picked up at the political level, where EU institutions (European Parliament, European Commission) have started working on issues of circular economy and European, national and multinational organizations have set the CE incipiently on the policy agenda. At the same time, examples of business models, managerial approaches and good practices have emerged. Technological developments integrating CE principles have been studied and guidelines on eco-design and waste management, reporting and tracking, as well as a standard providing guidance to apply CE in practice (BS 8001:2017) have emerged.

Despite this surge of activity and the European and national commitments to the CE, public investment in the CE is still very limited compared to R&D and innovation activity in other sectors. Private investment and funding faces barriers such as lack of understanding of the concept and need for alternative risk assessment/valuation of benefits mechanisms. Still, some actions, such as raising awareness on the problem and launching the Circular Economy Finance Support Platform have taken place. There are attempts to further promote the CE and achieve wide-spread adoption. However, the approach is still mostly present in niches – especially when it comes to adoption within the whole value chain.

Analysis of the current European policy mix has established that the circular economy policy package has no clear roadmap of implementation. There is no clarity as to the role of previous directives. Policies are currently focusing on input policies or development, rather than upscaling and creating stability for innovations to take off. Crucial are policies supporting standardisation, trade, employment and above all competition circular economy oriented are lacking. Thus, the circular economy agenda has very limited impact in the economy and the environment.

3.1.2 Conservative scenario – Moderate evolution

Scenario two takes a positive but conservative stand concerning the advances of Circular Economy. It sees incremental developments across many of the stages of Circular Economy European wide upscaling. Still, without aggressive, decisive, and prompt measures, progress in the adoption of CE is

7 For example, non-recyclable powder in 3D casting, toxic gases in laser cutting applications, high energy consumption running "clean rooms" for new micro-printed electronics, etc.

8 Mature concepts like industrial ecology and industrial symbiosis are likely to be rebranded as Circular Economy. See examples: http://www.emmind.eu/ ; http://www.ntnu.edu/indecol

9 Such as Ellen MacArthur Foundation Circular Economy, the Club of Rome, GSTIC conference, etc.

only marginal and still appears in islands of change but this is not widespread through Europe and all industries. In the medium term, the CE is expected to see implementation in leading sectors like manufacturing and recycling. As time progresses, more examples of adoption of CE principles in a whole value chain are expected to emerge and vertical (intra sectoral) integration pilots advance further. Some pioneers in capital and durable goods industries provide examples of business models in which full servitization is becomes much more successful as customers characterized by *Millenias* and *Silvering* mentalities find it not appealing due to new forms of fiscal disincentives and preference for services rather than ownership to bear individually the total costs of ownership of durable goods.

The relationship between i4.0 and the CE continues to develop, to a large extend is acknowledged that CE rides partially on i4.0, so any advances in i4.0 affect CE. Stakeholders engaged on developing new technologies for waste management and producer extended responsibility develop private-public partnerships in which the developments in CE and i4.0 are seen as complementary and going hand and hand. Within i4.0, support continues to widespread favorably and technologies like sensors, data analytics and protocols for data-based process guidance become part of sectoral roadmaps guiding innovation and industrial change. As consequence there is wide recognition of the need to converge on approaches of systems integration of real and virtual worlds / interfaces for customer intimacy along manufacturing networks.

The communication on Free Data Flows promoting the Fifth Freedom Pillar of European integration is under debate and in process of ratification in the European Parliament to become a directive. In parallel, frameworks for big data governance become accepted clear necessity to enable programs focusing on i4.0 generate new skills and encourage systems thinking. In parallel, sustainability and CE principles become more common at University level programs and vocational training. This leads to deployment of more sustainable practices in industry and services.

As time passes, policy makers advance in their agenda and a CE European roadmap is further detailed and implemented in different sectors. At this stage, sectoral branch organizations become actively involved, clarifying how CE principles and circularity are applied in their sector. The issue of sustainability and in particular the CE is adopted at the policy level in European RTOs infrastructures and Universities with a moderate uptake in operational research and roadmaps across technology themes. Zero waste as a factor for capital, durable and consumer goods design and production is widely acknowledged by innovators as an imperative but this remain a long shot to implement given the massive legacy systems that need replacement in the industrial technology stock. At the same time the CE rhetoric is adopted by large companies with high stakes on R&D and innovation investments.

The private sector continues to develop and respond to policy activities with a strong supporting message by large industrial players and adoption of the CE principles in companies with sustained large investments across time on R&D and innovation. With these developments, more Private-Public Partnerships (PPPs) of CE emerge and are coordinated with PPPs on i4.0 regarding wide diffusion of expertise on sensors, data analyses infrastructures and protocols for data-based process guidance and regulating cyber-physical communication. The potential of this developments for track-and-trace during good lifetime and extended producer responsibility are acknowledge but not yet in the forefront of debate in policy forums.

As the adoption and spread of the CE continues, issues of standardization come to the forefront. Standardization practices like in the RAMI model for the integration of diverse business functions widely adopted as part of i4.0 are also streamlined and adopted as reference model to standardize CE practices across the value chains in vertical and horizontal integration. In addition, IoT security and safety protocols invoke more regulation in the form of EU directives supporting Free Flow of Data in Member States. Data flows governance has an intrinsic value for CE extended producer responsibility but at this stage many value chains across industry are not ready for such step.

As time progresses and more examples and policy measures targeting CE emerge, customers start to change their behavior. New forms of business models are enabled by the combination of higher loyalty to brands that embrace smarter industry with a sustainability orientation. Also, the integration of real and virtual worlds (digital twins) gains track and are further linked to interfaces for further customer intimacy in manufacturing and marketing networks. This increases a new culture of consumption that enable longer lifetime for product-service systems, not only for high-end products but also for relatively low-cost products. This leads to more supply chains implementing leasing services and organizing their supply chains with shared responsibility of products (artefacts, devises, etc.) take back after their a given lifetime-usage defined period for further refurbishing, remanufacturing or disassembly and recycling.

3.1.3 Optimistic scenario: Circular Economy and industrial Digitalisation in full swing

As time passes continuous effort and policy and industry push are provided, the principles and agenda of the CE are widely accepted by different ID stakeholders (citizens, industry and policy-makers) and are being integrated throughout the value chain and different sectors. This fosters more collaboration, cooperation and new business models based on shared incentives. To reach this full, long-term implementation however, a decisive move from industry and policy and educating the customer to stimulate demand is necessary.

As more and more examples of CE businesses emerge and a critical mass of projects TRL 7-9 is achieved in the single market thanks to well defined calls for mission-oriented projects; pilots and deployment projects regarding CE solutions and their application in different sectors is continues. The development and upgrade of new skills across EU Member States come to the forefront. Education and skills for CE engineering related industries and sectors are common practice in University curriculars, vocational education and even secondary school level. Awareness raising and education of citizens via media, arts, culture, are common and continues practice.

In this scenario looking at the longer-term future, the policy making turns to implementation with national and regional governments supporting CE policies and city/local initiatives implementing Circular Economy becoming the norm. The progress on the CE adoption is continuously followed through the widespread adoption of national and regional indicators. With these developments, lobbying groups become co-opted via the integration of their agendas into mainstream institutional policy at the EU and national levels and the debate turns from implementation of the CE to effects of the past policies and gaps not covered by the then operating policies, standardization and certification issues. Additionally, policies and regulations start being consolidated and clear references towards the CE are seen more often. Regulatory incentives such as internalizing externalities are fully adopted further making the CE model economically feasible and desirable for companies.

The first Zero Waste regulations and standards in pioneering aspects of manufacturing are in place, this is seen as setting worldwide standards that give European a new competitive edge. As consequence, there is wide debate for the extension of such regulations across all sectors of the EU economy. The notion of “downstream” industrial symbiosis that in the past was seen as taking advantage waste streams of complementary industries has evolved to be complemented by the notion of “upstream” innovation ecosystem applying CE principles to spur innovations that aim at Zero Waste from design. With the further implementation of free data flows directive across Member States, the track and trace of products along the product-service life cycles become easier and more widely spread and accepted by customers and business, thus enabling CE business models such as product as a service. Issues of data ownership, privacy and security for both consumers and businesses are well regulated Europe wide.

When it comes to industry, the spur of project examples, policy initiatives and increased debate, create a conductive ecosystem for CE adoption. Within industry, a wide diffusion of systems engineering with focus on interdependences and unintended inter-generational consequences (social and environmental) become a normal part of product-services systems design. The focus of the key actors involved turns to value chain design and integration, with CE principles being implemented across sectors, products and product components, thus allowing for materials to be reclaimed and re-used in different industries. Funding for CE implementation solutions is available as VC and private investors update their risk models, and public R&I funding becomes much more targeted and is increased.

All these developments lead to increased CE products-service supply. While many challenges still remain, in the longer-term there is a clear connection between the business models implemented and sustainability goals. Both customers and industry players put more emphasis of benefits to the society and environment, thus bringing new competitive advantages. This also leads to mass-customized markets growth, competition and distribution of production locations to become issues for industrial policy.

4 Twin transitions structuration stages

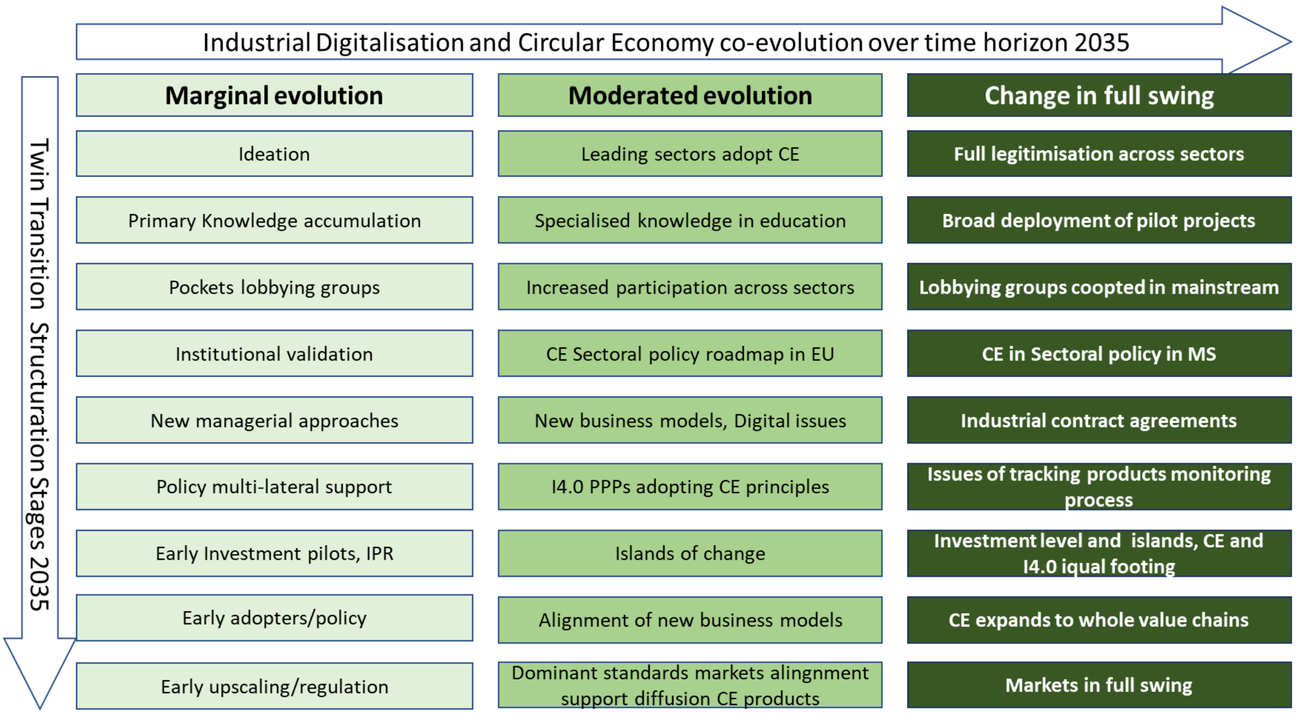
The CE and ID have a process that can be stages considering the main characteristics of each of the evolution scenarios. The staging in the pessimistic scenario is characterized by the following structuration features: Ideation and assimilation of the “twining” of the circular economy and industrial digitalization, support of applied science goes to primary knowledge accumulation, salient lobbing groups (e.g., EFFRA, BDVA and Circular economy stakeholder forums), the “twin” concept is institutionally validated by European Institutions and supported by multilateral policy actions, some early investments in pilots addressing digitalization, the later with minimal protection of IPR (methods and models of valorization and protection not well defined) and there are attempts to do early upscaling (supported by standardization roadmaps and regulation). This is linked to the early definition of Industrial Data Spaces and industrial Digital Platforms.

The conservative scenario is characterized by: Leading sectors adopt circular economy practices, specialized knowledge is recognizable in university curricula, noticeable increased participation across sectors, CE sectoral policy roadmaps in the EU, fragmentation and digitalization issues are tackled via industrial agreements and private public partnerships, noticeable islands of change appear in leading manufacturing companies, alignment of new business models with digital connected factories, and dominant standards support the diffusion of CE production processes and products.

The third scenario in the evolution of the twin transition include: Widespread legitimization of both transitions, broad deployment of CE-ID twining projects, existence of CE-ID mainstream lobbying groups, CE-ID sectoral policy in European Member States, formalization of CE-ID industrial contract agreements templates, legal and technical issues of tracking products usage, remanufacturing, reuse and recycling are reflected in standards and regulatory agreements, CE-ID expands beyond industrial champions in to a whole new value chains. The later enables expansions of markets in new digital technologies application in production processes, products and services. While many challenges still remain, in the longer-term there is a clear connection between the business models implemented and sustainability goals. Both customers and industry players put more emphasis of benefits to the society and environment, thus bringing new competitive advantages. This also leads to mass-customized markets growth, competition and distribution of production locations to become issues for industrial policy.

Besed in the staging summary outlined above the figure below describes graphically the logic of the progressive scenarios and the corresponding structuration stages.

Figure 1: Industrial digitalization and Circular Economy structuration scenarios



5 Conclusion

This paper aimed to contribute to filling a gap in the literature by providing an approach to describe the complexity of multi-transitions structuration process using the example of the circular and digital twin transition. Such approach could be fruitful to facilitate an outlook of what is the road ahead to be transited to institutionalize a process of change supporting sustainability while strengthening industrial increased efficiency and productivity. The structuration path is likely to take several decades as current production legacy systems and consumptions patterns are to continue for several decades to come. Currently there are still major gaps, like, new skills requirements for digital factories, lack on actual technological opportunities in circular industrial technologies and thus lack of capabilities and resistance in industry to implement CE principles in its full extend.

Given the need for scientific breakthroughs in material sciences and recycling, reuse and remanufacturing it is likely that CE will continue to lag behind relative the pace of ID deployment. Saying the later is possible to see that ID is a positive development that most likely will enable some aspects of the circular economy. Given the systemic nature of CE a frequent question posed by industry and companies managers is: where do we start to implement CE? The structuration process described provides an outlook to position current and planned efforts for industry strategy and policy making.

The structuration path provided gives an indication of all the road that is ahead. The scenarios indicate that a multiplicity of stakeholders need to be involved now and in the future at each evolution and structuration stage. Each stage outlined at different points of evolution can help to identify the likely stakeholders, roles and responsibilities. Different agendas, incentives, guiding norms and capabilities must be aligned across participating stakeholders that are likely to be different ones across different stages of structuration and evolution. The idea that there are multi-transitions at stake requires a strong role for supranational policies to guide and support change at the level of detail required in the scenarios outlined.

Salient limitations of this study can be linked to the convenience of arriving to a more robust approach in terms of the empirical validation of the proposed twin transition structuration process. Therefore, a next, logical step derived from this study is the operationalization and modelling of the different stage in the structuration scenarios. A dynamic approach would be needed in order to identify enabling and hampering conditions guiding the twin transition process of CE and DI. Empirically grounded agent based modelling and dynamic modelling based on Corral (2002); Montalvo 2007) and Wehn and Montalvo (2018) can be used to that end.

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Annex. Projects interviewed

- 3D HIPMAS - Pilot Factory for 3D High Precision MID Assemblies
- AMCOR - Additive Manufacturing for Wear and Corrosion Applications
- BAMB - Buildings as Material Banks: Integrating Materials Passports with Reversible Building Design to Optimise Circular Industrial Value Chains
- BOREALIS - the 3A energy class Flexible Machine for the new Additive and Subtractive Manufacturing on next generation of complex 3D metal parts.
- CABRISS - Implementation of a CirculAr economy Based on Recycled, reused and recovered Indium, Silicon and Silver materials for photovoltaic and other applications
- CABLEBOT - Parallel Cable Robotics for Improving Maintenance and Logistics of Large-Scale Products
- FiaD, - Factory-in-a-day
- FIBREMAP - Automatic Mapping of Fibre Orientation for Draping of Carbon Fibre Parts
- T-REX - Lifecycle Extension Through Product Redesign And Repair, Renovation, Reuse, Recycle Strategies For Usage&Reusage- Oriented Business Models
- Futuring

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[10] https://www.euspri2021.no; An extended abstract of 2000 words is available in the conference website

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