D 2.5
Pathways instantiation from DT-ICT-07 domains- Second Iteration

Action acronym	ConnectedFactories 2
Action Full Title	Global-leading smart manufacturing through digital platforms, cross-cutting features and skilled workforce
Grant Agreement Number	873086
Instrument	CSA: Coordination and Support Action
Project coordinator	VTT
Deliverable Number	D2.5
Deliverable Title	Pathways instantiation from DT-ICT-07 domains - First Iteration
Lead Beneficiary	VTT
Work package	2
Work package leader	FPM
Dissemination level[1]	Public
Type[2]	R
Due date according to DoA	30 September 2022
Actual submission date	13 October 2022
Main editors and contributors:	FPM, VTT

[1] PU: Public, CO: Confidential, only for members of the consortium (including the Commission Services)
[2] RE: Report, OT: Other; ORDP: Open Research Data Pilot

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 873086.

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Revision No.	**Date**	**Description**	**Author**
0.1	29/08/2022	Draft outline	K.V.
0.2	15/09/2022	Extended Draft	K.V.
03	27/09/2022	Additions by Polimi (F.A), final version of CE pathway, modifications agreed at WP leader meeting (20.9.)	K.V.
04	07/10/2022	Modifications based on internal (VTT) review	

Abbreviations and acronyms

TERMS, ABBREVIATIONS AND ACRONYMS	
WPL	Work Package Leader
GA	Grant Agreement / General Assembly
EB	Executive Board
CO	Coordinator
DoA	Description of Action
EC	European Commission
WP	Work package
QM	Quality Manager
DPO	Data Protection Officer
QMP	Quality Management Plan
CA	Consortium agreement
SyGMa	System for Grant Management
ORDP	Open Research Data Pilot

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Executive Summary

The present deliverable aims to instantiate the pathways of Connected Factories 2- project within the four domains of the DT-ICT-07 (i.e. (1) Agile Value Networks: lot-size one, (2) Excellence in manufacturing: zero-defect processes and products, (3) The human factor: human competences in synergy with technological progress, (4) Sustainable Value Networks: manufacturing in a circular economy). 'The report shows how the Connceted Factories pathways support the DT-ICT-07 domains and projects, and analyse the progress and obstacles in the green and digital transformation of manufacturing.

The DT-ICT-07 domains and projects address the challenges that the manufacturing sector is currently experiencing. In particular, the European Commission has designed an Industrial Strategy to guide the manufacturing sector towards a sustainable development being helped by the current digitalisation of factories. The COVID-19 crisis made clear that relying on a growth-oriented paradigm, based on value-extracting, highly energy-, materials- and resource-intensive approaches, will not help the world reach sustainable development in ways that respect planetary boundaries. In this transformation, the role of European Manufacturing sector is essential. This change towards more sustainable manufacturing industry entails a fundamental redesign of value chains to embrace new technology possibilities, sustainability, the application of circular economic design principles and regenerative approaches[3]

Circular Economy paradigm is one of the main elements of the European Green Deal since it can represent a great solution towards climate neutrality and efficient use of resources. Actually, its adoption can be highly facilitated by the introduction of different digital technologies as reported in the document developed by the European Policy Centre named “A digital roadmap for a circular economy[4]”.Four key elements must be respected to obtain the expected goals:

- *Define a vision and act accordingly* to make Europe become leader is utilising data and digitally-enable solutions and to extend the product lifecycle by being supported by the synergies among the digital and sustainable solutions,
- *Use governance, policies and regulations to provide a framework for action* by allowing the data and information sharing and access, providing digitally-enabled services, improving the e-commerce and the eco-design.
- *Use economic instruments to encourage and enable the transition* by introducing the right financial tools, by supporting the reskilling and upskilling of the workforce and by directing the investment.
- *Strengthen partnerships and empower citizens* by relying on the usage of the already existing stakeholders’ platforms, by underlying the benefits for data exchange increasing the trust in their relationships.

The overall ambitions and strategies of the European union towards sustainable, circular and digitalised will not be realised without transforming the manufacturing industries. In this document, pathways and innovative approaches supporting the transition to circular and digital manufacturing are described. The focus is on the DT-ICT-07 domains and innovations developed in the respective projects.

[3] Industry 5.0: A Transformative Vision for Europe Governing Systemic Transformations towards a Sustainable Industry ESIR Policy Brief No. 3.
[4] https://www.climate-kic.org/wp-content/uploads/2019/07/DRCE.pdf

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1 Introduction

The introductive chapter clarifies the objective of the deliverable and elucidates the structure of the deliverable in order to clearly address the objective. It also shows the main links that are present among the activities and pathways characterising the ConnectedFactories 1 (CF1) and ConnectedFactories 2 (CF2) and last, to create the ground to explain the activities performed by the Digital Manufacturing Platforms (DMP) cluster projects[5].

The objective of the deliverable is to provide an overview of the pathways developed throughout the CF2 project. Indeed, the previously submitted deliverable D2.1.was the first deliverable of Work Package 2 of CF2 and, more precisely, the D2.1 was associated to the task T2.1 Pathways instantiation in DT-ICT-07 domains. The D2.1 focused on the work performed around the concept of Circular Economy, as the related Circular Economy Pathway was under construction. This deliverable D2.5 is the Second Iteration of D2.1 and aims to instantiate the three pathways configured during the CF2 project. The pathways are describing the developments around:

- Data Spaces
- Circular Economy
- Artificial intelligence

Therefore, D2.5 considers all four domains of DT-ICT-07, which are: 1) Agile Value Network, 2) Zero Defect manufacturing, 3) Human Factor, 4) Sustainable Value Chains. . However, main focus will be on the circular economy pathway that is strongly linked to the Sustainable Value Chains domain. In line with the paradigm of Twin Transition and Industry 5.0 sustainability development is closely linked with digitalisation and data utilisation. For that reason, a combined innovation on both sides allows to be more successful on the transition. In particular, the exploitation of the data economy and allows the development, deployment and scale-up of the sustainable, digitally-enabled solutions identified to boost a more sustainable circular economy. Therefore, the three novel pathways of CF2 project are closely linked together.

The structure of the deliverable is elucidated as follows.

- In chapter 1, a brief introduction is given regarding the context in which the project has been put in place. To be more precise, the four domains of the DT-ICT-07 (i.e. (1) Agile Value Networks: lot-size one, (2) Excellence in manufacturing: zero-defect processes and products, (3) The human factor: human competences in synergy with technological progress, (4) Sustainable Value Networks: manufacturing in a circular economy) are elucidated to classify the actions developed within the project boundaries to figure out the main impacts provided through different related projects to Connected Factories 2. Furthermore, the three novel pathways developed during this CF2 are presented.

[5] The Digital Manufacturing Platforms (DMP) cluster is composed of six projects funded by the EU through the DT-ICT-07 calls in 2018 and 2019. The DMP cluster is pursuing joint activities in a number of areas (platform interoperability, dissemination, business models, standardisation etc) to synchronise the related activities taking place in different projects.

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- In chapter 2, the manufacturing industry trend and roadmaps are reported to guide the reader throughout the strategic plan proposed by Europe, focusing on twin transition of industry and the SME aspects. Following the ambitions of the European Green Deal and associated industrial strategies and actions (including Horizon Europe program, the needs to be paid to the digital and sustainable solutions within the manufacturing domain. to integrate digital and sustainable solutions within the manufacturing domain. With this goal in mind indeed, it is spoken about the "Twin Transition" in Horizon Europe Program and the topics to be addressed and furthermore the concept of Industry 5.0 is discussed. At the end of chapter the objectives of ICT-07 projects are reflected in connection with the research agenda of European Manufacturing industry.

- The chapter 3 considers the current development related to circular and sustainable manufacturing as well as vision for the required paradigm change of green transition. This chapter aims to facilitate the reader in understanding what characterises this paradigm change towards more Sustainable Manufacturing and Industry 5.0 in terms of principles and possible strategies to be adopted to address the principles.

- The chapter 4 summarises the research and development work done regarding the Circular Economy pathway. The development work has included testing with the illustrative cases, which are shortly presented.

- At the chapter 5, the practical case examples from Digital Manufacturing Platforms (DMP) cluster projects are presented to provide success stories and barriers and drivers for change including four domains of these DMP cluster projects.

- The chapter 6 is connecting the European research agenda of manufacturing and Circular Economy pathway configured at the Connected Factories 2 project. Based on these reflections, the chapter discusses the future trends of manufacturing industry at Europe, and highlights the main drivers and barriers emerged from project and case examples.

- At the chapter 7, the conclusions of the deliverable D2.5 are reported to summarise the outcomes from the activities performed and to pave the way to future opportunities.

The link with the pathways and activities performed in ConnectedFactories 1 (CF1) and ConnectedFactories 2 (CF2) are described as follows. Connected Factories 1 (CF1) identified a number of key enablers and cross-cutting factors and developed five pathways based on them. These have been further refined in Connected Factories 2 (CF2) and needs for novel pathways have been recognised related to the data spaces, circular economy and artificial intelligence. At the CF2, WP1 studied the building blocks (presented at D1.2 and D1.4) that WP2 has used to develop the pathways. Those pathways will be broken down into five stages or levels of increasing maturity. The pathways will then be mapped across several key operations and milestones will be identified for each operation at each level Figure 1.

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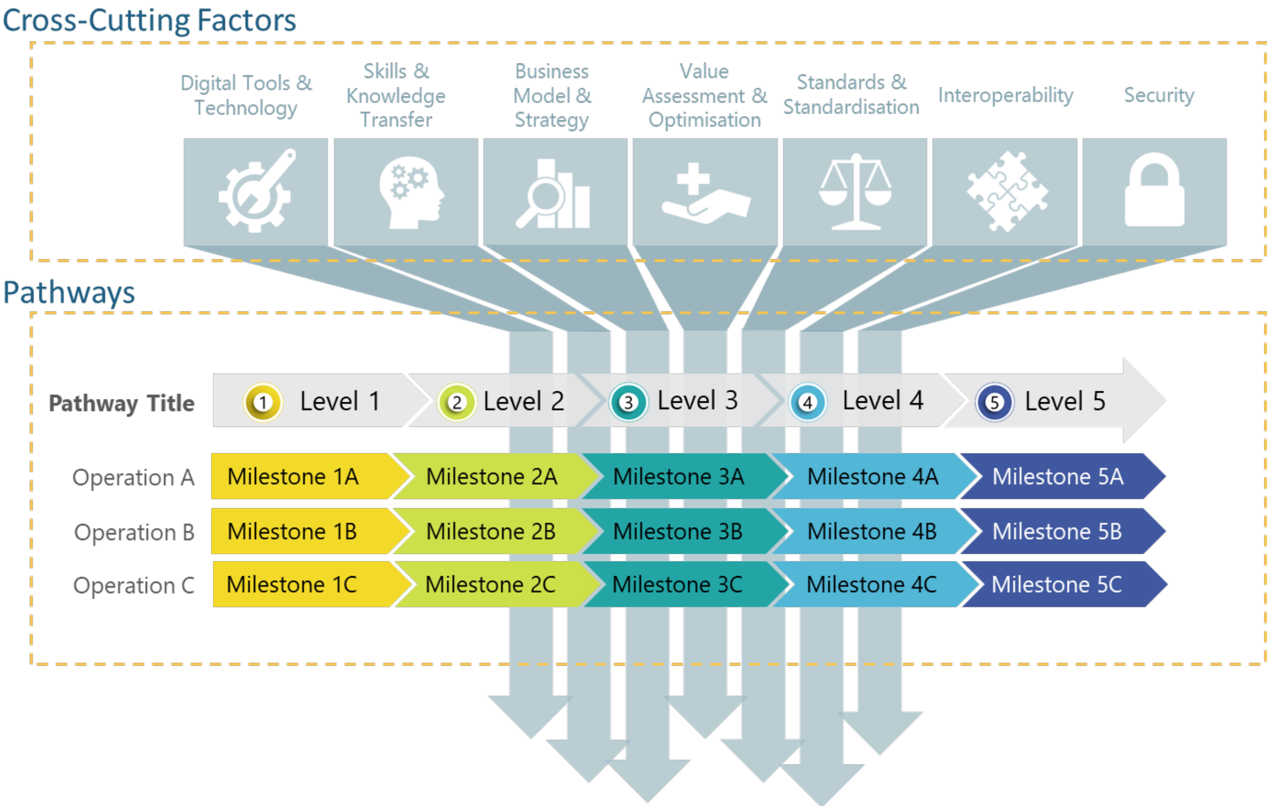

Figure 1 Connected Factories pathway development.

At the beginning of the project, we identified several questions: Will the cross-cutting factors (CCFs) have the building blocks of the pathways or will they become the pathways themselves? Are the CCFs common to all pathways or specific to certain one(s)? Some of the CCFs have already been discussed in CF1, whereas some of them are new or modified at CF2.

1.1 The DT-ICT-07 four domains

The project belongs to is operationalised within the domain of "DT-ICT-07-2018-2019: Digital Manufacturing Platforms for Connected Smart Factories", anconsisting of six innovation actions covering the four domains and one CSA. Digital platforms are the essential elements for manufacturing companies to make possible the integration of new technologies, applications and services to face the continuous external change of supply and value networks, a special attention is required on them. The challenges of twin transition enhance the role of digital manufacturing platforms, as the integration of different technologies and making data accessible is in the core of green and digital transformation of industry. More precisely, the development of the digital platforms for connected smart production focus on four domains:

1. Agile Value Networks: lot-size one (2018 call)
2. Excellence in manufacturing: zero-defect processes and products (2018 call)
3. The human factor: human competences in synergy with technological progress (2019 call)
4. Sustainable Value Networks: manufacturing in a circular economy (2019 call)

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The following Innovation Action projects were selected for funding:

I. **Agile Value Networks: lot-size one** (2018 call)

- **eFactory[6]. European Connected Factory Platform for Agile Manufacturing**. *The eFactory project realises a federated smart factory ecosystem by primarily interlinking 4 smart factory platforms, from the FoF-11-2016 cluster, through an open and interoperable Data Spine. The federation of the 4 base platforms is complemented by industrial platforms, collaboration tools and smart factory systems, specifically selected to support connected factories in lot-size-one manufacturing. The federated eFactory platform enhances value and reduces the barrier to innovation by providing seamless access to services and solutions that are currently dispersed. In parallel the platform provides the necessary infrastructure, tools and support for novel service creation and validations by third parties. Further, by fostering healthy competition in the smart factory ecosystem, the eFactory platform will ensure that the needs of the evolving smart manufacturing industry are met for the long term*.

II. **Excellence in manufacturing: zero-defect processes and products** (2018 call)

- **ZDMP[7]. Zero Defect Manufacturing Platform.** *Smart, SME Friendly, open, Zero-Defect Manufacturing Reference Platform, Apps, SDK, and Marketplace for Product and Process Quality in any factory for achieving excellence in European and Global Manufacturing. The ZDMP project combines state of the art technological approaches based on commercial grade standard or open-source or previous-project software with an innovative integration concept based on proven and integrating technologies. It provides Process and Product Quality support on top of a platform layer. These all can utilise ZDMP core services which can also be used to build ZD Apps which are placed on the ZD Marketplace. The ultimate aim is to establish a sustainable business and technological approach at the end of the project and launch "ZDMP Limited" assisted by the possibility of a crowdsourcing approach and ZDMP ambassadors.*
- ***QU4LITY[8] Digital Reality in Zero Defect Manufacturing****. QU4LITY will demonstrate, in a realistic, certifiable and highly standardised, SME-friendly and shared data-driven ZDM product and service model for Factory 4.0. QU4LITY will also demonstrate how European industry can build unique and highly tailored ZDM strategies and competitive advantages (significantly increase operational efficiency, scrap reduction, prescriptive quality management, energy efficiency, defect propagation avoidance and improved smart product customer experience, and foster new digital business models; e.g. outcome-based and product servitisation) through an orchestrated open platforms ecosystem, ZDM atomized components and digital enablers (Industry 4.0 digital connectivity & edge computing package, plug & control autonomous manufacturing equipment, real-time data spaces for process monitoring & adaptation, simulation data spaces for digital process twin continuity, AI-powered analytic data spaces for cognitive digital control twin composable services, augmented worker interventions, European quality data marketplace)*

6 https://www.efactory-project.eu/ now EFPF https://www.efpf.org/
7 https://www.zdmp.eu/
8 https://qu4lity-project.eu/

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across all phases of product and process lifecycle (engineering, planning, operation and production).

III. **The human factor: human competences in synergy with technological progress** (2019 call)

- **SHOP4CF[9] Smart Human Oriented Platform for Connected Factories**. *Europe's factories are getting smarter, and more sustainable. Finding the right balance between cost-effective automation and repetitive tasks and involving workers in areas such as adaptability, creativity and agility is the ultimate aim. In accordance with the highly connected factory model, a lot of data is being generated within the factory – by the embedded sensors and connected production equipment. All this information is useful in improving processes. The EU-funded SHOP4CF project will develop a platform on an open architecture that can support humans in production activities and provide basic implementation as a free, open-source solution. It will rely on pilots acting as the testing facilities and seeds for adoption of the platform.*

IV. **Sustainable Value Networks: manufacturing in a circular economy** (2019 call)

- **DigiPrime[10]. Digital Platform for Circular Economy in Cross-sectorial Sustainable Value Networks**. *Digital technology plays a big role in our transition to a circular economy, which aims to make optimum use of resources within industries. The EU-funded DigiPrime project will develop the concept of a circular economy digital platform in order to create circular business models based on the data-enhanced recovery and reuse of functions and materials. Specifically, it will create and operate a federated model of digital platforms for cross-sector business in the circular economy. DigiPrime will be validated through several cross-sectoral pilots, further detailed in 20 use cases covering different European industrial sectors (automotive, renewable energy, electronics, textile, construction), and by additional pilots in new sectors, funded through an open call mechanism.*
- **KYKLOS 4.0[11]. An Advanced Circular and Agile Manufacturing Ecosystem based on rapid reconfigurable manufacturing process and individualized consumer preferences**. *In circular manufacturing (CM), manufacturers find ways to eliminate waste by reusing and recycling materials and goods. The EU-funded KYKLOS 4.0 project aims to show how cyber-physical systems, product life-cycle management, life-cycle assessment, augmented reality, and artificial intelligence technologies and methods are able to transform CM. It will achieve this through seven large-scale pilot projects that will demonstrate improvements in operational efficiency and deliver solutions for resource reuse. It will further ensure the scalability of novel CM technologies, engage over 100 European industry actors, transfer know-how and mobilise additional sector investments. The project's advanced ecosystem can reshape factory processes and services so as to benefit manufacturing throughout Europe*.

To support collaboration of the DT-ICT-2018-2019 domains and projects, the Digital Manufacturing Platform (DMP) project cluster was built up. Several meetings have been held in and in particular, on March 24th 2021

[9] https://www.shop4cf.eu/
[10] https://www.digiprime.eu/
[11] https://kyklos40project.eu/

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meeting with ICT-07 cluster project was focusing on the Circular Economy, and the CF2 project has been organising this event. The content of this meeting is discussed at the Chapter 4.2.

1.2 Three Pathways of Connected Factories 2

Together with above mentioned experts and stakeholders across Europe, CF2 project developed pathways that support manufacturing companies when navigating through the digital opportunities and challenges, i.e. the transformation of European Manufacturing Industry. The pathways focus on data, artificial intelligence and circularity as these are key aspects and enables of the twin transition of manufacturing. The pathways are divided to five steps that describe the development (maturity). Thus, is should be stated that the fifth level is not always the objective of a company, i.e. based on their strategic choices, business models or value chain positions companies can be targeting to other levels.

1.2.1 Data Spaces

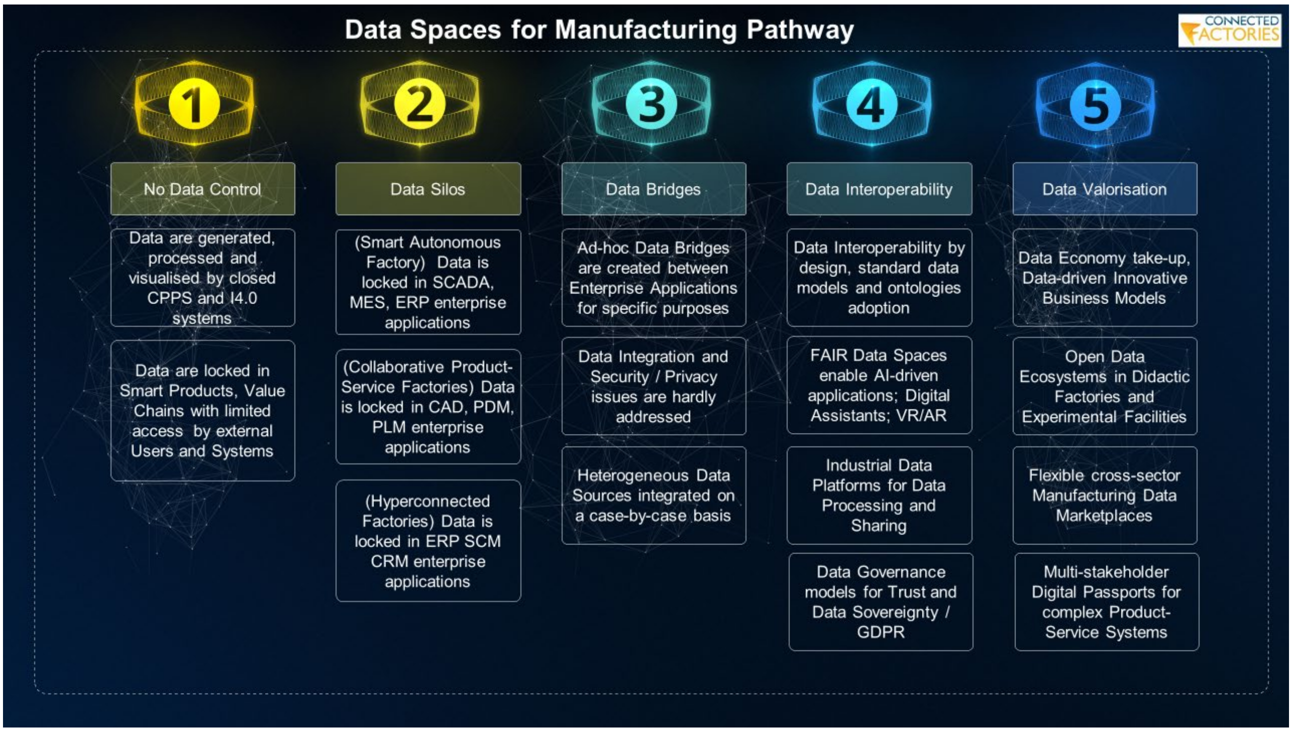

Figure2A Connected Factories Data Spaces for Manufacturing Pathway.

The starting point in Data Spaces pathway is a company at *No data control* (level 1), in which the data are generated, processed and visualized in closed independent systems. Also at the second, data silos (level 2) the data is locked in these systems that are not connected. The *Data bridges* (level 3), ad-hoc integrations are created between systems for specific purposes. Then, at the *Data Interoperability* (level 4), standard data models and ontologies are adapted at the company level, and industrial data platforms considered for data processing and analytics. At the *Data Valorisation* (level 5) utilization of data is based on data-driven innovative business models, open data ecosystems and marketplaces enabling data economy.

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1.2.2 Circular Economy

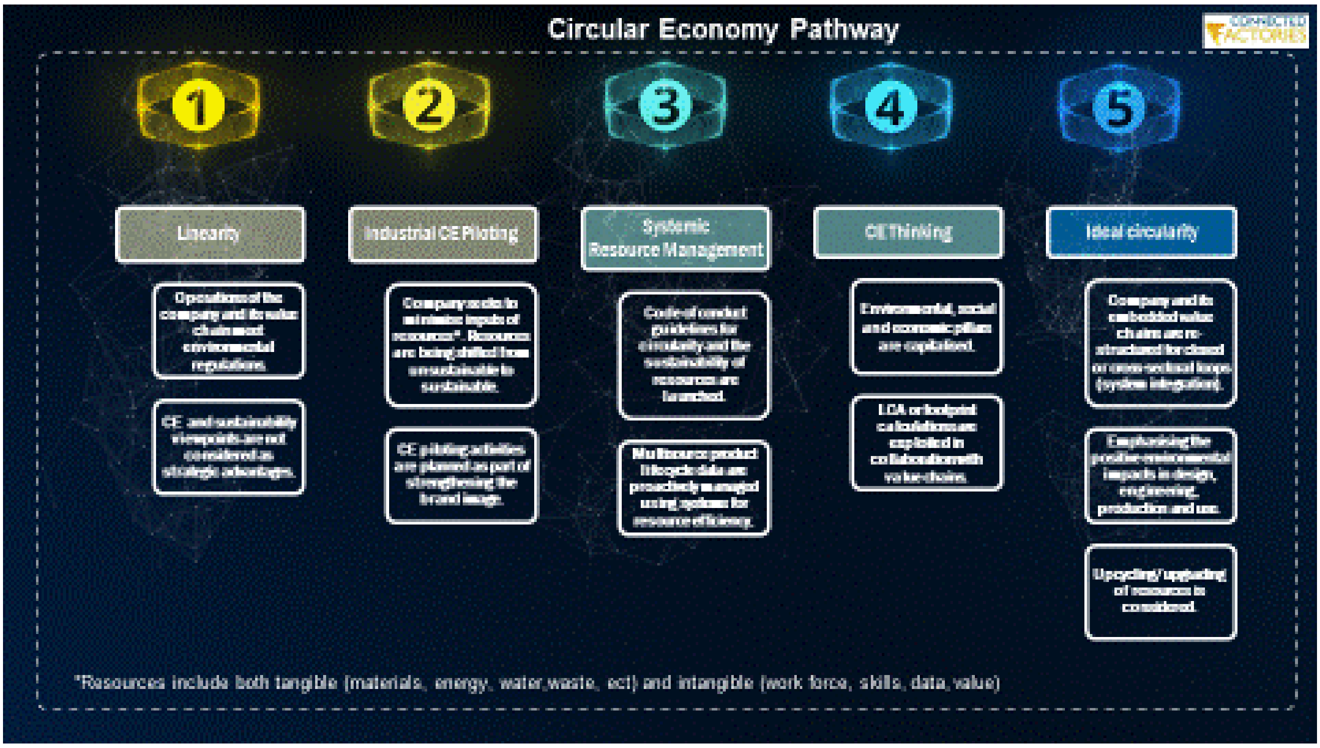

Figure2B Connected Factories Circular Economy for Manufacturing Pathway.

The starting point of CE pathway is a company and its value chain in *linearity* phase, where the environmental regulations are met, but CE and sustainability viewpoints are not considered as strategic advantages (level 1). The next step for many companies is start *piloting* in order to minimise the inputs of energy and materials, however often the driver is strengthening the brand image (level 2). A crucial step towards more sustainable manufacturing is *systemic resource management* where multisource product lifecycle data is exploited systematically for resource efficiency and circularity gains (level 3). Further, at the next, *CE thinking,* level the environmental, social and economic pillars of sustainability are explored in collaboration with value chains. This network level activity is required to truly take advantage of circular economy (level 4). The most advanced phase is *ideal circularity*, where the company and its embedded value chains are re-structured for closed or cross-sectoral value loops. Here, the data flows and (federated) data spaces are one of the crucial enablers for emphasizing the positive sustainability impacts (level 5).

1.2.3 Artificial Intelligence

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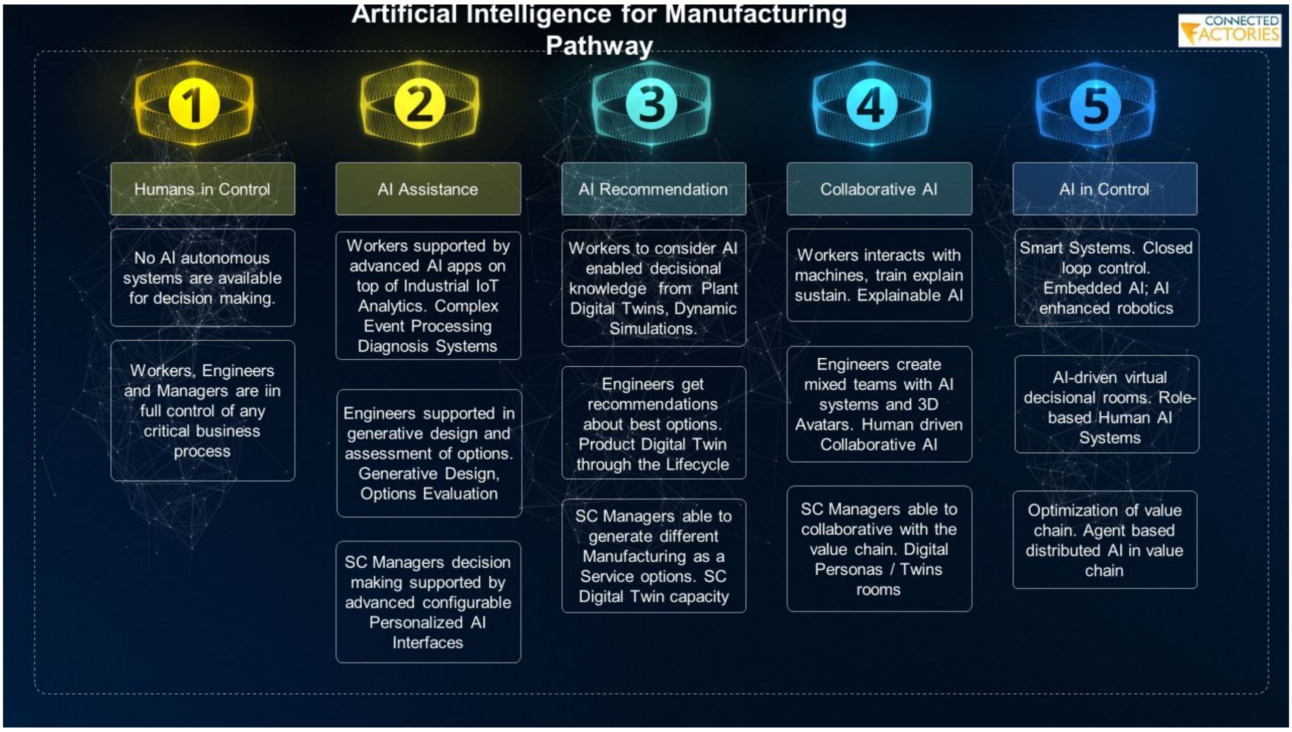

Figure2C Connected Factories Artificial Intelligence for Manufacturing Pathway.

The starting point of Artificial Intelligence pathway is a company at *Humans in control* (level 1), in which no AI autonomous systems are available for decision making. Workers, Engineers and Managers are in control of all critical processes. At the second, *AI Assistance* (level 2) workers are supported by advanced AI apps and Engineers by generative design and assessment options. Also Supply Chain Managers use advanced configurable personalized AI interfaces in their decision making. The *AI Recommendation* (level 3), more advanced tools are used by workers, engineers and managers. Then, at the *Collaborative AI* (level 4), workers interact with machines, engineers can create mixed teams with AI tools, and managers use AI enabled tools, such as digital personas for value chain level collaboration. At the *AI in Control* (level 5), there are variety of tools used, such as embedded AI solutions, AI enabled virtual decision making rooms and agent based distributed AI value chain level.

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2 Manufacturing Industry trends and roadmaps

Europe's industry is a forerunner in the green transition and a global technology leader in most manufacturing market segments, but retaining this position has constantly been challenged by international competitors[12]. In particular, Europe faces severe competition in mastering industrial data, which is crucial for manufacturing competitiveness. Therefore, investments in manufacturing and digitalisation innovations are a necessity[13].

The manufacturing sector is experiencing a great period of change and innovation. The fourth industrial revolution has impacted in a positive way mainly on the productive activities of this sector and it is continuing to stimulate potential new improvements. This technological development and societal changes will create different transition paths when organisations shift towards higher sustainability and autonomy in manufacturing. The three novel pathways of Connected Factories 2 project concretise the development steps within these paths (see 1.2.).

Although many positive changes are characterising this sector, many obstacles should be overcome. Uncertainty of the global markets and supplies, pollution, scarcity of materials and components, skill shortage and limited access to renewable and affordable energy are among the biggest challenges.

Furthermore, COVID-19 crisis had made clear that Europe's economy and society by seeking to reconstitute the status quo ante is not the correct response to ensure medium- and long-term prosperity. Current paradigms of value-extracting economic, social and industrial activity are among the root causes of global warming and the destruction of the natural environment, resources and systems that human welfare and life together with millions of other species depend on. Therefore, engagement with leading industrial actors, and support for industrial innovation that delivers scaled solutions that are more sustainable and follow the principles of circular economic, are essential to the EU vision of "competitive sustainability". In line with these changes, the chapter 2 is reviewed from the Deliverable 2.1 which presented the first iteration.

The competitiveness of enterprise nowadays needs to take into account not only the economic sustainable pillar but also the social and environmental one. To support enterprise in this direction, the European Commission proposed the European Green deal[14] at December 2019 (see section 2.1). In addition several connected actions plans has been presented since that and this chapter reflects shortly the most relevant policies of the European Commission on this front are discussed at below sections as follows:

- The European Industrial Strategy of March 2020, and the Update of May 2021: there is now a renewed momentum in the EU to tackle its strategic dependencies as well as to boost its resilience across key strategic areas. The Covid-19 crisis revealed the importance of improving production response and preparedness of EU industry, in support of its long-term competitiveness. (section 2.2)
- The Digital Decade of March 2021, where the Commission presented a vision, targets and avenues for a successful digital transformation of Europe by 2030.

[12] VTT vision paper (2022). Towards Sustainable Manufacturing: How is autonomy paving the way towards a sustainable industry?
[13] European Commission (2021). MADE IN EUROPE. The manufacturing partnership in Horizon Europe – Strategic Research and Innovation Agenda (SRIA).
[14] https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en

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- The Circular Economy Action Plan of March 2020 announced initiatives along the entire life cycle of products. It targets how products are designed, promotes circular economy processes, encourages sustainable consumption, and aims to ensure that waste is prevented and the resources used are kept in the EU economy for as long as possible. (section 2.3)

- The Fit for 55 Package of July 2021, delivering the EU's 2030 Climate Target on the way to climate neutrality, given the process industries' 20% share of global greenhouse gas emissions.(2.4)

- The Zero Pollution Action Plan of May 2021 addresses both pollution and waste, where research needs could be tackled and is particularly relevant to advanced materials and the process industries, as well as to the manufacturing industry. (2.5)

European industry is a key driver in the economic and societal transitions that we are currently undergoing. As already stated, the current crisis have changes remarkable the business environment at Europe and therefore, as an emerging approach Industry 5.0 , which is bringing together the sustainability and resilient growth with the human-centric view, is highlighted. It will be shortly discussed at the 2.6. Thus, as the European the manufacturing sector is based on a multitude of SMEs there is an obvious need to look at them and one of starting points is the " An SME strategy for a sustainable and digital Europe2 considered at the section 2.7. Finally, the section 2.8 reflects the objectives of ICT-07 projects in line with the policies presented at the previous sections.

2.1 A European Green Deal Strategy

The overarching goal is to reach climate neutrality by 2050 by stimulating the investments in the right directions. Therefore, the European Green Deal provides an action plan devoted to:

- Sustain the transition towards more clean and circular economy relying on the efficient use of resources
- Reduce at minimum pollution and restore the biodiversity

.The Green Deal it is expected to support a drastic change and start a period of prosperity in a conscious and fair way towards nature. The goal is also to protect, conserve and enhance the EU's natural capital, and protect the health and well-being of citizens from environment-related risks and impacts, thus to decouple the economic growth from the resource use. Therefore, it will be necessary to support the **sustainable innovation of industries.** Figure 3 represents the element characterising the European Green Deal.

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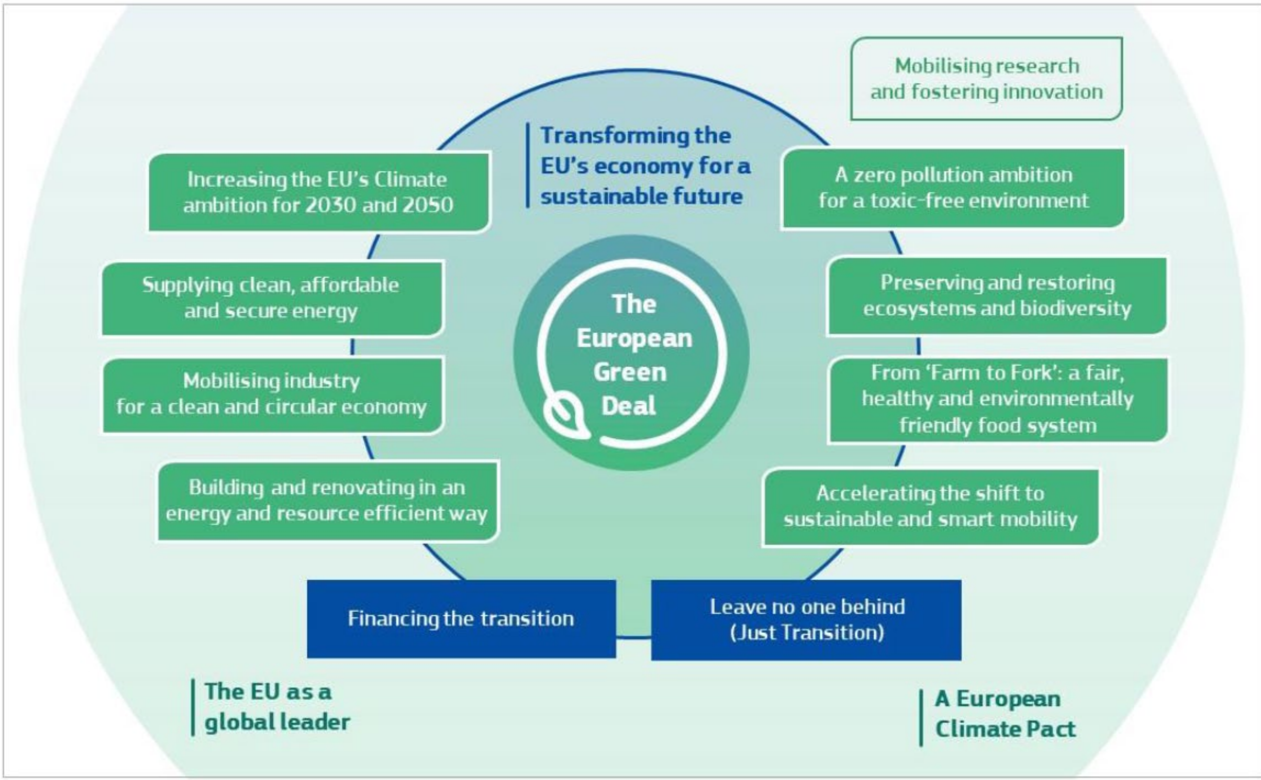

Figure 2 European Green Deal elements from the "European Green Deal" official documents

To allow that this transition would happen in an inclusive manner, new policies are required and these need to be ad hoc designed. Thus, while new values must be given to the protection and the restoration of natural systems, on the other side there is also the necessity to stimulate the digital innovation and transformation since these tools are fundamentals to undertake the sustainable change of the society. Some successful actions have been already put in place. In March 2020 it was proposed the first "Climate Law" that allows to insert in the legislation concrete actions to achieve the climate neutrality by 2050. The new legislation aims also to ensure the right carbon pricing throughout the economy by supporting a change in the behaviours of consumers and enterprises. In line with that also the taxation will be updated and aligned with the goals for the 2050.

To achieve the climate neutrality objectives and reduce the greenhouse gas emissions, as just stated, it is necessary also to introduce the decarbonisation of the energy system and industry. Smart infrastructures need to be created and the energy poverty needs to be addressed to ensure to give everyone basic standard of living. Steel, chemical and cement sector are energy-intensive sectors but represent indispensable value sources for the European economy. For this reason, their decarbonisation and innovation in industry are essential.

Another important issue regards the still widely present linear economy. Indeed, only the 12% of resources comes from recycling while the others are extracted and this inevitably increases the greenhouse emissions levels. Thus, products need to be designed differently to respect the expected results by 2050. For this reason, it has been launched the Circular Economy action plan in which sustainable product policy is defined and guidelines on how to design circular products are reported to enable the multitude reuse of the same product or its resources through subsequent lifecycles. Moreover, this action plan aims to involve consumers

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by stimulating a change in their behaviours. Indeed, enterprise will be encouraged in offering circular products and consumers will be allowed to choose reusable, durable and repairable products in a more conscious way.

In circular business, the information management and sharing cannot be neglected. Therefore, information needs to be reliable, comparable and verifiable to enable buyers to make more sustainable decisions limiting the so called "green-washing" effects. Indeed, companies will be required to assess their products based on a standard procedure to make "green claims" in order to ensure their reliability and avoid false claims.

Besides the greenhouse gas emissions reduction also the waste generation needs to be managed appropriately. Therefore, the value retained in waste needs to be recovered to be fully exploited, and the waste impacts on climate change needs to be eliminated or at least minimised. To cope with this issue, ad hoc legislation requires to be developed and new measures needs to be adopted. Indeed, the Commission has to consider legal requirements aiming at boosting the market of secondary raw materials with mandatory content.

Another important element for Europe is to ensure the supply of resources and of the sustainable raw materials. To be more precise, it is necessary to set the correct strategy by diversifying the primary and secondary sources, to ensure to have the critical raw materials necessary for clean technologies, digital, space and defence applications. In addition, it is necessary to develop breakthrough technologies in key industrial sectors by 2030 to address the main goal (e.g. clean steel breakthrough technology leading to zero-carbon steel making process).New forms of collaboration are essential to commit enterprises in this transition. New sustainable value chains need to be created and empowered (such as the Strategic Action Plan for the Batteries to create a European Battery Alliance).As just mentioned digital technologies are fundamental elements in green transition. Indeed, digital technologies such as artificial intelligence, 5G, cloud and edge computing and the internet of things might boost and maximise the impact of policies designed addressing climate change and protect the environment.

While many ambitions of the Green Deal address the society as a whole, the manufacturing sector is a key enabler of the green transition. It is crucial e.g. for the energy efficient buildings, electric mobility, sustainable food sector, circular textiles etc. Thus, innovations in manufacturing are need in order to achieve the ambitions goals of the European Green Deal. Also direct researches in this direction is necessary to achieve sustainable goals. Indeed, innovation and new technological solutions are core elements for the transition. It is necessary to keep the competitive advantage in clean technologies. Furthermore, the basic training will be adjusted at companies' level too and a re-skilling and upskilling will be supported.

2.2 A new Industrial Strategy for Europe

The European region has been always considered the place of Industry where new ideas for industrial innovation, and new business activities have been designed and shared worldwide. This allowed to position Europe as a pioneer for many industrial activities to be emulated by other foreign countries. There are different EU programmes, such as Horizon Europe, the Digital Europe Programme, the Single Market Programme, the Innovation Fund, InvestEU, the European Social Fund, the European Defence Fund and the EU Space Programme, and all European Structural and Investment funds which will help to promote the competitiveness of EU industry also in the future. The document entitled "a new industrial strategy for

Europe" elucidates the current status and strategic plan[15]. At the May 2021, the strategy was updated in order to ensure that European industrial ambition takes full account of the new circumstances following the COVID-19 crisis and helps to drive the transformation to a more sustainable, digital, resilient and globally competitive economy[16].

The updated Strategy reaffirms the priorities set out in the March 2020 Communication, while responding to the lessons learned from the crisis to boost the recovery and enhance the EU's open strategic autonomy. It proposes new measures to **strengthen the resilience of our Single Market**, especially in times of crisis. It addresses the need to better understand our **dependencies in key strategic areas** and presents a toolbox to address them. It offers new measures to accelerate the green and digital transitions. The updated Strategy also responds to calls to identify and monitor the main indicators of the competitiveness of the EU economy as a whole: single market integration, productivity growth, international competitiveness, public and private investment and R&D investment.

Already the 2020 Industrial Strategy announced actions to support the green and digital transitions of EU industry, but the pandemic has drastically affected the speed and scale of this transformation. Therefore, in order to accelerate the twin transitions, the Commission outlines new measures to support the business case for the green and digital transitions, by:

- Co-creating transition pathways in partnership with industry, public authorities, social partners and other stakeholders, where needed, starting with tourism and energy intensive industries. Such pathways could offer a better bottom-up understanding of the scale, cost and conditions of the required action to accompany the twin transitions for the most relevant ecosystems leading to an actionable plan in favour of sustainable competitiveness;
- Providing a coherent regulatory framework to achieve the objectives of Europe's Digital Decade and the 'Fit for 55' ambitions, including by accelerating the rollout of renewable energy sources and by ensuring access to abundant, affordable and decarbonised electricity ;
- Providing SMEs with Sustainability Advisors and supporting data-driven business models to make the most out of the green and digital transitions;
- Investing to upskill and reskill to support the twin transitions

Furthermore, the ongoing **extensive review of the EU competition rules** also makes sure that they are fit to support the green and digital transitions to the benefit of Europeans, at a time when the global competitive landscape is also fundamentally changing. In order to understand the sectoral dependencies, 14 industrial ecosystems were identified as follows: aerospace and defence, agri-food, construction, cultural and creative industries, digital, electronics, energy intensive industries, energy-renewables, health, mobility – transport – automotive, proximity, social economy and civil security, retail, textile and tourism.

Thus, as European manufacturing industry is heavily dependent on global export and import, **strengthening EU's open strategic autonomy** was recognised as important aspect. COVID-19 has shown disruptions in global supply chain and led to shortages of certain critical products in Europe. This is why the need to further improve open strategic autonomy in key areas is crucial, as already set out in the EU's 2020 Industrial Strategy.

[15] https://ec.europa.eu/info/sites/info/files/communication-eu-industrial-strategy-march-2020_en.pdf
[16] Updating the 2020 Industrial Strategy (europa.eu)

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2.3 Circular Economy Action Plan

The European Commission adopted the new circular economy action plan (CEAP) in March 2020. It is one of the main building blocks of the European Green Deal, Europe's new agenda for sustainable growth (see next chapter 2.3). The EU's transition to a circular economy will reduce pressure on natural resources and will create sustainable growth and jobs. It is also a prerequisite to achieve the EU's 2050 climate neutrality target and to halt biodiversity loss. The new action plan announces initiatives along the entire life cycle of products. It targets how products are designed, promotes circular economy processes, encourages sustainable consumption, and aims to ensure that waste is prevented and the resources used are kept in the EU economy for as long as possible. Thereby, it introduces legislative and non-legislative measures targeting areas, where action at the EU level brings real added value.

The plan presents a set of interrelated initiatives to establish a strong and coherent product policy framework that will make sustainable products, services and business models the norm and transform consumption patterns so that no waste is produced in the first place. This product policy framework will be progressively rolled out, while key product value chains will be addressed as a matter of priority. Further measures will be put in place to reduce waste and ensure that the EU has a well-functioning internal market for high quality secondary raw materials. The capacity of the EU to take responsibility for its waste will be also strengthened.

It is clear that Europe will not achieve this transformative change by acting alone. Therefore, the EU will continue to lead the way to a circular economy at the global level and use its influence, expertise and financial resources to implement the 2030 Sustainable Development Goals. This circular economy action plan (CEAP) plan aims also at ensuring that the circular economy works for people, regions and cities, fully contributes to climate neutrality and harnesses the potential of research, innovation and digitalisation. It foresees the further development of a sound monitoring framework contributing to measuring well-being beyond GDP. in line the plan focus on the sectors that use most resources and where the potential for circularity is high such as: Electronics and ICT, Batteries and vehicles, Packaging, Plastics, Textiles, Constructions and buildings, Food, water and nutrients.

In line with the idea of twin transition, digitalisation represents the way in which it is possible to achieve the European goal and adopt Circular Economy by using resources through different lifecycles by maximising their values. The data and digitally solutions to be adopted to empower business activities embracing circular economy principles can be based on digital platforms, smart devices, Artificial Intelligence, 3D-printing, digital twins, IoT and blockchain. Therefore, all these solutions can be the great options required when it is necessary to enhance transparency, connectivity and information sharing. Circular Economy needs to be embraced by consumers as well to be effective and to have long term impacts. For this reason, it is necessary to create the right awareness in them to make conscious choices on products and on their usage, and this can be done via digitalisation (e.g. by introducing smart products on the market). Digital technologies can also boost the adoption of Circular Economy considering different issues among which the design, production, consumption, reuse, repair, remanufacturing, waste management and recycling.

In order to allow that the twin transition would take place in a structured way means that the contributions developed on the digital side needs to be directed in a manner that would allow the achievement of the

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sustainable goals and to avoid the rebound effect. Therefore, four key elements must be respected to obtain the expected goals[17]:

- *Define a vision and act accordingly* to make Europe become leader is utilising data and digitally-enable solutions and to extend the product lifecycle by being supported by the synergies among the digital and sustainable solutions,
- *Use governance, policies and regulations to provide a framework for action* by allowing the data and information sharing and access, providing digitally-enabled services, improving the e-commerce and the eco-design.
- *Use economic instruments to encourage and enable the transition* by introducing the right financial tools, by supporting the reskilling and upskilling of the workforce and by directing the investment.
- *Strengthen partnerships and empower citizens* by relying on the usage of the already existing stakeholders' platforms, by underlying the benefits for data exchange increasing the trust in their relationships.

2.4 Fit for 55 package

As Presented by the European Commission on 14 July 2021, the package will enable the European Union to reduce its net greenhouse gas emissions by at least 55% by 2030 compared to 1990 levels and to achieve climate neutrality in 2050. According to the Fit for 55 agenda, the member states adopted a common position on EU emissions trading system (EU ETS), effort-sharing between member states in non-ETS sectors (ESR), emissions and removals from land use, land-use change and forestry (LULUCF), the creation of a social climate fund (SCF) and new CO2 emission performance standards for cars and vans[18]. All these key actions, include variety of means to gain the ambitious targets. They are shortly summarized below, keeping mind the relevance to European Manufacturing Industry.

EU emissions trading system (EU ETS)) is a carbon market based on a system of cap-and-trade of emission allowances for ***energy-intensive industries*** and the power generation sector. The overall ambition is 61% of emissions reductions by 2030 in the sectors covered by the EU ETS. Furthermore, EU-level greenhouse gas emissions reduction target of 40% compared to 2005, for the sectors not covered by the ETS, namely domestic maritime transport, agriculture, waste and ***small industries***. Effort-sharing between member states in non-ETS sectors (ESR) were aimed to make more flexible and transparent through enhanced reporting obligations. The land use, land- use change and forestry (LULUCF) sector covers the use of soils, trees, plants, biomass and timber. For the LULUCF sector, the overall objective is 310 Mt CO2 equivalent of net removals, which means an increase of removals of about 15% compared to today. The creation of a social climate fund (SCF) aims to support vulnerable households, **micro-enterprises** and transport users to support the creation of an emissions trading system for the buildings and **road transport sectors.** CO2 emission performance standards for new cars and new vans gains to reduction to 55% instead for cars and to 50% for vans by 2030 and furthermore introduce a 100% CO2 emissions reduction target by 2035 for new cars and vans.

[17] pub_difital_roadmap_for_circular_economy.pdf (flexious.be)
[18] Fit for 55 package: Council reaches general approaches relating to emissions reductions and their social impacts - Consilium (europa.eu)

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2.5 Zero pollution action plan

Among the key deliverables of the European Green Deal is the EU Action Plan: 'Towards Zero Pollution for Air, Water and Soil' published at the May 2021. The vision for 2050 is that: "Air, water and soil pollution is reduced to levels no longer considered harmful to health and natural ecosystems and that respect the boundaries our planet can cope with, thus creating a toxic-free environment". When navigating the EU towards zero pollution, **more sustainable industrial systems** is important enabler for this transition - in close synergy with the circular economy action plan (see 2.2) as well as with the new industrial strategy for Europe (see 2.1.). In addition, the implementation requires: cleaner technologies, less polluting business models and consumption habits, faster implementation of the polluter pays principle, and further application of extended producer responsibility. Consequently, the Industrial Emissions Directive (IED)[19] is the main instrument regulating air, water and soil pollutant emissions from over 52 000 of the largest EU industrial installations.

Implementation the zero pollution ambition in production and consumption also means that chemicals, materials and products have to be as safe and sustainable as possible by design and during their life cycle[20] , leading to non-toxic material cycles. For that reason, the Product Environmental Footprint (PEF) and the Organisation Environmental Footprint (OEF) methods are proposed as common means to support a transparent, robust, systematic, and integrated comparison of products and organisations in the EU market[21]. From the perspectives of manufacturer common ways are important as currently, the manufacturers aiming to market its product as environmentally friendly in several Member State markets faces a confusing range of choices of methods and initiatives. This results in extra costs for companies as well as confusion for consumers.

2.6 Industry 5.0 as an emerging approach

The Industry 5.0 approach contributes to three of the Commission's priorities: "An economy that works for people", "European Green Deal" and "Europe fit for the digital age". Thus, the elements pertinent to Industry 5.0 are already part of major Commission policy initiatives:

- adopting a human-centric approach for digital technologies including artificial intelligence (Proposal for AI regulation
- up-skilling and re-skilling European workers, particularly digital skills (Skills Agenda and Digital Education Action plan)
- modern, resource-efficient and sustainable industries and transition to a circular economy (Green DealSearch for available translations of the preceding)
- a globally competitive and world-leading industry, speeding up investment in research and innovation (Industrial Strategy)

These are just some examples that demonstrate the strong links between the industrial transition and other societal developments.

[19] Directive 2010/75/EU
[20] EEA briefing (2021) : 'Safe and sustainable by design'; Mapping study for the development of sustainable-by-design criteria (21 April 2021).
[21] Single Market for Green Products Initiative

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2.7 An SME Strategy for a sustainable and digital Europe

The above chapters provided the big picture concerning the European manufacturing sector current strategies, policies and programmes. While the manufacturing sector is based on a multitude of SMEs[22], it is important to look at the SME related scenarios and policies such as "An SME strategy for a sustainable and digital". The obvious challenge is to engage them to stimulate innovation in the climate neutrality and social cohesiveness allowing to address the European Industrial Strategy (section 2.1). The SME Strategy for a sustainable and digital Europe[23] requires addressing all the needs coming from the different panels of European SMEs that are of various types in terms of business models, size, age, and entrepreneurs' profiles involving both women and men. In particular, three main pillars guide this strategy with the intention to lead a successful twin transition:

- Capacity-building and support for the transition to sustainability and digitalisation;
- Reducing regulatory burden and improving market access;
- Improving access to financing.

Concerning the sustainable transition, almost a quarter of the European SMEs, is already involved in this direction. Most of them already offer to the market sustainable products and services and they are based on flexible, high-tech innovative and well equipped systems. Part of them instead is experiencing administrative and legal challenges which limit their transition. Especially for this second group, the Enterprise Europe Network is offering tailored services to support SMEs in investing in more resource-efficient and circular processes and infrastructures and in finding the right partners to collaborate with.

SMEs can be highly supported by digitalisation in improving the efficiency of production processes and the ability to innovate products and business models. Nevertheless, many SMEs are not able to grasp the value of data since they are not even aware about their value or they are not enough protected to participate in the agile economy. To cope with this problem, the Commission will devote efforts in improving data accessibility, allowing data flows between enterprises and governments based on common European data spaces. In guiding SMEs in the digital transition, the European Digital Innovation Hubs cover prominent roles by also connecting the different structures.

SMEs have troubles in developing the right strategies for intellectual property and thus protect their R&D investments appropriately that is crucial for the twin transition. Among the actions, the Intellectual Property Action Plan will help in creating a more effective Intellectual Property systems effective for SMEs (e.g. by simplifying the registration procedure). Another relevant challenge to be considered for the transition of SMEs regards their workforce and the limited availability of skilled employees due to the scarce financial resource usable for training activities or new employment. The skill gap is especially visible for digital skills. Activities for SMEs managers and employees in terms of upskilling are essential. These will be supported also by Member States that need also to pay attention and focus on the empowering of women to become founders themselves and thus, improve the gender balance. In addition, the Commission will update the Skills Agenda for Europe by including a Pact for Skills with a special element focused on the SMEs empowering based on vocational education and training (VET) that covers a relevant role for the SMEs workforce.

[22] there are around 25millions SMEs characterising the economy of our countries

[23] https://ec.europa.eu/info/sites/default/files/communication-sme-strategy-march-2020_en.pdf

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Actually, SMEs are often blocked due to regulations, standardisation and administrative formalities burdens. Due to the limited financial and human capital resources they face bigger problems than larger companies. The scaling up of the SMEs is limited in Europe and for this reason different actions have been put in place to improve their position and to make start-up develop their businesses. SMEs are essential elements in the more and more dense networks of corporates, start-ups and SMEs alike working together across sectors and value chains to create the products and services of the future. For this reason, is necessary that SMEs and start-up would be supported in addressing their specific needs and would be involved in the EUs strategic values chains. Financing remains still be overarching challenge for SMEs.

2.8 Towards competitive sustainability through Twin Transition (objectives of ICT-07 Cluster projects)

In the previous chapters, current strategies and approaches to accelerate twin transition and to enhance the Industry 5.0 concept. As Horizon Europe Program is the main R&D&I program in Europe, it also invests heavily in the twin transition. The focus is on the way industry develops, creates new products and services, that are central to any sustainable future. The COVID-19 pandemic, the war against Ukraine and other disruptions have also shown the need to strengthen the industrial base of the European Union enhancing its resilience and flexibility both in terms of technologies and supply chains, so as to reduce dependencies on third countries.

The planned investments under Horizon Europe Cluster 4 Digital, Industry and Space gain to position Europe as a technology and industrial leader of this transition. The expected impact of Cluster 4 is emphasized as follows: **Global leadership in clean, climate-neutral and resilient industrial value chains, circular economy and climate-neutral and human-centric digital systems and infrastructures**, through innovative production and manufacturing processes and their digitisation, new business models, sustainable-by-design advanced materials and technologies enabling the switch to decarbonisation in all major emitting industrial sectors, including green digital technologies. Within Cluster 4 the Destination 1 'Climate Neutral, Circular, and Digitised Production' has following three key strategic orientations:

- Make Europe become the global leader to exploit digital potentials to address circular, climate-neutral and sustainable economy by modifying different sectors among which the mobility, energy, construction and production systems

- Make Europe promote the open strategic autonomy based on the leadership of the development of digital enabling and emerging human-centred technologies, sectors and value chains to boost the twin transition

- Make Europe the leader in creating a resilient, inclusive and democratic society.

Accelerating the twin transition allows to strengthen the position of Europe globally and to confirm its competitiveness based on a long lasting prosperous growth. This transformation necessitates new technologies, investments and researches in innovative solutions to make happen the concurrent exploitation of the two sides of the change.

With these goals in mind, the outcomes from Destination 1 must address the following aspects:

- Boost twin transition of manufacturing and construction sectors

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- Develop new green, flexible and digital solutions to design and produce goods
- Attract new workforce for the construction and manufacturing sectors
- Define concrete and applicable pathways to contribute to address the climate-neutrality goal
- Empower Europe making it increasing in terms of productivity, innovation, capacity, resilience, sustainability and global competitiveness
- Find solutions to reduce waste generation and CO2 emissions

For the manufacturing sector, an important project cluster in the Destination 1 is the consisting of the DT-ICT-07 calls: (1) Agile Value Networks: lot-size one, (2) Excellence in manufacturing: zero-defect processes and products, (3) The human factor: human competences in synergy with technological progress, (4) Sustainable Value Networks: manufacturing in a circular economy. Table 1 presents the aims of the ICT-07 cluster projects and their linkages to four above mentioned topics.

Table 1. The summary of project aims regarding the four domains of ICT-07 calls

<table>
<tr><th></th><th>Expected impact</th><th>Aims of ICT_07 projects</th></tr>
<tr><td>Agile Value Networks: lot-size one</td><td rowspan="4">Significant increase in the options for SMEs and mid-caps to integrate different technologies, unlock the value of their data, deploy complementary applications, and to become a more responsive link in changing supply and value networks.

Strengthened competitive position of European platform providers.
Increased cooperation between industrial and academic communities; increased synergy and collaboration between</td><td>eFactory/EFPF (European Connected Factory Platform for Agile Manufacturing) realises a federated smart factory ecosystem. It provides seamless access to services and solutions that have been dispersed.</td></tr>
<tr><td>Excellence in manufacturing: zero-defect processes and products</td><td>ZDMP provides a Smart, SME Friendly, open, Zero-Defect Manufacturing Reference Platform, Apps, SDK, and Marketplace for Product and Process Quality in any factory for achieving excellence in European and Global Manufacturing.
QU4LITY demonstrates, in a realistic, certifiable and highly standardised, SME-friendly and shared data-driven ZDM product and service model for Factory 4.0.</td></tr>
<tr><td>The human factor: human competences in synergy with technological progress,</td><td>SHOP4CF develops a platform on an open architecture that can support humans in production activities and provide basic implementation as a free, open-source solution.</td></tr>
<tr><td>Sustainable Value Networks: manufacturing in a circular economy</td><td>DigiPrime creates a federated model of digital platforms for cross-sector business in the circular economy.

KYKLOS 4.0 aims to show how cyber-physical systems, product life-cycle management, life-cycle assessment, augmented reality, and artificial intelligence technologies and methods are able to transform Circular Manufacturing (CM).</td></tr>
</table>

As indicated at the table 1 the emphasis on platforms that collect information about the use of physical assets and make this information available for further processing are also a common feature of the projects.

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Furthermore, the pilot projects from different industrial sectors are implemented in order to test, and demonstrate variety of digital tools and applications. Some of these case examples are collected to the EFFRA web page in order to disseminate the lessons learnt (see chapters 4 and 5).

In particular, the emphasis is on the technical implementation of platforms that collect information about manufacturing processes and potentially about products throughout their entire lifecycle. So, manufacturing firms can exploit additional revenue sources through offering data-driven services and act on feedback to improve process and product (e.g. projects QU4LITY and ZDMP). However, there is also concern with the development of platform infrastructure that allows the deployment of human-centric industrial applications, combining in a complementary way machine capability such as high accuracy and precision, with human assets such as creativity and adaptability (project SHOP4CF). Furthermore, digital platforms enabling circular manufacturing are piloted in variety of industrial sectors (projects KYKLOS and DigiPrime).

3 Materialising Circular Economy in the Manufacturing Sector

In the last decades the consciousness and awareness about the need to modify the traditional unsustainable behaviours of companies and people, especially considering the environmental and the social spheres of the sustainable development concept (WCED, 1987), started to gain momentum due to the intense growth of resource consumption (OECD, 2019). To be more precise, multiple actions have been proposed and promoted to cope with this issue, and among all it emerged the need to identify new promising solutions to go from linear business models to circular ones to keep as much as possible the value of the resources extracted and used (Garza-Reyes et al., 2019). Circularity is highly linked to sustainability paradigm especially as far as manufacturing sector is concerned, since circularity in this context aims at facing environmental and social pillars without lagging behind the economical advancements (Pieroni et al., 2019).

Resource circularity concept takes its place within the Circular Economy paradigm. This term started to be diffused almost all over the world quite recently while the concepts behind this paradigm are quite old. Indeed, Circular Economy has been recently defined as "*an industrial economy that is restorative and regenerative by design*" (The Ellen MacArthur Foundation, 2013). Therefore, its concrete diffusion has been highly supported by the awareness created on the society as a whole by the Ellen MacArthur Foundation through its speeches and concrete actions stimulating people to react to create a sustainable world.

Actually, two main cycles traditionally characterise this economy: biological and technical as reported in the Figure 9 depicted below taken from (Ellen MacArthur Foundation, 2015):

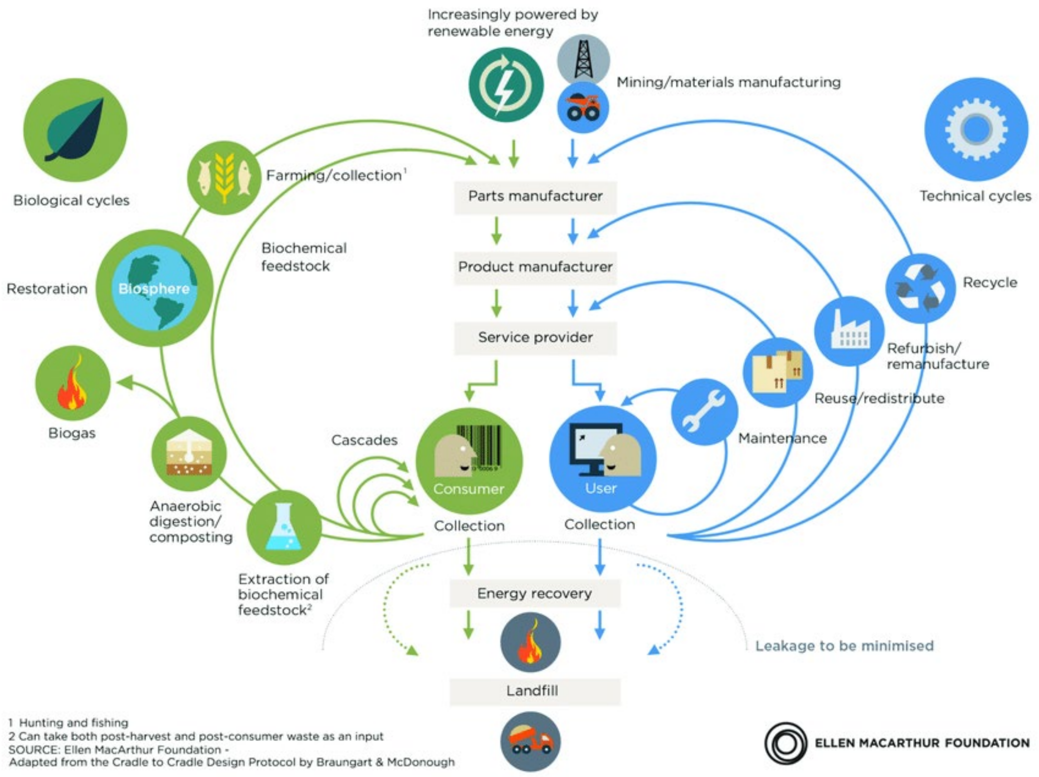

Figure 3 Butterfly Diagram from (Ellen MacArthur Foundation, 2015)

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These two cycles are driven by three pillars (Ellen MacArthur Foundation, 2015):

1. **preserve and enhance natural capital**: *by controlling finite stocks and balancing renewable resource flows – for example, replacing fossil fuels with renewable energy or returning nutrients to ecosystems.* This takes place at the top of Figure 1 since the goal is to identify substitute material and resources to be inserted in the cycles to be more sustainable.

2. **optimize resource yields**: *by circulating products, components, and materials in use at the highest utility at all times in both technical and biological cycles – for example, sharing or looping products and extending product lifetimes*. This takes place at the middle of Figure 1 since at that level the cycles to regenerate the resource are performed.

3. **foster systems effectiveness**: *by revealing and designing out negative externalities, such as water, air, soil, and noise pollution; climate change; toxins; congestion; and negative health effects related to resource use.* This takes place at the bottom of Figure 1 since the resources that cannot be treated to be inserted in new cycles need to be treated to be disposed and they need to be as few as possible.

Based on these principles, circular economy facilitates the transformation of inefficiencies of linear value chains such as unsustainable materials, underutilised capacity, prematurely ended product lives, wasted end-of-life value and unexploited customer engagement, that are described by Circular Economy Playbook[24], into business value.

Actually, considering the digital revolution that the society is experiencing, these flows, to be more effective are backed by a third flow: the informational one (Valkokari et al., 2019). This requires guaranteeing the alignment among different stakeholders along the value chain and within the companies' boundaries at different hierarchical levels (Acerbi and Taisch, 2020a).

Moreover, the principles characterising this paradigm, that direct the adoption of specific business models, have been defined as well by the Ellen MacArthur foundation and they are the following: (1) Design out waste, (2) Build resilience through diversity, (3) Rely on energy from renewable sources, (4) Think in 'systems', (5) Waste is food (The Ellen MacArthur Foundation, 2013).

Considering the principles characterizing Circular Economy, this paradigm is considered a great driver for sustainability especially for the manufacturing sector (Geissdoerfer et al., 2017) and in this context it takes also the name of Circular Manufacturing (Acerbi and Taisch, 2020b). To be more precise, the regeneration of resources happens though different strategies, also called circular manufacturing strategies, which if concurrently adopted allow to support the sustainable development of manufacturing firms. These strategies might have impacts on different levels among which the micro (e.g. product, firm), meso (e.g. network of firms) and macro (e.g. nation) level proposed by (Ghisellini et al., 2016) and are reported below in Table 2 taken from (Acerbi and Taisch, 2020c).

[24] Sitra, Technology Industries of Finland, and Accenture: Circular Economy Business Models for the Manufacturing Industry: Circular Economy Playbook for Finnish SMEs. Sitra, Technology Industries of Finland, and Accenture, Helsinki (2020)

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Table2 Circular Manufacturing strategies definitions from (Acerbi and Taisch, 2020c)

Reuse	This strategy, once analyzed the product status and condition, aims to plan and perform all the activities and processes enabling to reuse the product directly at the end of its life cycle (e.g.(Liu et al., 2018))
Remanufacturing	This strategy aims to plan and perform all the activities and processes required to restore a used product in compliance with its original quality, specifications, performances, and warranty (e.g. (Sitcharangsie et al., 2019))
Recycling	This strategy, through chemical and physical transformation processes, aims to reuse the components or materials by reducing resources consumption and pollution generation (e.g. (Zhong and Pearce, 2018))
Disassembly	This strategy aims to define and perform all the activities and processes to disassemble in sub-components and materials the product and, under CE perspective, this strategy enables to easily recycle or reuse the single parts (e.g. (Favi et al., 2019; Marconi et al., 2019))
Circular Design	This strategy aims to plan and perform all the activities to be done at the design phase of the product life cycle in order to prevent excessive resource consumption. This strategy eases end-of-life circular practices such as disassembly and thus, recycling, reuse and remanufacturing (e.g.(den Hollander et al., 2017))
Cleaner Production	This strategy, being based on product optimization, input substitution and sharing of renewable and recyclable resources, enables to limit resources consumption and toxic substances used in the production processes (e.g. (Sousa-Zomer et al., 2018))
Material Efficiency (Reduce)	This strategy aims to plan and perform all the activities and processes to optimize material used along the production process and product usage (e.g. (Choi et al., 2019))
Waste Management	This strategy corresponds to all the activities and processes required to dismantle waste generated by manufacturers by also handling hazardous waste (e.g. (Rapsikevičienė et al., 2019))
Servitization (Product-Service system)	This strategy aims to plan and perform all the activities and processes to sell a service by using a product as a means. It uses both tangibles (products) and intangibles (services) to satisfy final customers' needs by limiting resources consumption (e.g. (Bocken et al., 2017))
Closed-loop supply chain/ Reverse Logistics	This strategy aims to plan and perform all the activities to establish reverse flows of resources along the supply chain (e.g. (Lapko et al., 2019))

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Industrial Symbiosis/Industrial Eco-Parks	This strategy refers to the physical exchange of resources as materials, energy, and by-products among industrial actors that do not belong to the same supply chain (e.g. (Domenech et al., 2019))

The adoption of these strategies is of extremely relevant for the entire society to address the overarching goal defined by Europe. Indeed, the benefits derived from their adoption of these strategies are almost known and this is the reason why governments, especially the European ones, are trying to boost the undertaken of this direction. Nevertheless, some limiting issues arise when companies face the transition. The main barriers have been studied by scholars among which (Ranta et al., 2018) which explored the barriers comparing the situation in US, China and EU and looking at especially the institutional barriers, (Agyemang et al., 2019) which explored especially the automotive sector with an empirical case study, and (Jaeger and Upadhyay, 2020) which investigated both from a scientific point of view and from an empirical point of view the barriers faced in manufacturing such as: *Resource-intensive development models, High start-up costs, Complex supply chains, Challenging B2B cooperations, Innovation diffusion challenge, Structural, Contextual, Restricted supply chain, Lack of industrial symbiosis, Logistics, Lack of information on product design and production, Recovery, Recycling, Lack of technical skills, Quality compromise, Disassembly of products is time consuming and expensive, No surety CE will help the environment, Quality assurance, Design irrespective of CE, Hygienic issue.* These barriers reflect the ambitious goals of Europe to become climate-neutral and the researches stimulated aim to address specifically these barriers to empower manufacturers in becoming circular.

Nevertheless, the adoption of CE can be facilitated by the technological advancements and the monitoring of the achievements through assessment methods and indicators. Indeed, a part of CE-related research deals with either on technologies or on assessment models as investigated in detail by (Acerbi and Taisch, 2020b) based on the following framework:

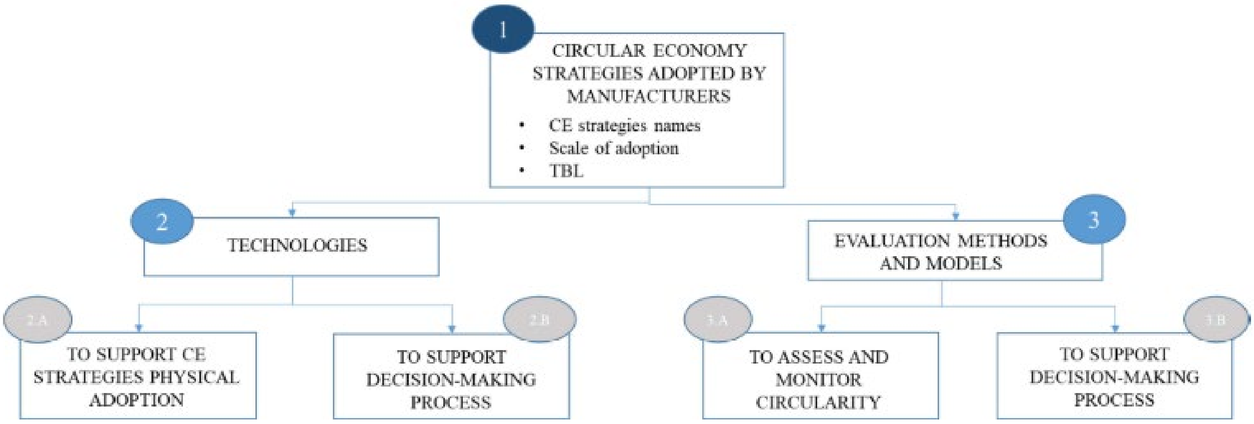

Figure 4 Theoretical framework from (Acerbi and Taisch, 2020b)

Actually, the introduction of these strategies in manufacturing companies is driven by the technological advancements which can be either useful to support the physical implementation of specific processes or to support the decision-making process to select the best option. To report some examples regarding the technological physical support, intelligent robotics has been studied as good solution to support the waste

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management and optimise the required processes (e.g. (Sarc et al., 2019)), 3D printing instead it has been adopted for spare part of medical devices to ensure resource circularity (Unruh, 2018). Instead, regarding the decision supporting technologies, artificial intelligence, internet of things and big data analytics are considered the main means through which selecting the best option for resources circularity in manufacturing (Kristoffersen et al., 2020).

To introduce or monitor the introduction of a certain strategy, the performance indicators are also adopted by manufacturers according to what scholars studied. In particular, these models and tools allow to take decisions on one side about the most convenient option among the possible scenarios (Vlachokostas et al., 2020) to choose for instance the most convenient investment (Rieckhof and Guenther, 2018), while on the other side to adjust the strategy according to the current performances and results obtained from the introduction (Krystofik et al., 2018). These assessment methods are highly relevant for the appropriate monitoring of the current approach towards circularity if they can monitor the CE-related performances or achievements (Sassanelli et al., 2019).

Indeed, one of the key elements of pursuing CE adoption is data collection, usage and exchange with actors along the entire value chain. While assessment methods can support the usage of these data, technologies may be fruitful for data gathering and exchange (Acerbi et al., 2022). Therefore, relying on the potentialities of data to gather huge amount of data, these data can be exploited through assessment models to pursue a circular transition across sequential levels of maturity as below proposed.

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4 The CF2 Circular Economy pathway

Circular Economy paradigm is one of the main elements of the European Green Deal since it can represent a great solution towards climate neutrality and efficient use of resources. For that reason, CF2 Circular Economy pathway rises within the scope of this project to highlight the importance of the Circular Economy paradigm for the sustainable development of the manufacturing sector. The goal is to stimulate the awareness and the consciousness of companies in embracing the Circular Economy paradigm. Therefore, considering that companies need to be guided in the ocean of changes, it has been developed a tool allowing to clarify their current status in addressing the paradigm and to envisage the main areas to be improved within their companies' boundaries and with external stakeholders. The tool is a maturity assessment model which indeed estimates the position of the company in an entire way considering the levels and the dimensions analysed. In addition, it allows to benchmark this position with the optimum and to compare it with other companies undertaking the same path.

Although it has been adopted as model a maturity assessment model, it is not mandatory for companies to undertake a linear process towards the optimum thus, by passing throughout all the maturity levels, but the process might be disruptive. This is true especially for the new comers rather than for the incumbents which might require bigger efforts for such an internal and external modification. In the next sections, the model is described in details. Starting first from the structure, thus the levels and the dimensions characterising the model, it is then elucidated the interactive sections held to show the model to a hybrid audience consisting of practitioners and researchers to gather some feedback and validate the model structure and deployment.

4.1 Circular Economy levels and dimensions

The maturity assessment model developed to evaluate the current maturity levels of companies in Circular Economy adoption is based on five main maturity levels (Figure 11). The levels and the dimensions characterizing the path constitute a matrix that allows to give the big picture to companies under analysis and to develop tailored suggestions for further improvements. On one side, the maturity levels allow to clarify the requirements to embrace this CE paradigm by highlighting first the need to have an initial internal cohesiveness to finally be able to bring these internal values into the external relationships established with various stakeholders. On the other side, the dimensions allow to clarify the strong areas and those, which needed to be stimulated to fully embrace the paradigm by the company under analysis.

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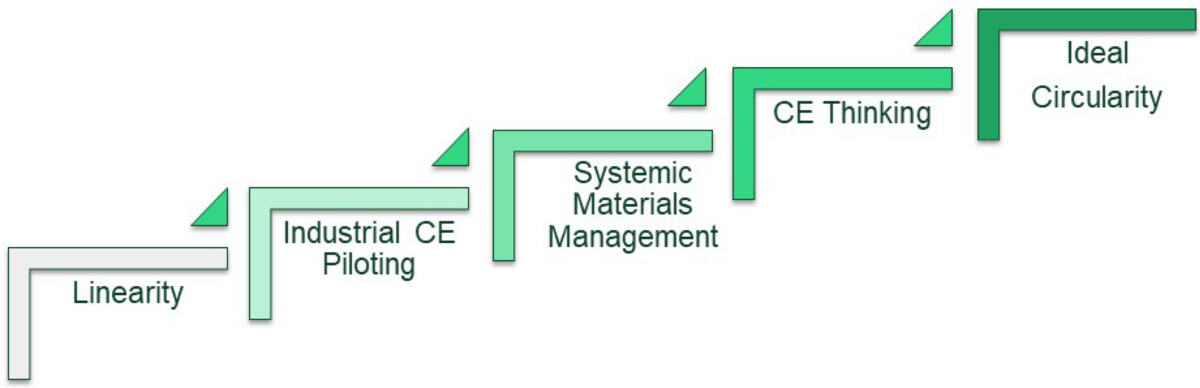

Figure 11. Five maturity levels

The first version of CE matrix, presented at the Deliverable 2.1., connected the five maturity levels with the dimensions covered by so called "6Ps" (i.e. Products, Process, Platforms, People, Partnership, Performance) which are reflected in two main spheres: the technical and the social-business one. The technical one is covered by the Product, the Process, and the Platforms dimensions; while the social-business sphere is covered by the People, the Partnerships and the Performances dimensions. This enabled a company to be positioned in different levels. Thus, during the process it was recognized in collaboration with ICT-07 projects and Connected Factories consortium members that this form of matrix does not provide a value network level view of circular manufacturing. The updated version of matrix combining value chain analyses and CE maturity assessments was developed during the project months 20 - 36. Thereby, both the description of maturity levels (Table 3) and the matrix were updated (Figure 13). A more detailed reflection on the dimensions of the matrix was done during the year 2021 by two conference publications, i.e. the international-conference-advances-in-production-management-systems (APMS2021) and collaborative networks (PROVE2021[25] . In addition, this conference publications aim to validate how the CE pathway and the maturity levels contribute to academic literature.

[25] Acerbi, F., Järnefelt, V., Martins, J. T., Saari, L., Valkokari, K. & Taisch, M., Sep 2021**Developing a Qualitative Maturity Scale for Circularity in Manufacturing.** , *Advances in Production Management Systems. Artificial Intelligence for Sustainable and Resilient Production Systems - IFIP WG 5.7 International Conference, APMS 2021, Proceedings.* Dolgui, A., Bernard, A., Lemoine, D., von Cieminski, G. & Romero, D. (eds.). Springer Science+Business Media, p. 377-385 9 p
Saari, L., Järnefelt, V., Valkokari, K., Martins, J. T. & Acerbi, F., 31 Nov 2021. **Towards sustainable manufacturing through collaborative circular economy strategies.** *Proceedings of PRO-VE 2021 : Smart and Sustainable Collaborative Networks 4.0.* Springer, (IFIP Advances in Information and Communication Technology).

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 873086.

Table3 . Matrix for the assessment of circularity

Level	Description
Ideal Circularity	Company and its value network have achieved ideal circularity of products, processes and operations, which are sustainable on the environmental, social and economic levels. This is accomplished by a broad understanding of value flows (such as synergies among forward and reverse logistics, local value chains and zero-waste manufacturing) and the co-creation of new value circles within manufacturing networks (such as flexible remanufacturing networks, upgrading of products and on-demand production) as a key managerial practice
CE Thinking	Eco design and circularity are an essential part of new products and the deployment of new services. The company is internally able to re-purpose industrial materials, but further opportunities are found externally. In particular, the exchange of resources with third parties is promoted through the creation of an industrial symbiosis network, and an attempt to establish a closed-loop supply chain is envisaged
Systemic material management	The adoption of CE is extended to the whole company to identify and exploit all the emerging opportunities, at least from an internal perspective. The 'R-cycles' of industrial materials have become standard practice adopted by the company in order to systematically identify possibilities to reuse, refurbish, recycle and remanufacture materials.
Industrial CE piloting	Senior management has pushed pilot projects for some strategies that seek resource sufficiency either internally or by exchange with external industrial actors.
Linearity	Senior management of a manufacturing company is stuck in the traditional linear concept of make–take–dispose. Legal requirements for recycling, waste management and other environmental obligations are met, and the company's performance is monitored only to ensure no additional costs rather than to find new opportunities.

The updated version of CE matrix was developed in line with the fact that collaboration is a crucial enabler of sustainability in the context of manufacturing. Following the paradigm of twin transition sustainability can be practically implemented using Industry 4.0 (or Industry 5.0) technologies and is necessary to enable interaction and transparent data exchange between companies. The CE provides opportunities to turn the inefficiencies of linear value chains (unsustainable materials, underutilised capacity, prematurely ended product lives, wasted end of-life value and unexploited customer engagement (Figure 12) into business value.

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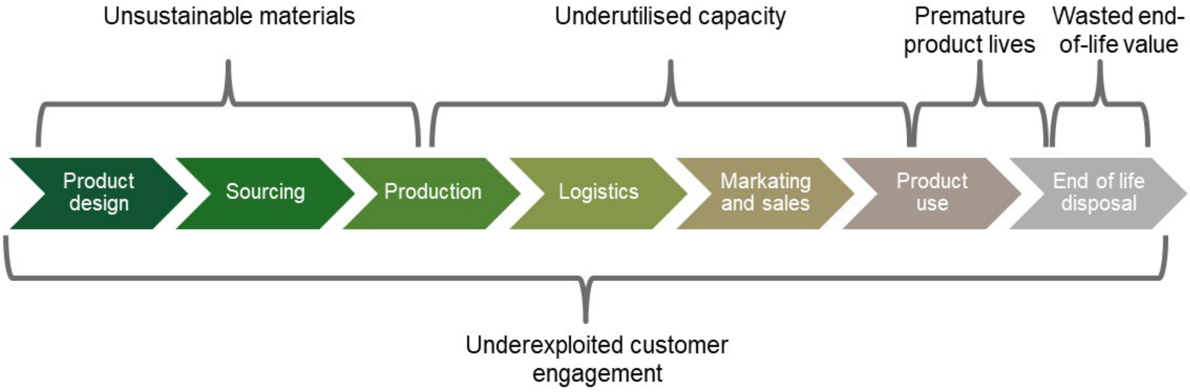
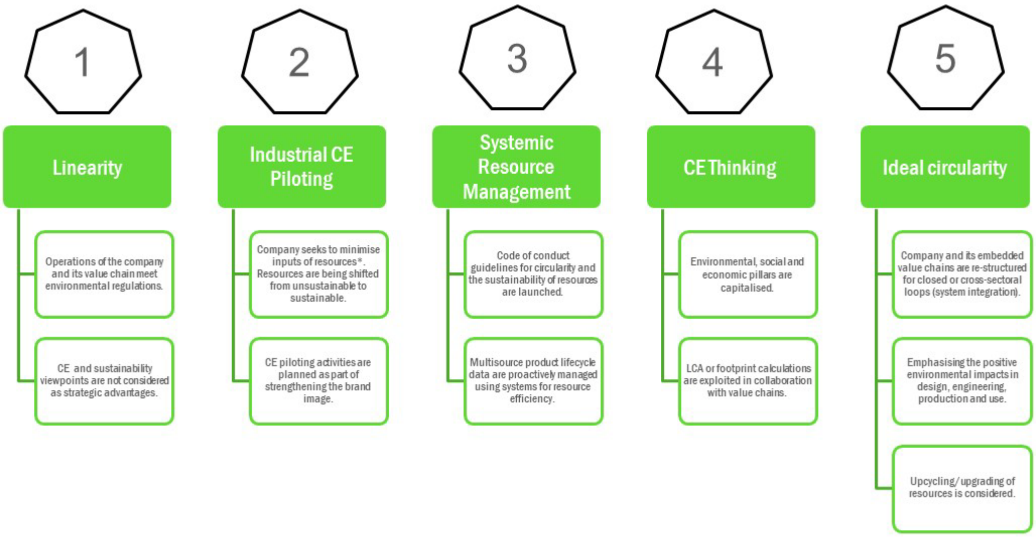


Figure 12. Substantial inefficiencies may occur in all parts of the manufacturing value chain. Adapted from Circular Economy Playbook[26]

To overcome inefficiencies along the manufacturing value chain (as presented at Figure x), deeper investigation is needed of the distinct points at which the different levels be implemented. Collaborative strategies are needed to enable meta- and macro-level transitions —that is, to broaden the approach from the concept of sustainable islands towards a green transition—and the environmental challenge calls for commitment from and collaboration by companies, industries and authorities.

Figure 13 presents the final version of CE pathway, which was summarized from the more comprehensive matrix through the reflections with different expert groups (for instance the Finnish forerunner cases presented at the following chapter 4.2 and ICT-07 Cluster projects (discussed at the section 5). Here the resources include both tangible (materials, energy, water,waste, ect) and intangible (work force, skills, data, value)



[26] Sitra, Technology Industries of Finland, and Accenture: Circular Economy Business Models for the Manufacturing Industry: Circular Economy Playbook for Finnish SMEs. Sitra, Technology Industries of Finland, and Accenture, Helsinki (2020)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 873086.

Figure 13. The Circular Economy pathway

However, due to production and consumption often taking place in different countries, manufacturing value chains may need to be reorganised to facilitate reuse and remanufacturing, and product lifetimes can be extended by upgradeability. Collaborative incentives throughout the value chain are needed for companies to actively consider sustainable materials, durability and reparability. Then, the close connection with Industry 5.0 approach is apparent.

4.2 Workshop with ICT-07 cluster projects

A collaboration workshop was organised at 24th March 2021 with ICT-07 projects in order to collect feedback to the CE pathway. At the workshop, three cases presented:

- DigiPrime use case , cross-industry synergies of material flows (Batteries pilot), Marcello Colledani, Polimi & Nicoletta Picone
- EFPF (European Connected Factory Platform) Circular Economy Pilot – A Wate to Energy Scenario, Alexandros Nizamis, ITI
- KYKLOS 4.0 use case, Wheelchair (virtual environment, 3D printing), Sarah de Cristofaro

The practical cases presented different aspects related to the circular economy in the context of the manufacturing. Thus they were highlighting the fact that changes are needed concurrently in the several value chain phases. And this reflection guided the further work of our pathway development

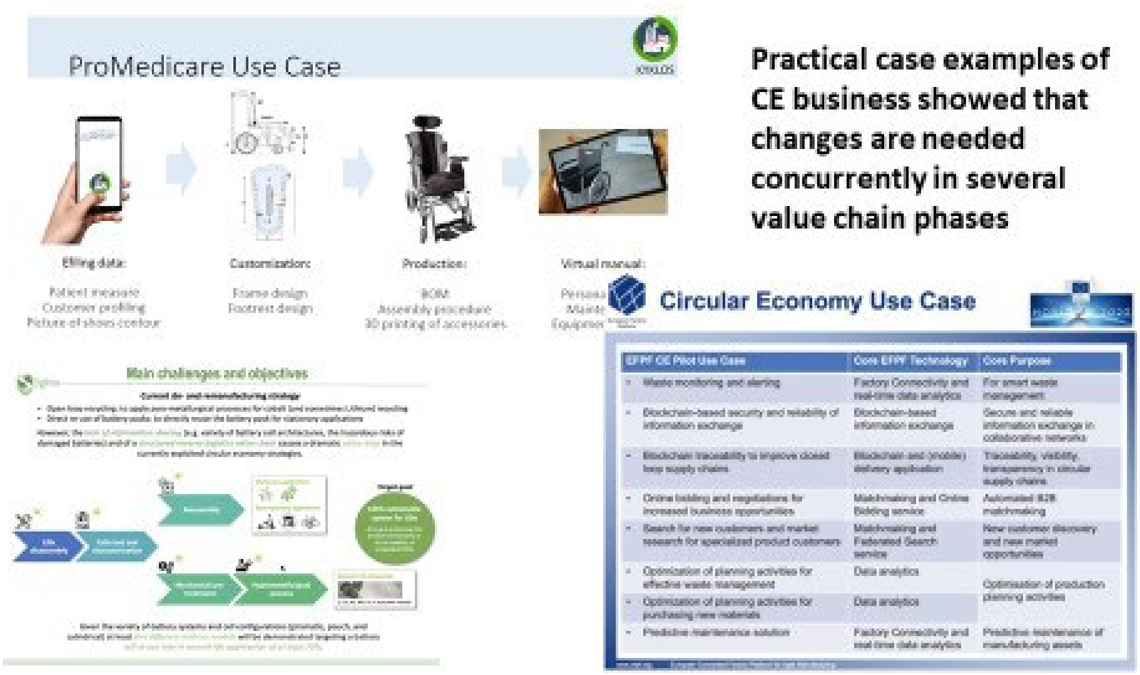


Figure 14. Illustrative cases of CE development in the context of manufacturing

During the workshop part of the workshop, the interactive Miro board[27] was used to collect the reflections to the presented CE maturity matrix. Transparency was the most common word in the stickers of the Miro

[27] Miro board: CF2 CE workshop, Online Whiteboard for Visual Collaboration (miro.com)

board (see Figure 15). Transparency is needed over the value chain and should enable both future estimations and revision of the past activities or materials (reverse BoM). It was also highlighted that the implementation of CE should reach also the economic (financial) goals in addition to the environmental ones.

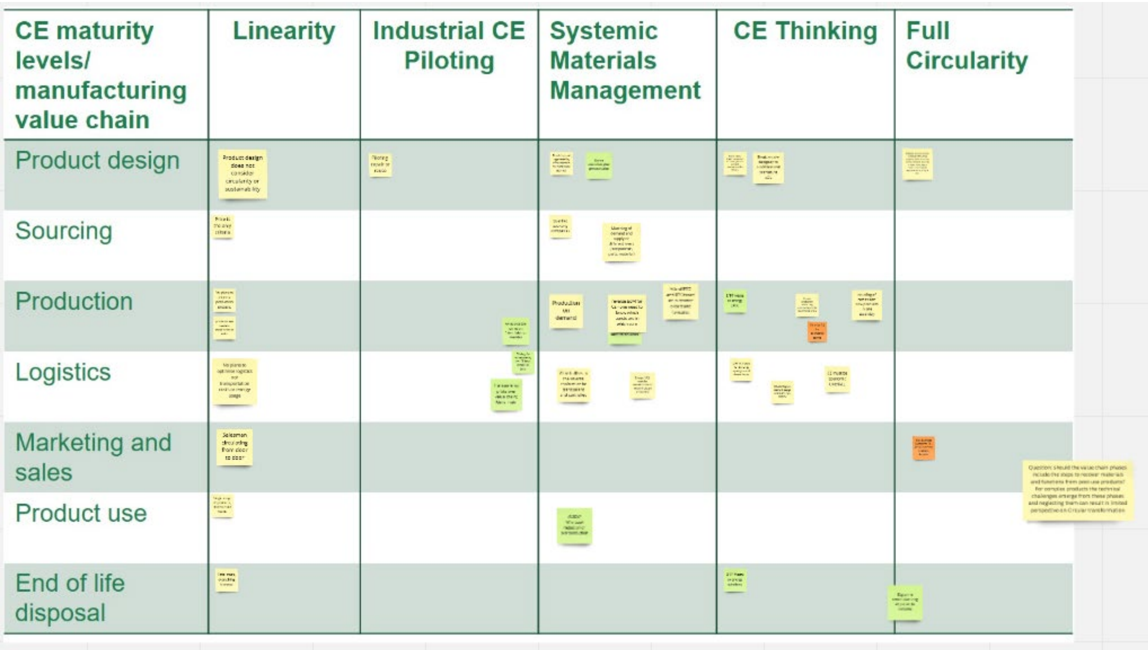


Figure 15. Feedback collected to the Miro board

The presented use cases as well as reflections at workshop were used in order to crystallize the most important development actions at each level of pathway. Based on this feedback and below presented test cases the final version of the CE pathway was configured (see Figure 13).

4.3 Testing the matrix with Finnish forerunner cases

During the development process the developed CE matrix was tested with the publicly available data from examples collected by SITRA[28]. From this list of most interesting company examples in the circular economy, four company examples (Konecranes, CombiWorks, Spinnova and EcoUp) relevant to the manufacturing industry were selected and analysed (Figure 16).

Konecranes is a manufacture and service of cranes and lifting equipment. It presents a well-established Original Equipment Manufacture (OEM) company, in which the circular economy agenda was connected with the servitization. Through a design for environment strategy, it aimed to modularity, durability, component repairability as well as energy and material efficiency to reduce the environmental impact of product lifecycles. In addition, re-utilization of pre-owned equipment was considered. Based on product-as-service strategy, it has developed a leasing-based warehousing concept, where comprehensive service and preventive maintenance were offered at fixed monthly cost. The solution included remote maintenance for products connected via platform (knowing when to maintain, replace or repair components). These digital

[28] Most interesting companies in the circular economy in Finland 2.1 - Sitra

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tools predict failures, optimize the need for maintenance and spare parts and extend the life cycle of equipment.

CombiWorks is following the manufacturing as a service strategy and offering factory production as a service mechanical engineering/ equipment manufacturing. The idea is based on taking advantage of underused capacity of existing factories where production is needed. This is enhancing the supply chain by combining the needs of several companies. The idea is that production is not tied to a certain place, capacity or methods. Product manufacture happens where it is most sensible to do it. This production ecosystem management service provides easy comparison of different options for production. The service enables companies saving time and freight costs and reducing the environmental emissions caused by transport.

EcoUp is a start-up company, which aims to manufacturing carbon-neutral thermal insulation by reusing the side streams from construction. This strategy of reuse, i.e. using recycled material as a raw material, enables increasing the resource efficiency of construction.

Spinnova is a science-based spin-off company with an aim to manufacturing textile fibre without harmful chemicals. Its patented technology allows wood pulp to be spun into textile fibre without harmful chemical processing and less water use. Currently, the pilot plant is connecting textile mill to an existing pulp mill. The manufactured fibre can be used to manufacture yarn, thread and fabrics for a variety of applications and the company is already collaborating with several global brand owners[29].

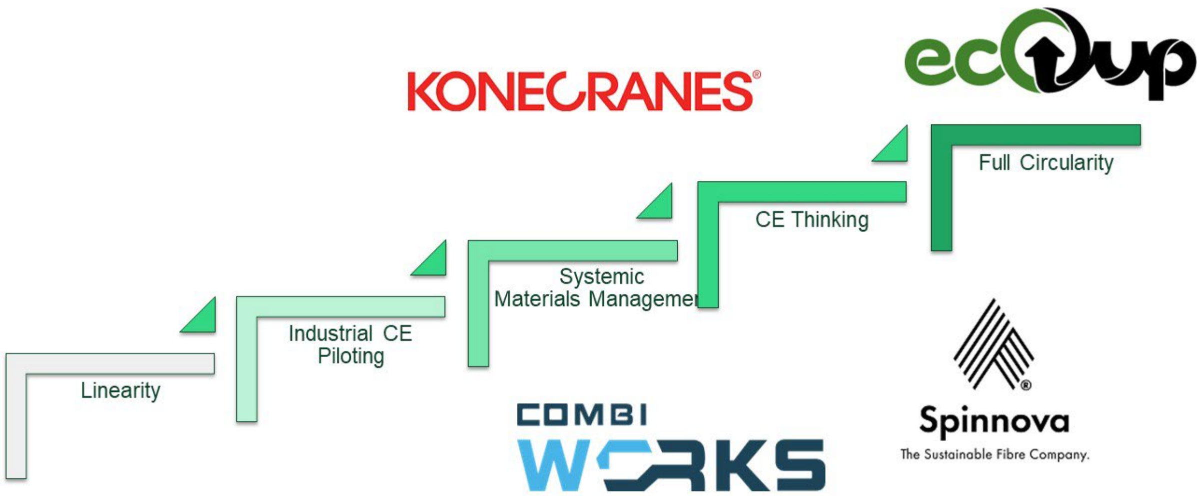

Figure 16. Mapping of case examples

This mapping showed that the fifth level of CE pathway, as it was described, cannot be easily reached by established companies that have a broad value networks and variety of products. Based on this reflection the final version of matrix was updated in order to update the description of fifth level. Thereby, the title of the fifth level was changed to “Ideal Circularity” instead of the former version aiming to “Full Circularity”.

[29] https://spinnova.com/

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5 Development actions – practical case examples from four domains

A more detailed intro to the each project is presented under the four topics. The several examples of the pilots of ICT_07 cluster projects are presented in the 'Digital Transformation Cases Catalogue' , which is integrated in the EFFRA Innovation Portal. This deliverable presents some of these cases as concrete examples of different aspects of digital transformation.

5.1 Agile Value Networks: lot-size one

EFPF/eFactory realises a federated smart factory ecosystem. It provides seamless access to services and solutions that have been dispersed. According to project objectives, the lot-size-one (LSO) strategy and Industry 4.0 come together to produce a product after the customer has been found, a system in which a customer orders exactly what they want and 100 % of the manufactured items are sold. So, personalised manufacturing gets support from an innovative platform for smart factories.

The Predictive Maintenance demonstrator[30] of EFPF project is focused on the monitoring of the operation of an edge banding machine to detect anomalous working conditions evaluating the risk of machine breakdown and take preventive actions through machine data analysis. This experimentation has been deployed in a real manufacturing environment in the Spanish company LAGRAMA. They produce high-quality home furniture and they are located in Vinaròs (Spain).

The operator gets live information from the UI, which is accessible from the portal. The operator can monitor information, such as the failure prediction and confidence in the prediction. Sensors readings can be monitored from the UI as well to help identify the location of a fault. Working in batches means many machine stops and, of course, affects whether a machine is running all the time continuously. Predicting when the edge banding machine may need maintenance of a part or motor is a significant advance for LAGRAMA since it can prevent any part from being damaged, decreasing productivity and consequently losses and a bad image in the face of customers for late deliveries. The benefits of this demonstrator were:

- Reduction of the reaction time when some problem arises during production
- Reduction of the machine downtime due to primary failure in the machine
- Avoiding failures that may affect the quality of produced goods through the detection of abnormal machine operation

5.2 Excellence in manufacturing: zero-defect processes and products

The **ZDMP** project aims to establish a *Smart Zero-Defects environment* by deployment and networking of an Intelligent and 'SME-friendly' Platform, Application Studio, and Marketplace of developed functionality (for product and process quality), applications, and services in any factory for achieving excellence in European and Global Manufacturing. In this context, ZDMP allowed end-users to connect their systems (i.e. shopfloor and ERP Systems) to benefit from the features of the developed platform. These benefits include products and production quality assurance among others. The concept of ZDMP can be simplified to a feedback and control system found in areas ranging from Human/Autonomous Driving through to Electronics. Steering the system will be the ZDMP Apps composed using the project's SDK and different components. Broadly these

[30] PredictFurn Predictive Maintenance demonstrator in lot-size-1 manufacturing furniture domain | EFFRA Innovation Portal

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receive (and present/actuate) information from sensors/APIs and then process the data. Influencing this are material and process flaws as well as errors which create defects. This data is processed through Process and Product Analytics Services which in turn feeds back to the Apps to complete the cycle reiterating until the system is optimised and Zero-Defect Product is achieved.

One example of collaborative business development at the value chain level, enhanced by digital platform of ZDMP project is the pilot case of construction industry[31]. This use-case involves three industrial partners: FLEX – the steel tubes producer, ALONG – the stone slabs produces and CONS – the construction company. The pilot showed, that it is important that all the parties have an early access to information about potential delays and about the quality of supplies to act quickly and, if needed, to reschedule activities. ZDMP platform allows automated exchange of the critical information that can affect the schedule. Ability to adjust the activities regarding potential delays has significant impact on the construction consortia performance.

A radical shift from established methods for ensuring quality in production to disruptive concepts of autonomous quality (AQ) is being realized by QU4LITY in this context. AQ allows manufacturers and solution providers (including SMEs) to use innovative, data-driven production solutions. The **QU4LITY** project demonstrates, in a realistic, certifiable and highly standardised, SME-friendly and shared data-driven ZDM product and service model for Factory 4.0. The QU4LITY project is creating a reference architecture that supports companies on the way to fully digitized production and establishes lasting competitive advantages. To speed up innovation cycles on the way to zero defect production, QU4LITY will establish a Europe-wide innovation ecosystem to promote the development, validation, and broad acceptance of such solutions based on the AQ paradigm.

The PRIMA Additive Manufacturing Pilot Adaptive Control Technology[32] of QU4LITY project provides a concrete example of next generation of manufacturing systems will be based on advanced technologies such as additive manufacturing. In this pilot, additive manufacturing machines for powder bed and direct deposition are considered to enhance process control for producing metal components. Traditional solutions and new concepts of machines are reflected to test new edge devices for process control, towards a ZDM result, and to work on data management and analytics to implement the whole manufacturing process by a platform and control loop approach. In laser-based additive manufacturing, production time has a great influence on the economic efficiency of the production process. To increase the productivity but also reliability of such processes, a zero-defect AM strategy is targeted. Starting from modular devices for real time detection of the process, it will be possible to collect data, deploy new parameters to adapt the machine control to the actual task and communicate data at management level, where not only the single machine is considered; approach will consider both new systems and new concepts of machines in parallel with AQ control loops.

5.3 The human factor: human competences in synergy with technological progress,

The **SHOP4CF** project aims to develop a platform that finds the right balance between cost-effective automation and repetitive tasks while involving the human workers in areas such as adaptability, creativity, and agility where they create the biggest added value. Also, to pursue the highly connected factory model to reap the benefits of all the data generated within the factory. The project develops a platform on an open

[31] https://portal.effra.eu/result/show/4511

[32] QU4LITY - PRIMA PILOT PRIMA Additive Manufacturing Pilot Adaptive Control Technology | EFFRA Innovation Portal

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 873086.

architecture that can support humans in production activities and provide basic implementation as a free, open-source solution. The variety of pilots of SHOP4CF provides examples of AR/VR technologies supporting assemble and maintenance work[33] They are examples demonstrating how novel technologies such as AR-based Teleassistance, Adaptive interfaces and Human Aware Mobile Robot Navigation can be utilised.

5.4 Sustainable Value Networks: manufacturing in a circular economy

The **DigiPrime** project creates a federated model of digital platforms for cross-sector business in the circular economy. The range of services are further developed within the DigiPrime project to support development of circular manufacturing. The services are divided to two main categories. First, circular oriented (CO) services are developed at the operational level, within the platform federation nodes. They include: Product in-use phase monitoring and data acquisition, Artificial Intelligence for prediction of product conditions, De- and remanufacturing decision support system (DSS), Digital twin for de- and remanufacturing adaptation to product conditions, Demand and supply forecasting, Circular production planning and control, Material testing and certification. Second category is Value-chain oriented (VCO) services, that are developed with the purpose to enable a vertical connection and communication between stakeholders such as remanufactures, recyclers or retailers along the value chain. They include: De- and remanufacturing oriented product information management, Product co-creation, LCA-LCC for eco-design, Demand-supply matching, Sustainable value network and reverse logistics configuration, Identification of cross-regional value-chains through open innovation, Material flow monitoring and aggregated system-oriented KPIs, Circular Innovation hubs integration and Barriers identification and legislation support.

The textile pilot[34] of DigiPrime- project is a good example demonstrating the role of the DigiPrime platform to support the creation of a robust circular economy for textile-made components through a cross-sectorial approach between automotive (especially for interior trim) and other textile sectors (e.g., furniture, technical textiles, etc.). The aim of the pilot is reduce the information gap among textile industries, automotive industries, and other possible production sectors (Figure 17).

[33] SHOP4CF-WP5-D51-DEL-201215-v1.0_FINAL.pdf

[34] https://portal.effra.eu/result/show/4497

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 873086.

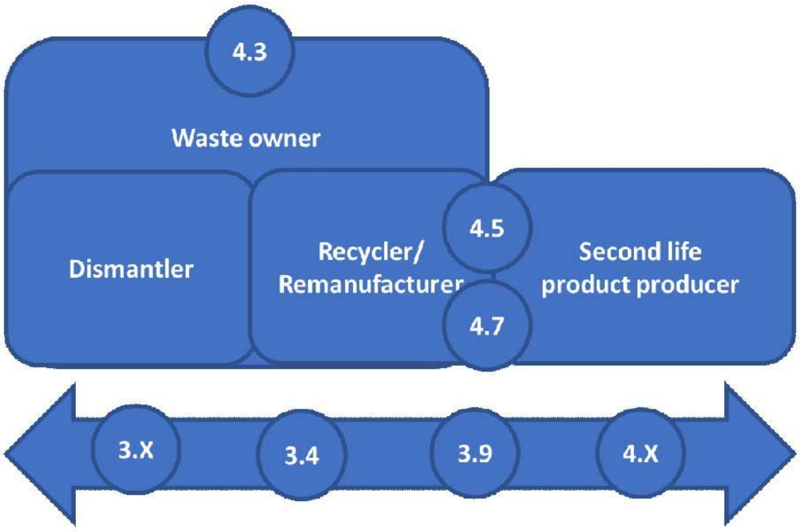

Figure 17. Key actors and activities of DigiPrime textile pilot

This requites several actions: identify and characterise specific composition of the main automotive textile waste, define and test their dismantling procedure and define and test recovery, reuse and recycle practices for them in order to select and validate cross-sectoral applications. Furthermore, validation of best potential second life scenarios for automotive textile materials is a key aspect, which should be made on the base of materials characteristics and of markets needs and availability. Thus, the pilots has shown that the waste regulation may bring additional challenges to such close-the-loop strategies. The use of second life material requires region-specific permissions, i.e. reuse is hindered, as there is need to go through the authorisation process at each region separately.

The **KYKLOS 4.0** project aims to develop an innovative Circular Manufacturing ecosystem based on novel CPS (Circular Production System) and AI (Artificial Intelligence) technologies. The aim is enhanced with novel production mechanisms and algorithms, targeting personalized products with extended life cycle and promoting energy efficient and low material consumption intra-factory production processes, resulting in reduced greenhouse gas emissions and air pollutants. In particular, it aims to show how cyber-physical systems, product life-cycle management, life-cycle assessment, augmented reality, and artificial intelligence technologies and methods are able to transform Circular Manufacturing (CM).

A concrete example of the synergies between manufacturing as a service and product as a service business models is explored in the pilot currently developing a new methodology and approach to design, produce and deliver the next generation of customisable wheelchairs integrating a system with postural device. The medical pilot[35] is developing a fully automatized process where users can configure the chairs through web modelling tools according to individual specifications, where unique components of the wheelchair are 3D printed; and where augmented reality manuals are available to users. In complement to this, blockchain certification of the wheelchair components ensures product standards and quality, and predictive maintenance is employed to identify repair needs and prioritise replaceable/ reusable components[6].

[35] https://portal.effra.eu/result/show/4537

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 873086.

6 Future of manufacturing Industry - ICT-07 pilots enabling the Horizon Europe agenda

As noted above, pandemic and growing geopolitical frictions have highlighted that critical value networks at European manufacturing industry should improve their resilience. The autonomy of European manufacturing has become a priority and main concern. Accordingly, manufacturing industry companies are striving for multi-sourcing strategies and supplier flexibility. This has resulted in further investments in digital technologies, automation and robotics. Parallel to the technological evolution, each company needs to prepare for the disruption of industrial work and the increasing shortage of personnel. New generations are looking for meaningful work careers that aren't based on dull and repetitive tasks. Thus, industries need to rethink how to attract future workers and, at the same time, motivate and reskill current personnel.

The ongoing transition towards a more sustainable and resilient manufacturing industry requires increasing autonomy in the whole value chains. One key enabler of autonomy is the increasing use of robotics and artificial intelligence, which results in self-healing and self-learning processes and change of industrial work. The *Artificial Iintelligence (AI) pathway* of CF2 project described the development in connection with this. Artificial Intelligence technologies could have variety positive impacts, especially on proactive maintenance, process automation and control and supply network management. In line with this, the above mentioned activities of ICT-07 cluster projects (ZDMP, QU4LITY, SHOP4CF) enhance the aim of autonomous manufacturing systems.

Another important target is the shift of manufacturing towards green values, which is connected with the *Circular Economy pathway* of CF2. This shift requires the use of recycled materials and green energy, along with focusing on resource-efficient, demand-driven production and circular value networks. Moreover, sustainable industrial production carefully considers material use and re-uses and repurposes waste streams as materials. Excellence in manufacturing enables the production of future green products with positive environmental handprint. In line with this, the above mentioned activities of ICT-07 cluster projects enhance the aim of circular manufacturing systems (DigiPrime, KYKLOS4.0) and zero-defect processes (Q4LITY, ZDMP).

Digitalisation and digital platforms are an important enabler of future competiveness of European manufacturing industry. Therefore, European ambition to realise fair, compliant and trustworthy data spaces, which requires a multidisciplinary and collaborative approach that engages a wide manufacturing value network. The *Data Spaces pathway* of Connected Factories 2 project contributes with the relevant development steps. Following the lines set by the European Data Strategy[36] , data spaces will contribute to the empowerment of data users and data holders and help establish a healthy balance between the rights and interests of any stakeholder involved, with the general objective to make a wider use of data possible to a broad range of actors.

Below (Table 4) is summarizing examples of research results from the ICT-07 cluster projects. Furthermore, possible future research agendas are mentioned based on the analyses of these project results and three above mentioned pathways.

[36] European data strategy | European Commission (europa.eu)

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Table 4.Possible future research agendas for future manufacturing

	Examples of research results from ICT-07 projects	Future agendas
Agile Value Networks: lot-size one	• Concept and tools for personalised manufacturing, including digital platform solution	Digital platforms, standards, rules and agreed procedures for data utilisation Measurement technologies, big data storage and sharing solutions, real-time data
Excellence in manufacturing: zero-defect processes and products	• A reference architecture that supports companies on the digitized production and in particular autonomous quality management (Q4LITY) • Platform solution(s) for a feedback and control system of factories, including Process and Product Analytics Services (ZDPM)	Remote real-time fleet control with secure and fast network connections Distributed analytics and cyber security
The human factor: human competences in synergy with technological progress,	• A platform based on an open architecture that can support humans in production activities (SHOP4CF) • AR/VR technologies supporting assemble and maintenance work (SHOP4CF)	Safe, user-friendly, collaborative and adaptive human-robot solutions Human-centric view
Sustainable Value Networks: manufacturing in a circular economy	• Technical solutions for product in-use phase monitoring and data acquisition (DigiPrime) • Tools to enable a vertical connection between value chain actors such as remanufactures, recyclers or retailers (Digiprime) • Novel production mechanisms and algorithms, targeting personalized products with extended life cycle (KYKLOS)	New manufacturing technologies enabling sustainable, circular and customised production Manufacturing exploiting green energy and sustainable materials

Building a manufacturing (business) ecosystem is mentioned as an overall aim in all of these ICT-07 Cluster projects. This is a natural objective as the digital platform requires a critical mass of users and providers in order to survive and thrive. For instance, ZMDP project summarizes the ecosystem aims and benefits to different partners as follows[37]: DMP will offer an open environment where a new generation of developed zero-defect service applications will be available in a marketplace contributing to create an ecosystem where ZDMP stakeholders would be able to interact with each other. In this ecosystem:

• Manufacturing users can ask for new applications and algorithms or find existing ones from the marketplace to solve their own zero-defect manufacturing problems

[37] Zero Defects Manufacturing Platform (ZDMP) | Tampere universities (tuni.fi)

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• Subscribed software developers can both respond to specific manufacturing user demands and self-innovate to design, build, and publish new applications and algorithms

• Service providers will interact offering infrastructure for communications, storage, and processing

• Consulting companies can interact as prescriber of the ZDMP solutions giving support to their customers

• Zero-defect technology companies can provide the marketplace with drivers and APIs to access to access their technical equipment.

The importance of ecosystem approach is recognised also broader and for instance ManuFuture WG7 has drafted a white paper related to "Innovation Infrastructures and Ecosystems Developments"[38]. Future competiveness of the manufacturing domain requires an integrated, long-term innovation strategy, ensuring that the European Manufacturing Innovation Ecosystems promote the necessary basic and applied research, its diffusion among the relevant stakeholders and facilitate the take-up by the companies. Building synergies among the variety of actors that push the innovation in Europe is one of the most significant targets of EU committee, aiming to create partnerships that use combined forces to achieve specified goals such as the European Green Deal, An Economy that works for people, Europe fit for the digital age etc.

Consequently, Manufacturing (Innovation) Ecosystems will play a major role in future research, development, and innovation, promoting synergies and contributing to peer learning, benefiting from cross-disciplinary knowledge transfer. As such, it is required to accelerate the transformation of prominent research results and the proof of concepts towards commercialization. To this end, **demonstrators, experiments, and pilot lines** should be promoted. Thus, the efforts for synergies between funding instruments and actors of manufacturing ecosystems shall also address the regional level of Manufacturing SMEs.

[38] The whitepaper will be published during autumn 2022. ManuFUTURE is a European Technology Platform (ETP) established in 2003 as "an industry-led stakeholder forum recognized by the European Commission as a key factor in driving innovation, knowledge transfer and European competitiveness"

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 873086.

7 Conclusions and Future Outlook

In this deliverable, the D2.5 associated to the task T2.1, we described, which key EU strategic programmes support and encourage a dual turnaround. Likewise, we showed that relevant Horizon projects such as DT-ICT-07 accelerate the dual turn called for by the strategies and how CF Pathways support and help to outline the concrete steps required for a dual turn. In particular, it elucidated practical case examples has been instantiated within the DT-ICT-07 four domains: (1) Agile Value Networks: lot-size one, (2) Excellence in manufacturing: zero-defect processes and products, (3) The human factor: human competences in synergy with technological progress, (4) Sustainable Value Networks: manufacturing in a circular economy. The findings of this deliverable portray a systemic transformation of manufacturing industry, which requires bold steps in technology development and business and societal advancements

These four domains are aligned with the emerging needs of the society of stimulating a sustainable development which concurrently relies on both digital advancements and circular systems. Therefore, on one side it is essential to avoid the disadvantageous consequences that our society would face in case no countermeasures would be put in practice against the uncontrollable usage of planet resources and emissions generation. On the other side, this change can be achieved relying on a digital transformation. This consciousness and awareness needs to be operationalised through concrete actions by manufacturers which require a great support. With this intention, in the “Circular Economy Pathway” a supporting tool has been developed to assess the maturity level of manufacturing companies in terms of circularity. Covering the different dimensions of manufacturing value chain, the model allows manufacturers to be pro-active in undertaking the twin transition. Indeed, the dimensions cover both the technical and the social aspects addressing the need to develop sustainable systems.

Different workshops have already been organized in order to build and validate the CF pathways, nevertheless further works must be performed in order to diffuse this knowledge at European level. Therefore, collecting the practical case examples has been an important activity in order to concretise the five maturity levels presented at the different pathways. At the deliverable D1.2, there was presented a first attempt to position the DT-ICT-07 project activities related to circular economy to the opportunities matrix. This second iteration, D2.5, deepens the understanding through the practical case examples presented at the chapter 5. Based on the analyses of ICT-07 project examples we then summarized the current and future research agenda in manufacturing ecosystems (chapter 6).

For a manufacturing company, becoming more sustainable and digital from typically quite a linear operation models of manufacturing networks, there is first need to make strategic decision and consider renewal of its business model and modify its culture moving towards a sustainable attitude and understand the core of the CE principles. Thus, at the level of strategic choices and business models, the above mentioned two dimensions (i.e. digital advancements and circular value systems), open several opportunities for manufacturing industry companies. The conceptualisation of the integration of digital manufacturing platforms and novel technologies to influence to business can be presented through the matrix (Figure 15), where different strategic opportunities are positioned.

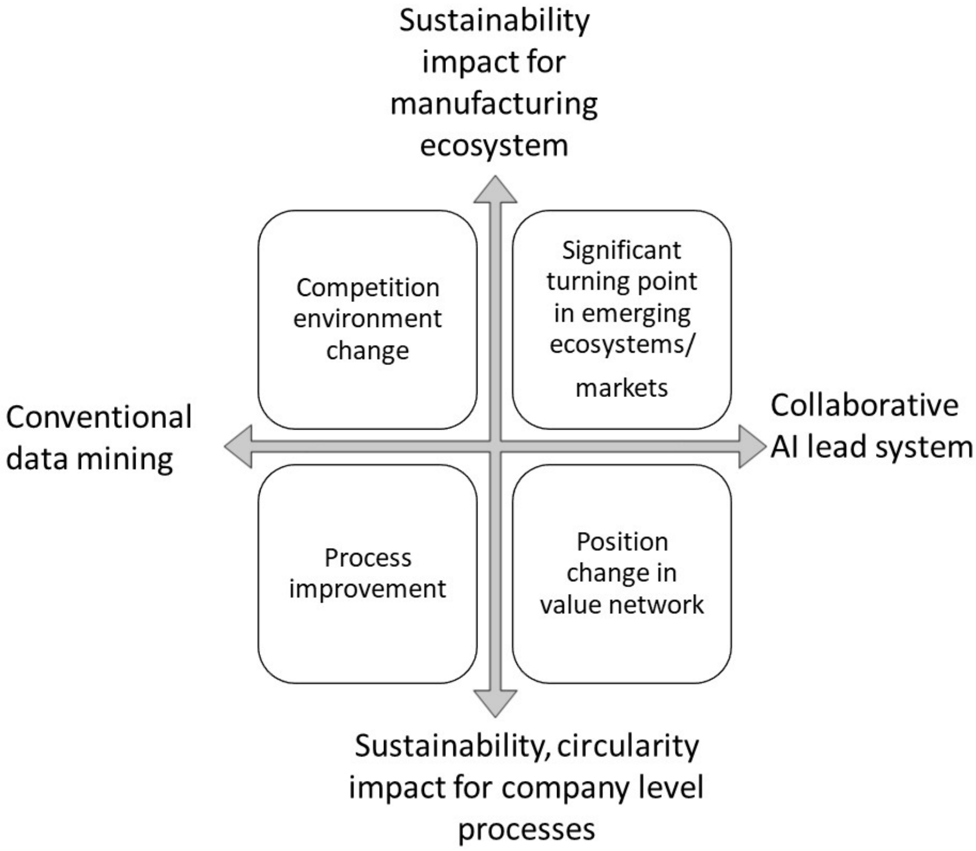

Figure 5 Future Opportunities at the crossroads of digital technologies and sustainable manufacturing systems[39]

Thus, the business impacts of digital technologies are complex and multifaceted, and seldom simply positive or negative. Comprehensive understanding of this issue is still lacking. Furthermore, the sense-making process of the business impacts of disruptive technologies seems to be broken up into technology- and business-oriented tracks both in practice and in the research agendas. Therefore, the practical case examples are an extremely important tool to concretise these opportunities. At the context of manufacturing industry, the Digital transformation case catalogue by EFFRA[40] provides rich and dynamically evolving resource for this purpose.

[39] Modified from Valkokari et al 2018. Business Impacts of Technology Disruption: A Design Science Approach to Cognitive Systems' Adoption Within Collaborative Networks.
[40] https://www.connectedfactories.eu/news/digital-transformation-cases-catalogue-now-launched

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 873086.

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This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 873086.