Twin Transition through Implementation of Industry 4.0 Technologies

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Key Enabling Technologies (KET) support the adoption of Industry 4.0 (I4.0) and are also considered the main drivers of the Circular Economy (CE) transition. In this respect, the guidelines and real use cases to inspire enterprises and industry to lead the twin digital and green transition are still poor.

Keywords: key enabling technologies ; circular economy ; industry 4.0 ; twin transition

1. Introduction

In the European Green Deal, the European Commission (EC) points out that we are currently facing significant environmental challenges because of the polluting and destructive activity of humans [1]. One of these challenges is making a transition from the current linear economic model, characterised by take-make-dispose, towards a circular model, which tries to maximise products and materials value as much as possible, closing both their technical and biological cycles [2].

In the meantime, industry is involved in the so-called fourth industrial revolution or Industry 4.0 (I4.0), characterised by the implementation of Key Enabling Technologies (KET) in the different industrial processes, which has facilitated smart systems and processes [3]. KET are Information and Communication Technologies (ICT) associated with high Research and Development (R&D) intensity, rapid innovation cycles, high capital expenditure, and highly skilled employment [4]. They are considered a key instrument for boosting the innovation and digital transformation in most of European industries, traditional sectors and society. They are characterised by their multidisciplinarity, covering many technology areas with a trend towards convergence and integration [5][6].

In the current European research and innovation funding programme 2021–2027, Horizon Europe, six KET are being prioritised: advanced manufacturing, advanced materials, life-science technologies, micro/nano-electronics and photonics, artificial intelligence (AI), and security and connectivity. However, KET also include many specific cutting-edge technologies, e.g., those included in **Table 1**, defined as the key pillars of the I4.0 transformation [7][8][9]. These technologies are clearly aligned with the KET's definition, as advanced technologies that foster industrial innovation.

Table 1. Key Enabling Technologies definition.

Key Enablign Technology	Definition
Internet of Things (IoT)	**It refers to the connection of physical objects from the real world with a representative in the virtual world.**
Big Data & Analytics	**It is the use of large amounts of data characterised by their volume, velocity, namely the speed at which they are generated, accessed, processed and analysed, and variety such as unstructured and structured data.**
Cloud Computing (CC)	**A network of remote servers to store, manage and process data**
Simulation	**A close imitation of a process or system operation, considering its characteristics, behaviour and/or physical properties. It can be used to reduce costs of production line processes and reduce the impact of modifications applied to it.**
Virtual Reality (VR) & Augmented Reality (AR)	**While Virtual Reality (VR) immerses users into a completely virtual world where they can interact with the environment, Augmented Reality (AR) adds virtual entities and information to a user viewport, combined with images of the real world.**
Artifical Intelligence (AI)	**Software that exhibits a behaviour traditionally identified as human intelligence that goes beyond what computers and machines are expected to do with conventional programming.**

Key Enablign Technology	Definition
Additive Manufacturing (AM)	**Additive Manufacturing (AM), also called 3D printing, is a process that creates a physical object from a digital design.**
System Integration	**To be a fully connected I4.0 factory, both horizontal and vertical systems need to be integrated together. Standard protocols and specific software packages should be used to achieve this integration among the disparate information technology systems used in the company.**
Robotic	**A mechanical system which executes various remote simple tasks with good accuracy. Autonomous and advanced robots are even able to adapt themselves to changes without any kind of human assistance.**
Cybersecurity	**It pursues the goal of preventing threats in the use of information technologies, such as confidential information, business secrets, know-how, employee and customer data, IT systems, software, networks, operational processes and operating facilities.**

According to current product lifecycles, KET offer a new perspective on automated and more efficient production systems. Therefore, Industry 4.0 technologies are considered a driving force of the Circular Economy (CE) transition [10][11], with a clear effect on the reduction of the environmental impact of manufacturing industries [12][13]. There are many projects and solutions on the market focused on implementing I4.0 technologies with the aim of fostering the CE transition, modernising the industry with disruptive technologies, but at the same time, seeking a CE model, mainly due to their capacity to enable information to travel with a product, a critical aspect to maintain the value of a product for as long as possible [14]. Experts use different terms in scientific and policy papers for this new paradigm: “twin transition”, “twin digital”, “green transition”, “Circular I4.0”, or “Digital CE” [15].

At a European policy level, accelerating the twin digital and green transitions has been set a European priority, in line with the EU’s new growth strategy, the European Green Deal, that will be key to build a lasting and prosperous growth. In this way, the EC states that Europe must leverage the potential of digital transformation, which is a key enabler for reaching the Green Deal objectives. This idea is reinforced in the New Industrial Strategy for Europe [16] that gives special emphasis on the need of introducing new ways of thinking and working to lead both transitions, green and digital; and translated in the recently approved Horizon Europe Programme, the EU’s key funding programme for research and innovation, with a set of funding calls to accelerate the twin transition in specific industry sectors and technologies [17].

2. European Policies for the Twin Digital and Green Transition

Policies play a crucial role in creating the enabling factors and paths towards a smart and sustainable industry. The EU policy agenda is broad and is covering a wide range of instruments and policy recommendations that spread across smart and sustainable economic development.

In relation with the promotion of a digital and green economy, the EU has launched a significant number of strategies, regulations, and directives to boost both transitions. In this way, the New Green Deal, that sets the EU objective to achieve a climate neutral society, outlined those digital technologies as critical enabler for attaining the sustainability goals. This is an ambitious and cross-cutting objective to all EU policies. Aligned with the Green Deal, different strategies and plans have been launched such as the Strategy on offshore wind, the “renovation wave” initiative for the building sector, or the Strategic Action Plan on batteries, among others [18].

From the point of view of the industry and digitalisation, the New Industrial Strategy [16] and the Digital Strategy [19] reflect the necessity to deploy technologies and reshape European industries towards a new reality, ensuring that it can become the enabler of this change.

Focusing on the CE aspect, the new Action Plan for the CE [20] includes measures for companies, public authorities, and consumers to adopt a sustainable model. It focuses on design and production and establishes the necessity to complement the circular transition through research, innovation, and digitalisation. The Action Plan is connected to four different strategies: chemicals, industrial, plastics, and zero pollution action plan. In the framework of these four strategies and the Action Plan for the CE, different policy frameworks have been launched, directives, and regulations that encompass the complete EU legislative framework of the CE at European level.

Table 2 summarises the existing legislative instruments classified in the different phases of the product production process from the raw materials extraction to the waste management process.

Table 2. European legislative instruments for the twin digital and green transition.

Process	Policy Framework	Directive	Regulation
Raw material	• Resource efficiency roadmap • Raw materials initiative • Minerals policy framework	• Restriction of the use of certain hazardous substances in electrical and electronic equipment (RoHS) Directive • Renewable energy Directive	
Product design and production	• Bioeconomy Action Plan • SME Strategy for a sustainable and digital Europe • Sustainable products initiative (on-going) • EU strategy for sustainable textiles (on-going)	• Ecodesign Directive • Industrial Emissions Directive • Directive on the reduction of the impact of certain plastic products Public Procurement Directive	• Ecolabel scheme • Eco-Management and Audit Scheme (EMAS) • REACH—Hazardous substances regulation • Environmental Technology Verification scheme • Legislative proposal for substantiating green claims made by companies (on-going)
Use and/or consumption	• Sustainable Consumption and Production Action Plan	• Plastic bags Directive	• Legislative proposal empowering consumers in the green transition (on-going) • Green Public Procurement criteria
Waste management	• Waste Framework Directive	• Waste Framework Directive • Landfill Directive • WEEE Directive • Packaging and packaging waste Directive • Batteries Directive • Extracting Waste Directive • End-of-life vehicles Directive • Sewage Sludge Directive	• Batteries regulation • Different end-of-waste criteria for priority waste streams: iron, steel, aluminium scrap, glass cullet, an

3. R&D Projects, Patents, and Commercial Solutions

In the last years, several European projects co-funded by the EC through different funding programmes such as Horizon 2020, Erasmus+ or Interreg, have focused on boosting the twin transition through different ways of acting. Regarding patents, only a few non-European patents of solutions that join the use of KET and CE practices have been found, mostly in China. Nevertheless, there are many commercial solutions already on the market that use KET to foster CE practices in different industry sectors. The quick expansion of Big Data in several applications joined to the multiply possibilities that offered by the CC, has originated many applications that seek to make more efficiently industry processes, while prevent waste generation and energy use.

From the analysed it can be set that there are three I4.0 technologies most used as enablers of CE: Big Data, AI, and IoT, mainly implemented to monitor energy consumption and dynamic analysis to support CE energy management. Robotic is a I4.0technology also vastly implemented as CE enabler, mainly due to its capacity to facilitate waste sorting and assembling processes. Finally, AM has been identified as facilitator of eco-design practices incorporating new sustainable materials.

Regarding industry sectors, waste management sector is being transformed rapidly through the application of different technologies (Robotic, Big Data, AI, IoT) that allow to improve the efficiency of the different processes: collection, sorting, and processing of waste, being the sector where I4.0 technologies are most applied to achieve the circularity.

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