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Review

Twin Transition through the Implementation of Industry 4.0 Technologies: Desk-Research Analysis and Practical Use Cases in Europe

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Abstract: 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. This work is aimed at contributing to this matter, with twofold goals: on the one hand, to show a depth desk-research analysis of the key existing policies at European level that foster this twin digital and green transition; on the other hand, to review practical use cases and international projects where CE practices are boosted through the implementation of KET. From the analysis, a set of recommendations are suggested as a guide for policymakers, researchers, and industry managers on how to foster the CE through the implementation of I4.0 technologies.

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

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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 [7–9]. 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.
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].

Nevertheless, besides all the recent efforts to boost and promote the necessary digital and green transition within the industry, there is a lack of information and examples on how KET could support the circular transition towards a smart and sustainable industry. Therefore, the goal of this paper is twofold: on the one hand, to analyse, at a European level, the existing policies that foster the twin transition, and on the other hand, to provide practical use cases and international projects where CE practices are boosted through the implementation of KET. From both analyses, a set of recommendations are suggested as a useful guideline on the necessary steps for a successfully twin transition.

The rest of the paper is organised as follows. Section 2 presents the adopted research method with the description of the research object. Section 3 presents the results obtained during the desk-research. Section 4 discusses the results, analysing the contribution of the different KET to the CE transition on different industry sectors. Finally, a set of recommendations are proposed to support the continuing fostering the twin transition.

2. Materials and Methods

This section details the methodology implemented in this research, summarize in Figure 1.

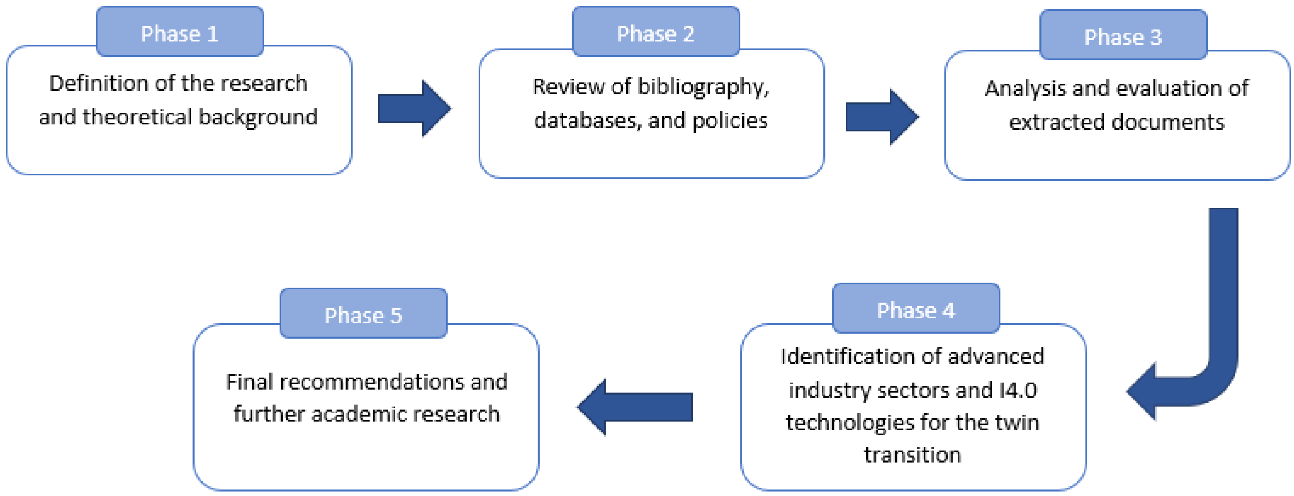

Figure 1. Methodological flow.

In phase 1 it was established the basic elements for this research, i.e., its objective and methodology, through a preliminary research about the topic. This previous research highlighted the relevance of the proposed review, as it had not been analysed in detail how KET could act as enablers of CE practices, for instance exploring the most appropriated or used KET for such transformation, although it is one of the key priorities of different EU policies and strategies.

In phase 2, for the review bibliography process, the methodology that has been used is based on the UNE 166006 Technology Watch System [18], used by CETEM (work centre of three of the authors of this paper). CETEM is a pioneer in the implementation of Technology Watch and Competitive Intelligence systems, with their own certified system on April 2008, under the experimental UNE 166002 standard. Within this management system, Technology Watch and Competitive Intelligence stand out as sources of information for processes such as External Analysis of Information.

Following this methodology, a review of the bibliography, inventions, innovation activities, policies, etc. related with the twin digital and green transition, has been performed based on two systematic processes: search and analysis of the information in which it focuses the state of the art in our topic. Policies have been evaluated at three different levels: policy framework, directives, and regulations. The practical cases reviewed are a summary of those where CE transition has been boosted through the implementation of different I4.0 technologies, differentiated R&D projects, patents, and commercial solutions.

The most important and well-known databases have been used in the search process of this research:

- Multidisciplinary databases for the scientific papers research such as Web of Science [19] and Scopus [20] at an international level, and the databases of CSIC [21] and Dialnet Plus [22] in Spain. The keywords predefined for the systematic review of the state of the art are the combined parameters entered in those sources of information to perform our research; the following terms are included among those keywords: Key Enabling Technologies (KET); Circular Economy; Industry 4.0; Twin Transition; Artificial intelligence (AI); Big Data; Blockchain; Cloud computing; Dematerialisation; Circular economy; Digitalisation; Digitally-enabled solutions; Digital twins; Lifecycle assessments (LCAs); Internet of things (IoT) and connected devices; Machine Learning (ML); Online platforms; Radio-frequency identification (RFID); Sensors; 3D printing or additive manufacturing. Additionally, other scholar search tools have been consulted such as Google Scholar [23] or Academia.edu [24] to supplement the search and identify possible information gaps.
- Patent databases. At the level of technological innovation, the following databases have been determined as sources of information: The Spanish Patent Office, at a European level Espacenet [25], USPTO database in the US [26], the Japanese Patent Office JPO [27] and WIPO [28] at a global level. Apart from the predefined keywords, the International Patent Code has been used, with the focus on the following codes: B25J Manipulators; chambers provided with manipulation devices; B25J9/00 Programme-controlled manipulators; G06N 20/00 Machine Learning; B33 Additive manufacturing technology. Likewise, other open patent databases were consulted such as Google Patents [29] or Lens [30].
- Research projects databases: a compilation of the European projects facing the twin transition has been carried out, especially at the industry level. For this purpose, the most relevant project databases at a global level have been used such as: CORDIS [31], which provides information on all EU-supported R&D activities; Interreg Europe [32], which helps regional and local governments across Europe to develop and deliver better policy; Keep: a source for Interreg, Interreg-IPA cross-border [33], ENI-CBC and IPA-IPA cross-border since 2000 [34], updated on a daily basis; European Investment Project Portal (EIPP) [35]: The EU Matchmaking Portal; LIFE [36]; ERASMUS+ PROJECT RESULTS [37]; European Circular Economy Stakeholder Platform [38].
- Policies and current solutions databases: a search for information on the policies framework, directives, and regulations related to the twin transition in manufacturing and traditional industries in Europe. For this purpose, the most important databases at a European level have been consulted such as Eurostat [39], the official data base of the European Commission [40], EUR-Lex [41], and the official site of the Advanced Technologies for Industry [42].

The phase 3 of this systematized process has been the analysis of the extracted documents in relation with the twin transition in every identified document or result. The analysis evaluated the relation with the twin transition of identified projects, through a complete description of each of the identified initiatives.

In phase 4 it is identified which I4.0 technologies are used for supporting the CE transition and the different industry sectors where they are applied. This identification allows to classify KET regarding their knowledge/use to foster CE practices, and industry sectors regarding their level of twin transition implementation. In addition, it has been identified some initiatives that are focused on training on I4.0 towards a sustainable industry model.

Finally, in phase 5, it has been proposed a set of recommendations according to the result obtained in previous phases. Recommendations are classified in three operational categories: at the industry, technological, and knowledge levels. In addition, further actions of academic research are proposed to continue the work of this paper.

3. Results

3.1. 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 [43].

From the point of view of the industry and digitalisation, the New Industrial Strategy [16] and the Digital Strategy [44] 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 [45] 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)

Table 2. *Cont.*

Process	Policy Framework	Directive	Regulation
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, and copper scrap

Funding Instruments

The EU objectives and principles set in the different policy frameworks and policies regarding the necessity to boost the twin digital and green transitions have direct impact on all the different EU funding instruments. Thus, the key R&D funding instrument, the Horizon Europe Programme, set as one of its Key Strategic Orientations the "promotion of an open strategic autonomy by leading the development of key digital, enabling and emerging technologies, sectors and value chains to accelerate and steer the digital and green transitions through human-centred technologies and innovations". Aligned with this, the Horizon Europe Work Programme 7 "Digital, Industry and Space" for the period 2021–2022 [46] encompasses different funding topics under the framework of a specific call for the twin digital and green transition with a total budget of 737.5 EUR million. In the framework of this specific call, it is expected that around 94 projects in these two years will be funded, which should be added to other topics of similar calls that also aim to foster the twin transition, such as some topics under the call "a digitized, resource-efficient and resilient industry".

Additionally, the EC has recently launched the new Programme for the Environment and Climate Action, known as LIFE Programme [47], which includes, among its different specific goals, the development of innovative techniques, methods and approaches for reaching the EU environmental objectives, as well as to act as a catalyst for the large-scale deployment of successful technical solutions on this aim. The LIFE Programme is divided in four sub-programmes: (1) Nature and biodiversity; (2) Circular economy and quality of life; (3) Climate mitigation and adaptation, and (4) Clean Energy transition. The overall indicative amount devoted to grants for the period 2021–2024 is 2357.27 EUR billion [48].

Finally, a big funding instrument, financed with the revenues of the EU Emission Trading System (EU ETS), is the Innovation Fund [49]. The Innovation Fund, tailored for big energy companies, aims to bring to the market industrial solutions of innovation low-carbon technologies to support the Green Transition. It is estimated that it will provide around 20 EUR billion over 2020–2030 to fund highly innovative technologies and big flagship projects that can bring on significant emission reductions, focusing on energy-intensive industries; carbon capture, utilisation and storage technologies; renewable energies; and energy storage.

3.2. *Twin Transition in the Industry: Practical Cases*

In the next subsection, the analysed practical industrial solutions are classified on R&D projects, patents and current commercial solutions, all of them where KET have been implemented to boost CE practices.

3.2.1. R&D Projects

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. R&D projects (Table 3) could be classified as projects that (1) act as Circular4.0 transition accelerator programmes (DigiCir and Circular4.0); (2) aim to research the industry skill gaps for the twin transition and develop a Joint Curriculum (DigiVIP, Single Market & Competition, and Sawyer); (3) are focused on new circular business models through the implementation of KET (C-SERVEES); (4) implement KET to support the monitoring and optimisation of different industry processes and energy use (SABINA, BIM2TWIN, and WASTE4think); and (5) R&D projects aimed at developing new solutions to enhance the sustainability of certain processes with the support of KET (SUSTAINair, BURBA and Rocycle).

3.2.2. Patents

From the desk-research, only a few non-European patents of solutions that join the use of KET and CE practices have been found, mostly in China. From the collected solutions (Table 4) most of them are focused on the implementation of IoT and Big Data technologies to develop smart systems that allow to increase the efficiency in different processes, such as logistic (AU2021101897A4) or energy monitoring and use (CN110138877A). Only one solution, CN103276910A, is about a different technology: a robot to process wallboard assembling for a more efficient and cleaner production.

Table 3. R&D projects focused on the twin digital and green transitions.

Project Title	Programme	Goal	Reference
DigiCirc—European cluster-led accelerator for digitisation of the circular economy across key emerging sectors	H2020 (873468)	Empower SMEs to leverage digital technology as a key enabler for innovative circular products/services, processes and business models.	[50]
DigiVIP—Building Virtual Learning Platform for Environmentally-Friendly Digital Transformation Management	Erasmus+ (2020–1-TR01-KA226-HE-098393)	The project aims to develop a digital transformation management curriculum and learning materials with a focus on "environmental sustainability" standards.	[51]
SUSTAINair—Bringing the aerospace and aviation sectors in line with circular principles	Horizon 2020 (Nº 101006952)	The project aims to research and develop solutions to increase resource efficiency and aircraft performance while cutting down on waste and material costs throughout the aircraft life cycle	[52]
Single Market & Competition Law in the Digital and Ecological Transition Era	Erasmus+ (620517-EPP-1-2020-1-ES-EPPJMO-CHAIR)	Offering an EU Economic Law Specialisation through two courses on "Single European Market" and "EU Competition Law"	[53]
Circular4.0—Strengthening the transition to the circular economy in the Alpine Space thanks to the SMEs digitalization	Interreg Alpine Space	Improving the Alpine eco-system of innovation and its contribution to the transition to Circular Economy in the Alpine Area by SMEs and economic operators, exploiting the potential and the added value of the digitalisation processes by SMEs.	[54]

Table 3. *Cont.*

Project Title	Programme	Goal	Reference
SAWYER—Holistic approach for the identification of skills and safety needs towards a growing sustainability & circularity of furniture sector	EU Support for Social Dialogue (VS/2019/0027)	Facilitating the transition of European furniture companies to a more circular economy.	[55]
C-SERVEES—Activating Circular Services in the Electrical and Electronic Sector	Horizon 2020 (Nº 776714)	Boosting a resource-efficient circular economy in the electrical and electronic (E&E) sector through the development, testing, validation and transfer of new circular economic business models based on systemic eco-innovative services that include: eco-leasing, product customisation, improved E&E equipment waste management, and ICT services to support the other eco-services	[56]
SABINA—Smart bi-directional multi energy gateway	Horizon 2020 (Nº 731211)	Developing new technology and financial models to connect, control and actively manage generation and storage assets to exploit synergies between electrical flexibility and the thermal inertia of buildings.	[57]
BIM2TWIN—Optimal Construction Management & Production Control	Horizon 2020 (Nº 958398)	Designing, implementing and testing a construction management platform able to make managers aware of real-time status of everything happening on site and throughout the whole supply chain.	[58]
WASTE4think—Moving towards Life Cycle Thinking by integrating Advanced Waste Management Systems	Horizon 2020 (Nº 688995)	Designing solutions based on the use of ICT that would enable the improvement of all waste management stages, adopting a global approach and particularly focusing on citizen participation in order to build more sustainable, eco-friendly cities.	[59]
BURBA—Bottom-Up selection, collection and management of urban waste	Horizon 2020 (Nº 265177)	Developing an automatic system to be used for intelligent waste management.	[60]
RoCycle	N.A.	Developing a robotic system that can detect if an object is paper, metal, or plastic.	[61]

3.2.3. Commercial Solutions

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. This is the example of some analysed commercial solutions (Table 5) such as Circulor, SEGARA, or AEVAE. Nevertheless, other KET, such as AM, robotic, or AI are advancing in their implementation and are already present in different commercial solutions like Ohmie, RetourMatras, or RecySmart.

Table 4. Analysed patents related to the twin digital and green transition.

Title	N° Patent	Abstract	Reference
Innovative manufacturing methods for next-generation products, processes, and systems	16/998366	A method for managing a modular product life cycle is described. A central computing device or system receives inputs representative of one or more of: an expected product life cycle, a market demand for the product, a manufacturing process for the product, a reverse manufacturing process for the product, and one or more technical engineering constraints associated with the product. From this information, a first modular product design is determined. Later in the life cycle of the modular product a second plurality of inputs representative of one or more of: a market demand, a manufacturing process, a reverse manufacturing process, and one or more technical engineering constraints are retrieved. From this information, a second modular product design is determined.	[62]
Energy monitoring method based on big data intelligent analysis technology and energy cloud platform	CN110138877A	The invention discloses an energy monitoring method based on a big data intelligent analysis technology and an energy cloud platform. The method comprises the following steps: S1, obtaining related index data from the energy cloud platform; S2, providing real-time monitoring of regional energy supply and consumption conditions from three dimensions of a whole region, partition and industry division; S3, performing statistics and analysis on the energy use condition data of the set area to obtain a statistics and analysis result; and S4, on the basis of the statistics and analysis result in the step S3, adopting a big data analysis method, and providing a regional energy analysis report for the target object through an energy cloud platform semi-automatic generation report function. According to the invention, online monitoring and dynamic analysis of energy consumption can be realised, regional energy development planning and multi-energy regulation are supported, diversified government supervision is realised, and CE and low-carbon economy of regional energy are realised.	[63]
Wallboard assembling robot	CN103276910A	The invention discloses a wallboard assembling robot which comprises a vehicle frame. A lifting frame is arranged in a guide rail A of the vehicle frame, and a piston rod of a lifting hydraulic cylinder is fixedly connected with the lifting frame. A sliding frame is arranged in a guide rail B of the lifting frame, and a lifting chain A which is fixedly connected to a stand column is fixedly connected with the sliding frame by winding around a guiding chain wheel A of the lifting frame. A lifting seat is arranged in a guide rail C of the sliding frame in a sliding mode, and a lifting chain B which is fixedly connected with the stand column is fixedly connected with the lifting seat by winding around a guiding chain wheel B of the sliding frame. A hanging basket is connected with the lifting seat. The wallboard assembling robot has the advantages of being capable of improving installation efficiency and degree of labour safety and reducing labour intensity, simple in structure, easy to maintain, convenient to operate, safe, reliable, and capable of achieving high lifting.	[64]

Table 4. *Cont.*

Title	N° Patent	Abstract	Reference
A machine learning and IOT based system for intelligent routing	AU2021101897A4	The present invention relates to a machine learning and IoT based system for intelligent routing. In order to improve the reliability and efficacy of public transport, many IoT attempts have been made. Many problems, such as car traffic congestion, road safety and improper use of parking spaces for vehicles, have been handled and controlled by the IoT. The present invention provides an intelligent routing based on a distributed cloud architecture of IoT for managing the traffic system combined with a machine learning to improve the process of finding the optimised route in the minimum time based on the state of traffic on the road.	[65]
Internet of Things system and method for waste selvage	CN109981791A	The invention provides an IoT system and method for waste selvage. The system comprises an internet platform, a monitoring computer and a waste cloth edge printing and weaving integrated unit, a processing state monitoring module is arranged on the waste cloth edge printing and weaving integrated unit; the monitoring computer is connected with the processing state monitoring module and the waste selvage data acquisition system, the waste selvage printing and weaving integrated unit and the monitoring computer are both connected with the router, the router is connected with the web server and the database server, and the database server and the web server are both connected with the Internet platform. According to the invention, centralised monitoring, online remote monitoring and real-time allocation can be carried out on the waste selvedge data acquisition and waste selvedge printing and weaving integrated unit of an enterprise, a basis is provided for decision making of an enterprise management layer, and meanwhile, the management level of waste selvedge's and related solid wastes of the enterprise and the additional value of solid wastes of textile, printing, dyeing and clothing production and processing enterprises are also improved.	[66]

Table 5. Commercial solutions that apply KET to implement CE strategies.

Product Name	Company	Description	Reference
Digital twins & Csense	General Electric (GE) Company	Digital Twin is most commonly defined as a software representation of a physical asset, system or process designed to detect, prevent, predict, and optimise through real time analytics to deliver business value. It has been tested in aviation and automotive sectors. Digital Twin integrates data from multiple sources and uses analytics to monitor, predict, and prevent generation of waste from production operations. Process Digital Twins create models of 'the best way' to run a process in a given environment—often referred to as 'the golden batch'. By identifying the most optimal process to manufacture a given product, plant operators can ensure they are consistently delivering against quality, cost, and volume objectives. In addition, through CSense Operations Performance Management solutions, Process Digital Twins help manufacturers meet the challenges of fast-changing consumer demand, regulatory requirements, and looming generation knowledge gap with results like reduced product waste by up to 75%, quality complaints reduced by 38%.	[67]

Table 5. *Cont.*

Product Name	Company	Description	Reference
Circulor	Circulor Ltd.	Circulor tracks raw materials from source, into components and finally to finished products, helping manufacturers and their suppliers build a sustainable future. Companies can secure deliveries, manage payments, and check provenance of their raw materials, as well as a host of other features, making Circulor designed for real world complexity. The solution is based on different technological applications, where traceability-as-a-service includes supply chain mapping, verification, specialist responsible sourcing expertise, and implementation know-how. It could be applied to different sectors, such as plastics, electronic waste, agriculture, or extractive industries. For instance, Volvo Cars commissioned Circulor to implement a technology-enabled traceability solution, to enable an end-to-end chain of custody to be constructed, initially for Cobalt and subsequently for Mica, with other materials being planned.	[68,69]
Ohmie	Krill design	Orange peels certainly are compostable, but Milan-based start-up Krill Design has come up with an interesting alternative use for them. The company is incorporating orange waste into its 3D-printed Ohmie lamp. Obtained as waste from the food industry, the peels are dried, ground into a powder, mixed with a plant-derived biopolymer, and extruded into the form of a filament. The filament is then used in a conventional FDM (fused deposition modelling) 3D printer to build the main body of the lamp. In that way, Krill design transform waste from the food supply chain through a CE process that enhances the resources of nature, enhancing waste by giving it new life and a renewed meaning in a product with a green soul, with a unique design and made with new generation biopolymers.	[70]
RetourMatras	RetourMatras B.V.	RetoruMatras has created a complete recycling system for mattresses, taking into account two key points: to be as much automatised as possible, and to maximizes dust extraction. They have implemented several technologies, as sensors, robotics, etc. to create their own equipment for the complete process of sorting, dissembling, classification, and even to produce a new foam from the processes foam waste: Aslon Refoam. Aslon Refoam have resulted in a high-quality solution for the secondary raw material flow foam that results from recycling discarded mattresses. Currently, it is used as underlayment for falling surfaces in parks, playgrounds, and sports fields.	[71]
Bollegraaf	Bollegraaf Recycling Machinery BV	Decades of experience with household waste and plastic recycling have made Bollegraaf Recycling Solutions. The company is a leader in process, technology & automation and robotics; developments in which it invests continuously and intensively. Bollegraaf is increasingly adding a new dimension to their globally recognised pioneering role in recycling. The recycling company created a world of difference for and with their clients. The machines are not only manufactures to do sustainable work, they are 'green' themselves. The devices are painted with water-based paint and have the lowest power consumption possible.	[72]

Table 5. *Cont.*

Product Name	Company	Description	Reference
Optibat RTO	Optimitive SL	OPTIBAT is a product based on AI that, connected to the control system of an industrial process (cement, chemist, paper, or energy sectors), reads the process data, learns from them and makes optimal adjustments to it on automatic pilot, achieving maximum efficiency in the operation of the process. Its objective is to optimise the efficiency and sustainability of the process, maximising production and quality, minimising energy consumption, and ensuring the stability and availability of the process.	[73]
SEGARA	Segara Environmental Consulting, SL	SEGARA automates the management of the carbon footprint through 4.0 technologies, such as Big Data. The developed software performs the integral calculation of the carbon footprint with scopes 1 and 2 according to the GHG Protocol and the ISO 14064 standard.	[74]
AEVAE	Spanish Association for the Valorisation of Containers, AEVAE	AEVAE has developed an innovative system to trace the full circle of the plastic material (HPDE and LPDE) to re-manufacture new packaging for the agricultural sector. In collaboration with a Blockchain-based asset traceability platform, a new system has been developed that allows, not only to uniquely identify the waste, but to incorporate its characteristics and geolocation into the Blockchain, allowing its monitoring in an agile, secure, and unalterable way by all agents, whether they are manufacturers, packers or distributors, involved in the management of waste originated in production processes. The new system allows manufacturers to incorporate the benefits of this technology into these environmental management processes and thus promote the impact of the systems that seek to guarantee compliance with the responsibility associated with the manufacture of fertilizers and associated products. The traceability and transparency offered by Blockchain, together with the fact that it is a PaaS (Platform as a Service) solution accessible by all actors, helps to know exactly the entire process through which a waste passes, ensuring that it complies with the international regulations and facilitating its traceability by all parties involved in the process.	[75]
RecySmart	Recircula Solutions S.L.	RecySmart is the IoT technology that allows citizens to recognise recycled packaging through AI. Citizens will use the RecySmart Citizen app or RFID cards to log in to RecySmart and begin the recycling process. Once logged in, they can deposit the items one by one (glass, plastic bottles, metal cans, and cardboard containers) in the corresponding container. The RecySmart device identifies each container using techniques with artificial intelligence algorithms in real time. For each container, citizens accumulate points that can be exchanged for money refunds, vouchers, or any other form of incentive managed by the local authority or third parties such as large brands, local businesses, etc. All information is sent to a server so that it is reflected in the Waste Platform Management, including the filling level of the containers. Thanks to this, third parties—city authorities, brands, businesses—can offer incentives motivating citizens' behaviour to increase recycling rates up to 20–30% and meet EU recycling targets.	[76]

4. Discussion

R&D projects, patents and commercial solutions were classified according to the implemented KET and addressed industry sectors, obtaining that several projects were focused also on training for the twin transition, and not in technological development of new solutions.

The analyses show that five technologies (robotic, big data, AI, IoT, and AM) are applied to a greater extent as key enablers to achieve a twin transition than rest of KET technologies analysed in Table 1. Moreover, it has been detected that there are specific sectors where the twin transition has achieved a faster velocity of implementation than others. Moreover, it also has been identified some projects that are focused on up and reskilling workforce on how to implement I4.0 technologies to boost CE within the industry. Table 6 summarises the relation of all R&D projects, patents, and commercial solutions already mentioned with the I4.0 technologies applied, distributed by industry sectors, and also those focused on I4.0 training.

Table 6. Analysed R&D projects, patents and commercial solutions classified per KET applied and industry sector, and those focused on training.

	Robotic	Big Data	AI	IoT	AM	Training
Energy		CN110138877A		CN110138877A		
Automotive & aviation	SUSTAINair	Digital twins & Csense	Digital twins & Csense	SUSTAINair		
Waste management	RoCycle RetourMatras	WASTE4think BURBA RecySmart	WASTE4think RoCycle AEVAE	WASTE4think BURBA RetourMatras RecySmart		
Construction	CN103276910A	SABINA	BIM2TWIN	SABINA		
Electrical and Electronic		C-SERVEES		C-SERVEES		
Multisectorial	Bollegraaf	Circulor SEGARA	16/998366 Optibat RTO SEGARA	16/998366 Circulor		DigiCirc DigiVIP Single Market & Competition Circular4.0
Mobility			AU2021101897A4	AU2021101897A4		
Furniture					Ohmie	SAWYER
Textile				CN109981791A		

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. From the analysed R&D projects, patents, and commercial solutions other identified industry sectors are automation and aviation, where two projects are focused on the improvement of the circularity of its value chain, reducing waste and improving its energy efficiency; the construction sector, with different R&D projects focused mainly on increasing energy efficiency through I4.0 technologies; the electrical and electronic sector, the implementation of Big Data and IoT as drivers to offer eco-innovative services has been studied; the mobility sector is clearly impacted by IoT and AI that allow drivers and traffic managers to find the best route, creating new opportunities for developing a sustainable and intelligent mobility system, and finally, other manufacturing sectors, such as furniture and textile, where IoT and AM has been used as enablers of eco-design principles and to reduce waste generation in production processes.

In addition, several solutions that are applied at a multisectoral level have been identified that aim to improve the circularity and efficiency of the different value chains. Through the implementation of AI and IoT technologies they improved the current techniques of life cycle, footprint and waste estimations and management.

Finally, several R&D projects are currently focused on improving competencies and skills in general twin transition concepts and techniques within SMEs, through different train and mentoring initiatives. These projects are aligned with different EU policies and strategies on re and up-skilling current and future workforce on digital and green competencies.

5. Conclusions

As conclusion of this research a set of recommendations for the improvement of the twin digital and green transition are proposed as a guide for policymakers, researchers, and industry managers on how to foster the CE through the implementation of I4.0, ensuring that the society reaches a sustainable and smart industry model. Recommendations, summarized in Figure 2, are classified according to three complemented levels of potential performance, following the three key aspects analysed in Table 6 as result of the R&D projects, patents, and commercial solutions analysis: industry sectors, KET, and training. Thus, final recommendations are classified at industry, technological, and knowledge level. For each operational category or level, it has been set two concatenated recommendations, allowing all actors to follow a logic order on their implementation.

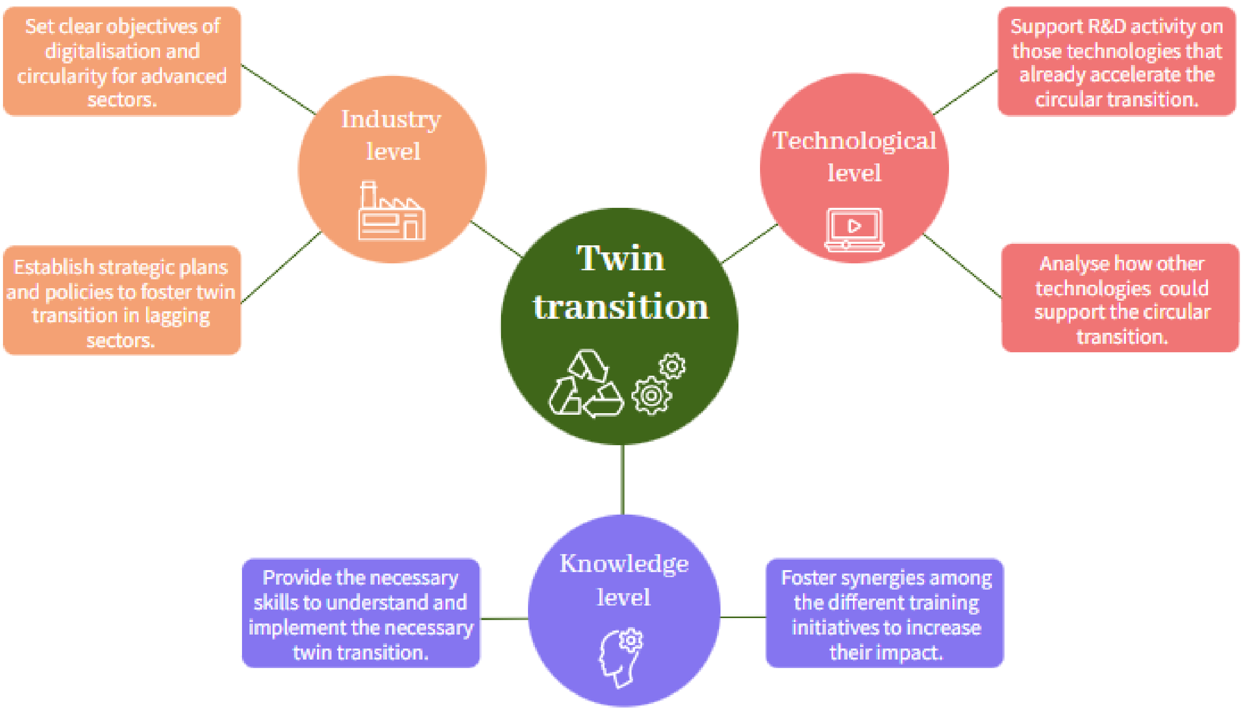

Figure 2. Recommendations to achieve a successful twin transition.

At the industry level, it has been established recommendations with two objectives: to boost the twin transition in those sectors where I4.0 technologies have been already introduced to a greater extent with green purposes, and to foster their implementation in those sectors less advanced. Thus, the two concatenated recommendations are:

- Set clear objectives of digitalisation and circularity for those advanced sectors (waste management, automotive and aviation, construction) to spread this process, and extend to the whole European system the already achievements.

- Establish new strategic plans and policies to foster the twin transition in manufacturing, energy, electrical and electronic, and mobility industry sectors, and set new specific funding programs for these sectors.

At the technological level, it has been detected that some I4.0 technologies are more implemented to achieve a more sustainable industry, reducing waste generation, and increasing energy efficiency. The following recommendations are intended to transfer these technologies across the industry system while exploring the green potential of other I4.0 technologies, with the goal of ensuring the development of the necessary technologies for an efficient twin transition.

- Support R&D activity on those technologies that already accelerate the circular transition (Big Data, AI, IoT, Robotic, and AM) with the aim to continue fostering the digitalisation of the industry while achieving sustainable goals.
- Analyse how other technologies currently not or less applied could support the circular transition in different industry sectors and foster them through strategic and funding plans.

At the knowledge level, different initiatives have been analysed that aim to improve the knowledge of workers and managers on the necessary digital and green skills for a successful twin transition. Following recommendations, aligned with analysed initiatives and EU industry policy [16], aim to guarantee a smooth twin transition, allowing all actors of the different industry value chains to acquire the necessary skills and competences,

- Launch new initiatives to provide the necessary skills and competencies to workers and managers of different industry sectors to understand and implement the necessary twin transition, through the application of I4.0 technologies and CE strategies.
- Foster synergies among the different training initiatives to increase their impact, for instance through a Centres of Vocational Excellence (CoVE) [77] focused on the twin transition.

Finally, aligned with detailed conclusions and recommendations, authors suggest that further actions should analyse how the different I4.0 technologies could foster CE practices, by a detailed research on each of the I4.0 technologies, and how to cover industry knowledge gaps and transfer the necessary knowledge through Vocational Education and Training (VET) and/or Higher Education (HE) programmes focused on twin digital and green transition, as currently most of the industry is not prepared for such transformation.

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References

1. European Commission. *Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions-The European Green Deal*; COM(2019) 640 Final; European Commission: Brussels, Belgium, 2019. Available online: https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1588580774040&uri=CELEX%3A52019DC0640 (accessed on 20 May 2021).
2. Ellen MacArthur Foundation. *Towards a Circular Economy: Business Rationale for an Accelerated Transition*; Ellen MacArthur Foundation: Cowes, UK, 2015.
3. Bag, S.; Yadav, G.; Dhamija, P.; Kataria, K.K. Key resources for industry 4.0 adoption and its effect on sustainable production and circular economy: An empirical study. *J. Clean. Prod.* **2020**, *281*, 125233. [CrossRef]
4. Romero-Gazquez, J.L.; Canavate-Cruzado, G.; Bueno-Delgado, M.-V. IN4WOOD: A Successful European Training Action of Industry 4.0 for Academia and Business. *IEEE Trans. Educ.* **2021**, 1–10. [CrossRef]
5. European Commission. *Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions—A European Strategy for Key Enabling Technologies—A Bridge to Growth and Jobs*; COM(2012)341 Final; European Commission: Brussels, Belgium, 2012. Available online: https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=celex:52012DC0341 (accessed on 15 May 2021).
6. Cañavate, G.; Moreno, F.; Bueno, M. Modernizing the Vocational Educational Training in the field social sciences and humanities towards the Key Enabling Technologies in the digital transformation. In Proceedings of the 12th International Conference on Education and New Learning Technologies (EDULEARN20), Online Conference, 6–7 July 2020; pp. 8125–8132. [CrossRef]
7. Martinelli, A.; Mina, A.; Moggi, M. The enabling technologies of industry 4.0: Examining the seeds of the fourth industrial revolution. *Ind. Corp. Chang.* **2021**, *30*, 162–188. [CrossRef]
8. Mabkhot, M.M.; Ferreira, P.; Maffei, A.; Podržaj, P.; Mądziel, M.; Antonelli, D.; Lanzetta, M.; Barata, J.; Boffa, E.; Finžgar, M.; et al. Mapping Industry 4.0 Enabling Technologies into United Nations Sustainability Development Goals. *Sustainability* **2021**, *13*, 2560. [CrossRef]
9. Mubarok, K. Redefining Industry 4.0 and its Enabling Technologies. In Proceedings of the International Conference on Science and Technology, Surabaya, Indonesia, 17–18 October 2019; Volume 1569. [CrossRef]
10. Rocca, R.; Costa, P.; Sassanelli, C.; Fumagalli, L.; Terzi, S. Industry 4.0 solutions supporting Circular Economy. In Proceedings of the International Conference on Engineering Technology and Innovation (ICE/ITMC), Cardiff, UK, 15–17 June 2020. [CrossRef]
11. Tronchoni, D.; Brennan, G. Industry 4.0: A Key Enabler of the Circular Economy, Climate Innovation Insights, Series 2, No. 7, EIT-Climate KIC. Available online: https://www.climate-kic.org/insights/industry-4-0-a-key-enabler-of-the-circular-economy/ (accessed on 13 November 2021).
12. Berg, H.; Bendix, P.; Jansen, M.; Le Blévennec, K.; Botterman, P.; Magnus-Melgar, M.; Pohjalainen, E.; Wahlström, M. *Unlocking the Potential of Industry 4.0 to Reduce the Environmental Impact of Production*; European Environment Agency, European Topic Centre on Waste and Materials in a Green Economy: Mol, Belgium, 2021.
13. Blunck, E.; Werthmann, H. Industry 4.0—An Opportunity to Realize Sustainable Manufacturing and its Potential for a Circular Economy. In Proceedings of the 3rd Dubrovnik International Economic Meeting (DIEM), Dubrovnik, Croatia, 12–14 October 2017; pp. 644–666.
14. Le Moigne, R. The Power of Digital Technologies to Enable the Circular Economy. 2021. Available online: https://medium.com/circulatenews/the-power-of-digital-technologies-to-enable-the-circular-economy-5471d097ee7f (accessed on 10 October 2021).
15. Rosa, P.; Sassanelli, C.; Urbinati, A.; Chiaroni, D.; Terzi, S. Assessing relations between Circular Economy and Industry 4.0: A systematic literature review. *Int. J. Prod. Res.* **2019**, *58*, 1662–1687. [CrossRef]
16. European Commission. *Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions—A New Industrial Strategy for Europe*; COM(2020) 102 Final; European Commission: Brussels, Belgium, 2020. Available online: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52020DC0102 (accessed on 18 May 2021).
17. Ortega Gras, J.J.; Garrido Lova, J.; Muñoz Puche, A.; Mouazan, E.; Gómez Gómez, M.V.; Rodriguez Fuentes, J.; Rajala, A. Joint Curriculum Design on Circular Economy Practices Within the Furniture Industry for a Vocational Education Training. In Proceedings of the 15th International Technology, Education and Development Conference, Online Conference, 8–9 March 2021; pp. 1227–1237.
18. Spanish Association for Standardisation (UNE). R&D&i Management: Technological Watch and Competitive Intelligence System. 2011. Available online: https://www.une.org/encuentra-tu-norma/busca-tu-norma/norma?c=N0046930 (accessed on 25 May 2021).
19. Web of Science Home Page. Available online: https://www.webofscience.com/wos/woscc/basic-search (accessed on 2 June 2021).
20. Scopus Home Page. Available online: https://www.scopus.com/home.uri (accessed on 6 June 2021).
21. CSIC Database Home Page. Available online: https://indices.csic.es/ (accessed on 18 May 2021).
22. Dialnet Plus Home Page. Available online: https://dialnet.unirioja.es/ (accessed on 25 May 2021).
23. Google Scholar Home Page. Available online: https://scholar.google.es/schhp?hl=es (accessed on 14 June 2021).
24. Academia Home Page. Available online: https://www.academia.edu/ (accessed on 16 June 2021).
25. Espacenet Home Page. Available online: https://worldwide.espacenet.com/ (accessed on 21 June 2021).

26. United States Patent and Trademark Office (USPTO) Home Page. Available online: https://www.uspto.gov/ (accessed on 22 June 2021).
27. Japan Patent Office Home Page. Available online: https://www.jpo.go.jp/e/ (accessed on 23 June 2021).
28. World Intellectual Property Organization (WIPO) Home Page. Available online: https://www.wipo.int/portal/en/index.html (accessed on 23 June 2021).
29. Google Patents Home Page. Available online: https://patents.google.com/ (accessed on 19 June 2021).
30. The Lens Home Page. Available online: https://www.lens.org/ (accessed on 25 June 2021).
31. Cordis Europa Home Page. Available online: https://cordis.europa.eu/es (accessed on 28 June 2021).
32. Interreg Europe Home Page. Available online: https://www.interregeurope.eu/ (accessed on 30 June 2021).
33. European Commission. IPA Cross-Border Cooperation Programmes. Available online: https://ec.europa.eu/regional_policy/en/funding/ipa/cross-border/ (accessed on 30 June 2021).
34. Keep. Interreg, Interreg-IPA, ENI, and IPA-IPA Cross-Border. Available online: https://keep.eu/home/ (accessed on 1 July 2021).
35. European Commission. European Investment Project Portal (EIPP): Using the Portal is now Easier than Ever. Available online: https://ec.europa.eu/investeuportal/desktop/en/index.html (accessed on 2 July 2021).
36. LIFE Public Database. Available online: https://webgate.ec.europa.eu/life/publicWebsite/index.cfm (accessed on 2 July 2021).
37. ERASMUS+ Project Results. Available online: https://ec.europa.eu/programmes/erasmus-plus/projects_en (accessed on 3 July 2021).
38. European Circular Economy Stakeholder Platform. Available online: https://circulareconomy.europa.eu/platform/ (accessed on 2 July 2021).
39. Eurostat Database. Available online: https://ec.europa.eu/eurostat/data/database (accessed on 5 July 2021).
40. AMECO Database. Available online: https://ec.europa.eu/info/business-economy-euro/indicators-statistics/economic-databases/macro-economic-database-ameco/ameco-database_en (accessed on 4 July 2021).
41. EUR-Lex Home Page: EU Law. Available online: https://eur-lex.europa.eu/homepage.html?locale=en (accessed on 8 July 2021).
42. Advanced Technologies for Industry. Available online: https://ati.ec.europa.eu/ (accessed on 10 July 2021).
43. European Commission. *Annex to the Communication to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions—The European Green Deal. Roadmap—Key Actions*; COM(2019) 640 Final; European Commission: Brussels, Belgium, 2019. Available online: https://ec.europa.eu/info/sites/default/files/european-green-deal-communication-annex-roadmap_en.pdf (accessed on 25 May 2021).
44. European Commission. *Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee of the Regions—Shaping Europe's Digital Future*; COM(2020) 67 Final; European Commission: Brussels, Belgium, 2020. Available online: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52020DC0067 (accessed on 7 July 2021).
45. European Commission. *Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee of the Regions—A New Circular Economy Action Plan—For a Cleaner and More Competitive Europe*; COM(2020) 98 Final; European Commission: Brussels, Belgium, 2020. Available online: https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1583933814386&uri=COM:2020:98:FIN (accessed on 14 May 2021).
46. European Commission. *European Commission Decision-Horizon Europe. Work Programme 2021–2022. 7 Digital, Industry and Space*; C(2021) 7804; European Commission: Brussels, Belgium, 2021. Available online: https://ec.europa.eu/info/funding-tenders/opportunities/docs/2021-2027/horizon/wp-call/2021-2022/wp-7-digital-industry-and-space_horizon-2021-2022_en.pdf (accessed on 30 October 2021).
47. European Parliament and the Council of the European Union. *Regulation (EU) 2021/783 of the European Parliament and of the Council of 29 April 2021 Establishing a Programme for the Environment and Climate Action (LIFE) and Repealing Regulation (EU) No 1293/2013*. Official Journal of the European Union L 172/53, 2021. Available online: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32021R0783&from=EN (accessed on 14 May 2021).
48. European Commission. *Annex to the Commission Implementing Decision on the Adoption of the Multiannual Work Programme for the Years 2021–2024 for the LIFE Programme*; C(2021) 4997 Final; European Commission: Brussels, Belgium, 2021. Available online: https://ec.europa.eu/info/funding-tenders/opportunities/docs/2021-2027/life/wp-call/2021-2024/wp_life-2021-2024_en.pdf (accessed on 12 September 2021).
49. European Commission. *Commission Delegated Regulation 2019/856 of Supplementing Directive 2003/87/EC of the European Parliament and of the Council with Regard to the Operation of the Innovation Fund*. Official Journal of the European Union L 140/6, 2019. Available online: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32019R0856&from=EN (accessed on 12 September 2021).
50. DigiCirc Project. Available online: https://digicirc.eu (accessed on 6 September 2021).
51. DigiVIP Project. Available online: https://ec.europa.eu/programmes/erasmus-plus/projects/eplus-project-details/#project/2020-1-TR01-KA226-HE-098393 (accessed on 11 July 2021).
52. SUSTAINair Project. Available online: https://www.sustainair.eu (accessed on 6 September 2021).
53. Single Market & Competition Law in the Digital and Ecological Transition Era Project. Available online: https://ec.europa.eu/programmes/erasmus-plus/projects/eplus-project-details/#project/620517-epp-1-2020-1-es-eppjmo-chair (accessed on 6 September 2021).

54. Circular4.0 Project. Available online: https://www.alpine-space.eu/projects/circular4_0/en/home (accessed on 6 September 2021).
55. SAWYER. Available online: https://circularfurniture-sawyer.eu (accessed on 6 September 2021).
56. C-SERVEES. Available online: https://c-serveesproject.eu (accessed on 6 September 2021).
57. SABINA Project. Available online: https://sabina-project.eu (accessed on 6 September 2021).
58. BIM2TWIN Project. Available online: https://bim2twin.eu (accessed on 6 September 2021).
59. WASTE4think Project. Available online: https://waste4think.eu (accessed on 6 September 2021).
60. BURBA Project. Available online: https://cordis.europa.eu/project/id/265177 (accessed on 6 September 2021).
61. RoCycle Project. Available online: https://www.csail.mit.edu/news/robots-can-sort-recycling (accessed on 6 September 2021).
62. Bradley, R.; Jawahir, I. Innovative Manufacturing Methods for Next-Generation Products, Processes, and Systems. U.S. Patent 16/998366, 25 February 2021.
63. Zhijun, P.; Bo, P.; Weiguo, H.; Jianzhong, S.; Bangpeng, X.; Wenkai, Z.; Jialin, W.; Xiaopeng, L.; Jing, G.; Yang, W.; et al. Energy monitoring method based on big data intelligent analysis technology and energy cloud platform. Patent CN 110138877A, 16 August 2019. Available online: https://worldwide.espacenet.com/patent/search/family/067583244/publication/CN110138877A?q=pn%3DCN110138877A (accessed on 11 August 2021).
64. Dingqi, T.; Duozhang, Y.; Yinbin, W.; Guibao, Z.; Xuewu, Z. Wallboard assembling robot. Patent CN 103276910A, 20 May 2013. Available online: https://worldwide.espacenet.com/patent/search/family/049059516/publication/CN103276910A?q=pn%3DCN103276910A (accessed on 11 August 2021).
65. Priyanka, D.; Bhawana, P.; Arundhati, A.; Uday, C.; Kavita, C. A Machine Learning and IOT Based System for Intelligent Routing. Patent AU 2021101897A4, 3 June 2021. Available online: https://worldwide.espacenet.com/patent/search/family/076132922/publication/AU2021101897A4?q=pn%3DAU2021101897A4 (accessed on 11 August 2021).
66. Yingchen, Z.; Hongyan, W.; Xianan, Z.; Ruonan, Y.; Li, X.; Tian, W.; Luning, T.; Yan, J. Internet of Things System and Method for Waste Selvage. Patent CN 109981791A, 5 July 2019. Available online: https://worldwide.espacenet.com/patent/search/family/067083408/publication/CN109981791A?q=pn%3DCN109981791A (accessed on 11 August 2021).
67. GE Digital. Available online: https://www.ge.com/digital/applications/digital-twin (accessed on 11 August 2021).
68. Circulor. Available online: https://www.circulor.com (accessed on 11 August 2021).
69. Circular Economy Stakeholder Platform, Good Practices. Available online: https://circulareconomy.europa.eu/platform/en/good-practices/volvo-cars-ev-battery-materials-traceability (accessed on 11 August 2021).
70. Ohmie. Available online: https://www.ohmie-krilldesign.net (accessed on 11 August 2021).
71. RetourMatras. Available online: https://www.retourmatras.nl (accessed on 11 August 2021).
72. Bollegraaf. Available online: https://www.bollegraaf.com (accessed on 11 August 2021).
73. Optimitive. Available online: https://optimitive.com/solutions (accessed on 11 August 2021).
74. Segara. Available online: https://segara.io/es (accessed on 11 August 2021).
75. AEVAE. Available online: https://www.aevae.net/tecnologia-blockchain-en-aevae (accessed on 11 August 2021).
76. Recircula Solutions. Available online: https://recirculasolutions.com (accessed on 11 August 2021).
77. European Commission, Centres of Vocational Excellence. Available online: https://ec.europa.eu/social/main.jsp?catId=1501 (accessed on 6 September 2021).