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Enabling the Twin Transition of the SMEs:
digital paradigms of Industry 4.0, Lean and Circular principles as enablers of SDGs 8, 9 and 12

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ABSTRACT

This study has the aim to detect and analyse the cause and effect relationships in an Industry 5.0 framework, between the digital paradigms of Industry 4.0 (I4.0), enabled by Key Enabling Technologies (KETs) and the targets of three Sustainable Development Goals (SDG), permeated by Lean Manufacturing (LM) and Circular Economy (CE) principles. The SDGs in question belong to the ones linked to the Economical dimension, according to the division of the Stockholm Resilience Centre and they are number 8, “Decent Work and Economic Growth”, number 9 “Industry, Innovation and Infrastructure” and number 12, namely “Responsible Production and Consumption”, that will be called “SME SDGs” from now on.

The current body of literature on the topic, investigated through a systematic literature review (SLR), presents very few quantitative analysis and an high rate of academics involvement, but a very low one of industrial players. In order to fill the identified research gaps, the TwinSME Model has been proposed. The work has been performed by applying a mathematically rigorous process, the Fuzzy version of the DEMATEL multicriteria method. In addition, the analysis has been conducted by exploiting the technological and commercial hands-on experience of production, logistic, marketing and IT managers of organizations that produce and/or commercialize 4.0 technologies for the SMEs of Piedmont and Valle d’Aosta. They have been selected from the Piedmont Digital Innovation Hub database dedicated to technology providers. They joined Canva applicative sessions articulated in two phases: a preliminary reasoning about the digital enabling power of the KET produced or commercialized by the vendor and the filling of the Fuzzy DEMATEL matrix, created by the author. The factors present in the matrix are twelve: seven digital paradigms of I4.0, the three selected SDGs, one factor related to the 9 R of the CE framework and one last criterion representing the Seven Wastes of LM. Applying the DEMATEL method, an Influential Relation Map (IRM) has been got, which is a graph that enlightens the cause-effect relationships between the previously listed factors. It was possible to formalize the net positive effect of digital factors on SDG targets achievement and the bridging role of Lean and Circular techniques.

At the end, the results have been depicted in the IDEF0 representation of the TwinSME Model that may support entrepreneurs in choosing a mix of digital investments, LM and CE principles, that can favor the Twin Transition of his/her SME, by selecting a specific SDG as strategic driver, aiming for sustainable competitiveness.

INTRODUCTION

The academics and politicians are increasingly being called upon to increase focus and awareness about the Twin, Digital&Green, enabling power of the Key Enabling Technologies (KETs) of 4.0. On the contrary, the SMEs knowledge on Twin Transition and Industry 5.0 factors is still limited, hence the aim of this study is to analyse the chances of a Small and Medium Enterprise (SME) in gaining a sustainable competitive advantage through the adoption of Lean and Circular approaches and with a particular attention to Human needs for the achievement of SDGs of Agenda 2030.

It should be stressed out that a company is able to reach a competitive advantage and to sustain it over time when it is able to generate value and to appropriate it. Sustainable competitiveness is the type of competitiveness which the thesis points at and it stands for “the ability to generate and maintain wealth without diminishing the capability of future generations to sustain or increase current wealth levels” (Zehua, et al., 2023).

In the previous century, the value was commonly measured through economic metrics, such as profit over revenues or economic returns on capital invested or on total assets, but the economic value is not the only one that matters. The Twin Transition introduces a more sophisticated idea of value creation, the success of a company depends on other two types of metrics, the environmental and social ones. The Triple Bottom Line (TBL) model states that a sustainable success exists only when economic, environmental and social dimensions are holistically accomplished (Bianchini, et al., 2023).

It should be considered that companies have difficulty in having a complete vision of the impact of their digital investments, it is clear for them the economic advantage they can bring, but not the sustainable effect on the SME organizatiosn, because there is no single and universal standard for such a performance (Chen, et al., 2022).

The following section details the methodology followed in this research, summarized in Figure 1:

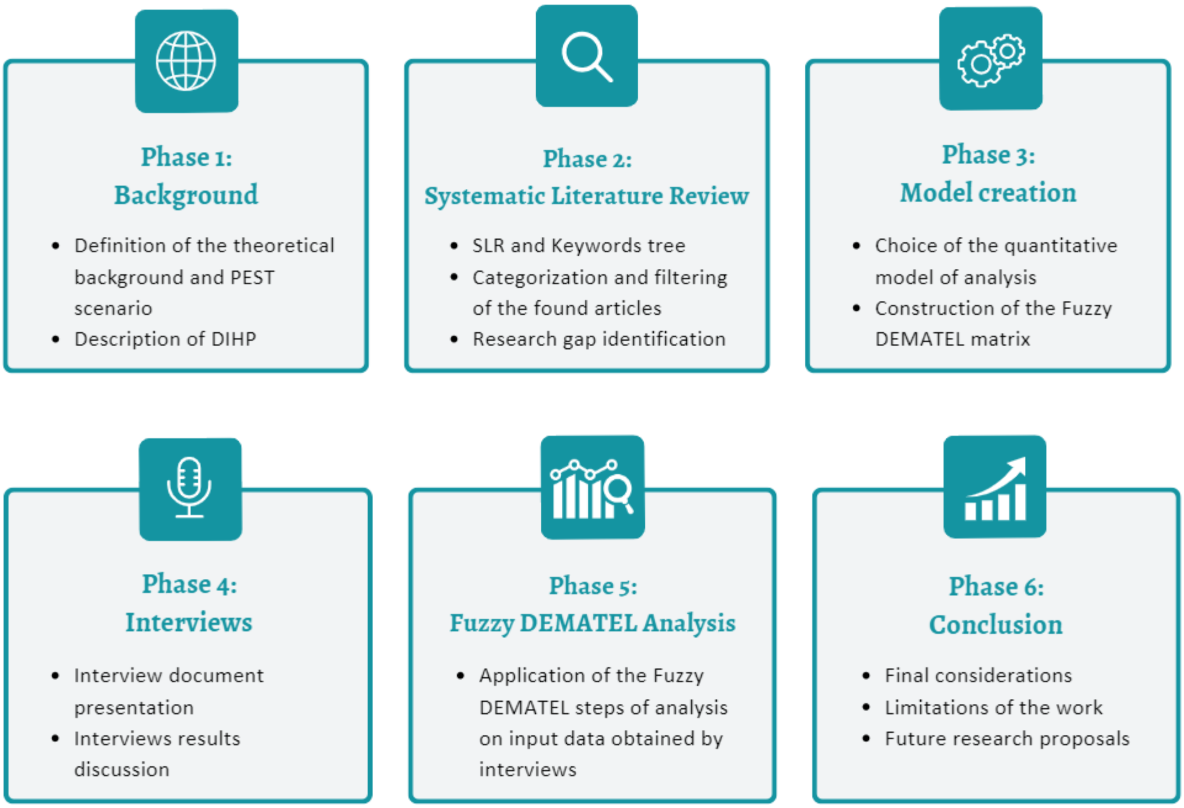


Figure 1: Phases of the applied methodological flow

In **phase 1**, corresponding to “**Background**” section, it was established the basic elements for this research and the theoretical framework. It shows the main governmental interventions at national and European level to sustain the Twin digital&green Transition, in such a way to define the PEST (political, economic, social and technological) scenario in which the study is collocated. A specific section is dedicated to the description of the role on the Piedmont territory of the no profit organization, Digital Innovation Hub Piemonte (DIHP) in which the author made her internship experience and from which information and contacts for the interview work of Chapter 4 have been obtained.

In **phase 2**, corresponding to “**Systematic Literature Review**” section, a SLR has been conducted by following the Snowballing procedure. The aim was to analyse the literature AS-IS situation about the mapping of the effects of KET on SDG targets achievement and defining as result a research gap.

In **phase 3**, corresponding to “**Model creation**” part, it was presented the choice of the quantitative methodology of analysis, that has resulted to be the Fuzzy DEMATEL framework and it was presented step by step the reasoning behind the choice of each digital and sustainable dimension that populates the matrix. It is then presented also the IDEF0 representation, called **TwinSME Model**, in which the obtained results will be shown in

Chapter 5 in a schematic and clear way. For the construction of the model the results of DRA (Digital Readiness Assessments) conducted by DIHP and SLR results have been used.
In **phase 4**, corresponding to "**Canva Applicative Sessions**" chapter, it was presented the consensus-based quantitative assessment conducted with fourteen technology providers of the territory and the results mapping of their contributions has been presented and discussed.
In **phase 5**, corresponding to "**Fuzzy DEMATEL Analysis and TwinSME Model Creation**" chapter, the Fuzzy DEMATEL methodology has been applied by using as input data the matrixes filled during the Canva sessions and the results of the analysis have been schematized in the IDEF0 TwinSME Model.
The **phase 6** corresponds to the final chapter, namely "**Conclusion**", where there are the final considerations, the list of academic and managerial contributions and the discussion of the limitations of the work with proposals of future research.

The thesis provides a foundation for the systematic exploration of the sustainable influence of the most adopted I4.0 technologies on the achievement of the "SME SDGs" from the perspective of technology providers. The study suggests that pursuing technological innovation, with particular attention to Lean Manufacturing, Circular Economy and Human needs, SMEs are capable of gaining a sustainable competitive advantage in the Twin Transition context, by affirming the strong effect of KETs on SDGs targets achievement. The model can assist industry experts, practitioners, and managers to understand which KETs should be adopted by organizations to support SDGs with their businesses.

CHAPTER 1

1. Theoretical Background

This chapter is aimed at describing the historical events, governmental policies and technical innovations that constitute the PEST (political, economic, social and technological) scenario in which the thesis has been written.
The theoretical background consists of three sections: Digital Transition (Section 1.1), Green Transition (Section 1.2) and Twin Transition (Section 1.3), in such a way to describe the role of the first two in the third Twin framework and present all the elements that play a role in the Industry 5.0 framework.

1.1. Digital Transition

The *Revolution* word derives from Latin term "Revolutio", that indicates a radical change in the social or technological structure of a society. Any type of Revolution is the answer to a social and/or technological diffused need [1]. The Industrial Revolution can be considered as the transition from traditional industrial practices to new techniques dominated by new technologies, resulting from incremental or disruptive innovations. Each revolution included the usage of new materials, energy sources, invention of new machines, new work organizations and the development of a new technological mindset. In the following a brief timeline of the Industrial Revolutions that preceded the one in which we are living.
The **First Industrial Revolution** (1780-1830) took the greatest changes in England working society, particularly in textile industry. It was the revolution of "Mechanization", through which in 50 years, the figure of the farmer that worked only with his hands transformed into the one of a firm laborer whose working life depended upon carbon machineries. One of the slogan of this period was "I can think of nothing else than this machine" by James Watt (Letter to Dr Lind, 29-04-1765), one of the protagonist of this Revolution that elected the Machine as the beating heart of the rising cities.
The **Second Industrial Revolution** (1850-1914) was the so called "Electrification" Revolution, new energy sources gave birth to new production systems like the assembly line. Alienation of workers because of repetitive tasks and mass production played a big role in this period, where the standardization of the products in favour of efficiency overcame the importance of real satisfaction of customers. A self-explanatory example is the famous sentence by Henry

Ford: “Any customer can have a car painted any color that he wants, so long as it is black” [B1].

The **Third Industrial Revolution** has conventionally started at the beginning of fifties. It is considered the Digital Revolution, characterized by technological inventions of the two World Wars, that led to partial automation of production and supply chains. For what regard the productive approach, the “Just in Time” by Toyota took the place of the standard productive mechanism of West Europe. Information increased its importance and new “Information Society” was born, permeated by radio, tv, PC and Internet flows of information.

This evolutive timeline describes in brief the route that led to the **Fourth Industrial Revolution**, passing through the machine culture of the second one, the standardization focus of Henry Ford, and the post II World War information empowerment. The Fourth Revolution, also known as **Industry 4.0**, is based on Cyber-Physical Systems (CPS). A usually accepted definition in the past of these systems refers to systems where software and hardware components are deeply intertwined, they are the integration of computation with physical processes. Nowadays, cyber-physical systems are considered the next stage in the continuous evolution of functions integration and in these last years, twin models, simulations, smart analytics and self-awareness technologies have been added to the set. They essentially enable the communication of the industrial systems, by networking them (Abdullah , et al., 2023).

A slightly difference between the fourth one and the previous revolutions is the fact that the last is not specifically based on inventions, but on a change of paradigm around the usage of technology in factories, the interconnection between the different elements is the crucial point. Industry 4.0 is considered a portfolio of solutions and combinations of new and old technologies that allows to transform each single element of the supply chain in a real-time data generator. Data have to be managed with the goal to digitalize, automatize and improve processes and performances.

The 4.0 Evolution can be considered an holistic process, on one hand it can embrace the factory as a whole, but on the other there is no a specific set of solutions that an entrepreneur has to adopt to transform its firm in a 4.0 company. The entrepreneur has to be helped by specific associations or consulting bodies to detect which enabling technologies reflect his/her strategic goals the most and to find the best way to interconnect them.

Key digital Enabling Technologies (KETs) of 4.0 are crucial, but they are not the I4.0 itself, they are its enablers. In this paper these technologies are also called pillars or building blocks of I4.0 or more frequently Enablers (E) due the semantic meaning of this word, they indeed support the realization of I4.0 which is not only about technology. It is better to be defined as a new philosophy of manufacturing, characterized by a new frontier of the interaction between human and machines. The organizations become intelligent environments with a technological backbone that have to enable the 3C “control, communication and computation”.

Industry 4.0 was brought to life as concept and as a term in 2011 at Hannover MESSE, where Bosch described the widespread integration of information and communication technology in the industrial production and its meaning was then consolidated in 2016 by Klaus Schwab as a part of the German industrial strategy.
The aim of this fourth industrial revolution is to achieve competitive advantage and higher operational efficiency. The success is measured by economical metrics or indexes, like amount of revenues, operating margin, return on capital invested. As Rehman paper (et al, 2023) sustains, Manufacturing businesses with higher technological aptitude can utilise these technological developments to enlarge market share and improve competitiveness through innovation, cost reduction, and productivity.
The digital transition is an ongoing process that is shaping the future of societies and economies [2], but the rules of the game are going to change, because a New Revolution is coming.
The world is indeed poised for the next big leap, the fifth Revolution, whose main elements are presented in Section 1.3.

1.2. Green Transition

In 1949, the United Nations Scientific Conferences on Conservation and Utilization of Resources took place in New York State. As it was the UN's first attempt to address and prevent further damage from natural resource depletion caused by exploitation, this conference was a milestone for all mankind [3].
The Green Transition, as all the previous Industrial Revolution, is a "radical transformation that comes out as a response to a number of persistent problems confronting contemporary modern societies" (Chatzistamoulou, et al., 2023).
Sustainability was originally defined by the World Commission on Environment and Development in 1987 as "The development which meets the needs of the present without compromising the ability of future generations to meet their own needs". Then its definitions evolved over the years, by embracing always a broader concept. United Nations defines sustainability as a movement for ensuring a better and more sustainable wellbeing for all, including the future generations, which aims to address the everlasting global issues of injustice, inequality, peace, climate change, pollution, and environmental degradation.
The rich literature about the topic favoured the definition of the three sustainable pillars: environmental, economic, and social sustainability. Environmental sustainability is mainly concerned with maintaining the earth's environmental systems equilibrium, the balance of natural resources consumption and replenishment (Glavič and Lukman, 2007). Economic sustainability concerns long-term economic growth while preserving environmental and social resources, not be at the expense of the decrease in natural or social capital (Choi and

Ng, 2011). Social sustainability is the process of recognizing and managing the positive and negative business, environmental, economic, and technological impacts on people (Dempsey et al., 2011).

Sustainable Manufacturing can be defined as the integration of processes and systems capable to produce high quality products and services using less and more sustainable resources (energy and materials), being safer for employees, customers and communities surrounding, and being able to mitigate environmental and social impacts throughout its whole life cycle (Machado et al., 2020).

In the green transition panorama, ESG principles play a big role. ESG stands for **Environmental, Social and Governance** and it implies a set of sustainability-oriented guidelines that provide a framework for monitoring and evaluating sustainability performance and opportunities of a business. Environmental issues may include corporate climate policies, energy use, waste, pollution, natural resource conservation, and treatment of animals. Social aspects look at the company's relationships with internal and external stakeholders, among them we find for instance employees, customers, suppliers, consultants. Governance standards ensure a company uses transparent and precise accounting methods, pursues diversity and integrity in selecting its leadership, and is accountable to shareholders. **Socially responsible investing** (SRI) is an investment strategy based on the ESG principles [4].

The European Union is a leader in climate and environmental action and it was the first global player to present a long-term action plan with the final goal to reach climate neutrality by 2050. The result of this vision was the presentation of the **European Green Deal** in December 2019, which aims at an ecological transition model, thanks to precise goals agreed at European level. The final goal is to let Europe be the leader in an ecologically and socially equitable transition, by boosting in parallel both competitiveness and sustainability. The European Green Deal 2019 is an integral part of this Commission's strategy to implement the United Nation's 2030 Agenda and the SDGs , and the other priorities announced in President von der Leyen's political guidelines [5].

This European Deal puts in evidence the urgency of responsible and sustainable governance and alights the three important challenges of our continent: circularity, digitalization and ecology. For each goal there is a specific action plan, more precisely the plan about circularity is the "**Circular Economy Action Plan**" (European Commission 2020) that introduces policies that promote the increase of material efficiency through the philosophy of the 3 R, Reduce, Reuse and Recycle. "**A Europe fit for the digital age**" is the one that concerns digitalization and it affirms the role of digital transformation in the achievement of green transitions goals. The third plan, "**A Renovation Wave for Europe. Greening our buildings, creating jobs, improving lives**" formalizes the requested contribution of all the members countries to the decarbonization process.

In order to clarify the concept of sustainability, the Lean Manufacturing and Circular Economy notions should be introduced. These concepts are incredibly important to go deep inside the targets aim of the SDGs, as it was explained by Enrico Giovannini, Founder and Director of the Italian Alliance for Sustainable Development (ASviS) in the Circular Economy Forum in October 2020 [6].

1.2.1. Lean Manufacturing (LM)

Lean production or manufacturing may be defined as a philosophy, a set of principles, a system of techniques, or a manufacturing paradigm that aims to increase customers value, by a no stop production and continuous improvement approach, promoting industrial flows analysis and data visualization, process standardization and wasteful activities elimination, that in Lean terms are the ones that don't add value (Chen, et al., 2023). The term "Lean Production" was introduced by MIT researchers to depict the adoption of Toyota Production System (TPS)[1] by occidental companies.
Going deep inside into Lean value creation philosophy it should be stressed out the *Just-In-Time* management strategy that aligns raw-material orders from suppliers directly with production schedules. This technique pulls components through production based on customer demand. The production philosophy as the suppliers collaboration is permeated by *Kaizen* practice of continuous improvement, meaning that employees of each level of the organization must be engaged in actively improving the company through a PDCA approach, that stands for Planning, Doing, Checking the results of the performed operation and finally Act to refine the activity. Generically speaking, Lean approaches, like Lean *Six Sigma* and *Kaizen*, are usually used to maximize productivity by eliminating the wasted effort, energy and materials generated from non-value-added activities (Tripathi, et al., 2021).
Operationally, some well-known Lean practices for an enterprise flow analysis and data visualization are the *Value Stream Mapping* (VSM) used to distinguish the activities that add value to the non-value-added ones, the *Bottleneck Analysis* to identify the operations the limit the performance of the firm and the *Kanban* system, that clearly distinguish the to-do activities, from the done and the in progress ones through signal cards. [6]. Production flow is a key issue, from the Toyota Production System introduction with the aim, by keeping the materials flowing through the processes in a continuous way without stagnation, in such a way to reduce WIP level and increase as much as possible the utilization of the machines (Dinis-Carvalho, et al., 2023).

[1] TPS was born after the II World War in Japan and it defines a radical change in the automobile industry production and logistics processes. It broke the prevailing paradigm of mass production and it was developed by Toyota Motor Company, in an environment where resources were limited, in such manner that its main goal was to achieve a reduction of production costs through the elimination of waste (Muda).

Lean techniques applied for process standardization are instead, the *Standardized Work* documentation to capture best practices, *Poka-Yoke* that formalizes errors detection and prevention to achieve zero defects and *Jidoka*, a method known as Autonomation, that consists in partial automation of the work and immediate production stopping by any worker in case of some errors to suddenly correct the quality issue (Chauhan, et al. 2023).
For what regard the standardization concept the *5S strategy* is largely adopted in a Lean 4.0 framework. It consists in the following five points: 1.Seiri/Sort which indicates the importance to classify the work instruments, by separating the useful ones from the not useful. 2. Seiton/Straighten, to grant a safe and ordered working station 3. Seiso/Shine, it indicates the importance to clean up the working station and the instruments 4. Seiketsu/Standardize, all the operations should follow a systematic and standardized procedure 5. Shitsuke/Sustainment of the previous 4S over time [8].
The fourth area of attention of Lean Manufacturing is the reduction of waste, the Lean Wastes are seven, also called Muda and they are: *excess inventory*, *over-production, defects that require costly correction, waiting time* and *resources motion with no value added,* reduced through enterprise flows analysis techniques, *unused talent and over-processing*. It should be noted that Lean is not a state that can be achieved once, but it is a process that has to be continuously monitored and it entails changes of work culture [7].
LM and I4.0 have similar objectives as both look for productivity efficiency, that could be reached through waste elimination and they are both customer-oriented (Reyes, et al., 2021).
The link between Lean Production and Green Management has been deeply studied in the last 30 years, one of the most prestigious studies is the one of the American Agency for Environmental Protection, namely U.S. Environmental Protection Agency (EPA), which stated that the 5S philosophy is an important working approach to reduce the environmental wastes. In addition, it underlined that the milestone of LM, slimming down and simplifying the production systems, is crucial to reduce the environmental impact of a business and construct a sustainable competitive advantage [9].

1.2.2. Circular Economy (CE)

CE is an economic model that aims efficient use of resources for waste minimization, long-term value retention, elimination of the primary resources, and favour closed-loop of products, parts, and materials inside of the field of environmental protection to boost socio-economic benefits (Kayikci, et al., 2021). The circular economy should be used as a model that considers economic activity from a system and business eco-system perspective, and is based on increased use of renewable energy and materials, and is inherently more distributed, diverse, inclusive and resilient [B3].

Operationally, CE refers to an economic system that is based on business models which replace the 'end-of-life' concept of a product, also known as " take-make-dispose", with the 3R cycle, based on the ideas to Reduce use of materials, alternatively Reuse a product or part of it and Recycling instead of simply dismissing. The aim is to achieve the maximum length of the life cycle of a product. Currently, the scientific community refers to the 9Rs strategy, listed from the one that is closer to Linear Economy concept up to the more circular: Recover, Recycle, Repurpose, Remanufacture, Refurbish, Repair, Reuse, Reduce, Rethink and Refuse (Viles et al., 2022). *Recover* stands for incineration of material for energy recover, *Recycle* for processing materials to obtain some others with same or lower quality and *Repurpose* and *Remanufacturing* for using parts of the discarded products into another one with respectively a different and the same function. Going on, *Refurbish* means restoring an old product and *Repairing*, bring a defective product to its original functioning, while *Reuse* indicates simply the second usage of an old product by another consumer. The term *Reduce* refer to the chance to diminish usage of natural resources and materials and CO2 emissions. To conclude the definition cycle, *Rethink* means making a product use more intensive and *Refuse* indicates instead the abandoning of a product to substitute it with a radically new different product [10].

The term 'Circular Economy' was first coined by Pearce and Turner in 1990 and it was scientifically defined by Andersen only in 2007 through the proposal of an analysis of the main principles and approaches that integrate environmental economics and sustainability. Japan and China were the first two countries to introduce environmental policies, while Denmark, Germany, the Netherlands and United Kingdom followed the early adopters after few years.

It is straightforward to see that a combined system of LM and CE principles could increase continually and constantly the organizational quality and sustainability level, to dramatically improve the capacity of either an enterprise or a whole supply chain to produce and provide value to its customers, society and environment. Industry 4.0, Lean Manufacturing and Circular Economy are closely linked, as they all focus on reducing waste, increasing efficiency, and minimizing environmental impact (Dinis-Carvalh et al, 2023). The integration of digital technologies with sustainable principles can help companies reduce their environmental impact, by not losing their efficiency, through an optimization of the processes, energy consumption reduction, and resource utilization improvement. A green competitive advantage could be reached.

The sustainable manufacturing is the main focus of the green transition that is of interests of manufacturing industry. Such a transition refers to making the European Union more sustainable by reducing environmental impacts, modernising its economy, and increasing its autonomy by becoming less dependent on energy and raw material imports [2]. Sustainability can be reached only in a complex system where supply chain management becomes fundamental, furthermore, the interaction between policymakers and companies is crucial, digital intermediaries and government incentives can be good ways to improve this collaboration.

1.3. Twin Transition

Sections 1.1 and 1.2 demonstrate that Digital and Green Transition are not independent one by the other and at a European policy level, accelerating the twin digital and green transitions has been set a European priority and EU has launched a significant number of strategies, regulations, and directives to boost both transitions (Ortega, et al., 2021).

The intervention of government for lean and circular economy boosting is essential, because their benefits are misunderstood by many companies, that don't see them as an advantage for the business.

In the following the result of a desk-research analysis of the key existing policies at European level that foster the twin digital and green transition. It is essential to consider that there is no a unique policy that defines the twin model, the best approach to analyse the twin ecosystem is to consider different aspects of sustainable production that relate to different European strategies, for example, Horizon 2020, the 9th Framework Program- FP9 and other sectoral policies (European Parliament and Council of the EU, 2019).

Between September 25 and 27, 2015, the platform, "**Transforming our world: the 2030 Agenda for sustainable development**", was launched for the creation of a global action to favour sustainable development for the entire planet. It's commonly known as the "3P Agenda" and represents the document adopted by the Heads of State and Government, which establishes the commitments for sustainable development to be achieved by 2030, identifying 17 **Sustainable Development Goals** (SDGs), 169 related targets and 330 indicators (United Nations, 2015). The 193 member states of the UN have committed to implement these ambitious goals by 2030. The 2030 agenda for sustainable development is urging the manufacturing industry to reduce the environmental impact of production activities to meet the UN Sustainable Development Goals (UN, 2015). The SGDs has become an unprecedented global compass for navigating extant sustainability challenges.

In any paper produced by European Commission, EU ensure that the green and the digital transitions reinforce each other and they are two of the main trends that will shape the European future. As outstanding proof of this statement, in the following, a part of the Executive Summary of "**Towards a green and digital future - Key requirements for successful twin transitions in the European Union**" (2022) [2]. This publication is a Science for Policy report by the Joint Research Centre (JRC), the European Commission's science and knowledge service and it aims to provide evidence-based scientific support to the European policymaking process towards environmentally sustainable lifestyles and economies. This paper shows on one hand the growing significance of digital technologies that is transforming societies and economies and on the other the green transition goal of sustainability achievement. As result, it comes the definition of "**Twin Transition**" as successful management of green and digital transition and cornerstone for delivering a sustainable, fair and competitive future. The goal of this European study is to gain a better understanding of the variety of interlinkages between the digital and green transitions, their synergies, tension points, and unintended effects. The term 'twin transitions' refers not only to the two crucial developing trends (the green and digital transitions), but also to the study of the interlinkages between the two in such a way to accelerate necessary changes. In this paper indeed, there is one of the first mapping of the effects of digital on green and of green on digital, that is why its analysis is so important for this work thesis. It has indeed confirmed that many enabling technologies can play an important role in the sustainability enhancement, but the enabling power is not unilateral. The green transition is also affecting digital technologies, because it can reduce their environmental impact.

Manufacturing field needs always higher operational efficiency, in other words, there is an economical incentive behind the adoption of new technologies. On the other hand, the rush for the best positioning in a market can cause negative impacts on society and environment. Negative consequences of industrial activities that are not reflected in market prices are called externalities. The digital infrastructure development indeed, can induce an increase in energy consumption and environmental footprint, being the reason of environmental externalities increase. It should be considered indeed that the Information and Communication Technology industry's contribution to global greenhouse gas emissions was estimated to be between 3.0 % and 3.6 % of total emissions in 2020. To wrap up, it should be stressed out the fact that digital technologies could speed up the achievement of important green results, but on the other hand, the green transition could help in reducing the footprint of electronic components [2].

On one side indeed, the industrial field is still trying to get the full potential of the 4th Industrial Revolution, but on the other, some academic and EU researchers have already started discussing the Industry 5.0. While I4.0 is focused on digitally connecting machines to enable flow of real time data that should be analysed to reach the highest possible efficiency, the I5.0 is believed to bring human creativity, problem solving and sensitivity at the centre. This attempt was also confirmed by CEO of Tesla Inc, Elon Musk, in an interview of April 2018, who acknowledged an excessive automation of his cars: "Yes, excessive automation at Tesla was a mistake. To be precise, my mistake. Humans are underrated".

The aim of I4.0 was an efficiency enhancement to gain a competitive advantage, while in the 5.0 world, the aim is a sustainability enhancement to gain a sustainable competitive advantage. "Industry 5.0" complements the existing "Industry 4.0" approach by putting enabling technologies of 4.0 at the service of sustainable transition, human-centricity and resiliency of European industry, through a Lean organization and CE principles to drive optimal outcomes in terms of efficiency and sustainability (Sehrish, et al, 2023). The vision of I5.0 that EU proposes moves from the traditional focus on technology or economic model for performance enhancement of 4.0 to a view of growth that is focused on human progress and well-being based on reducing and shifting consumption to new forms of sustainable, circular and regenerative economic value creation and equitable prosperity [B3]. Then Industry 5.0 nests the Industry 4.0 approach in a broader context, which adds to the digital transition program, the focus on people, planet and prosperity sustainability, by proposing approaches that are in the new Europe's concept of "Twin Transition". Hence, the world can choose to manage the digital and green agenda separately or to run them in parallel to benefit from their synergies. The twin transition should lead to a **sustainable increment of competitiveness**, by allowing the industry to realise its full potential, which is not only in terms of competitiveness, but also in sustainable ones [B3]. The combination of digital technologies, lean and CE practices to achieve SDG targets can be the basis for a sustainable and digital landscape that society can trust.

According to ESIR, expert group on the Economic and Societal impact of Research and Innovation of the UE, Industry 5.0 expands and complements Industry 4.0 scenario, this wider purpose constitutes three core elements: human-centricity, sustainability and resilience. [B4]. Human centricity means to adapt technologies to workers needs, rather than asking industry workers to adapt their skills to the adopted technologies. The type of competitiveness that is targeted is not anymore in terms of economical results, but it is sustainable competitiveness. It is then requested to develop circular processes for optimising resource-efficiency, reducing waste and environmental impact and re-using, repurposing and recycling dismissed products and tools. The third element is Resiliency, that refers to the ability to change and adapt to the changes. Industrial production has the need to develop an higher degree of robustness [B4].

By keeping the attention on European publishments, in the following the ten key areas that the EU Executive Summary, "Towards a green and digital future" considers crucial for the twin European transition:

1. *Strengthening resilience and open strategic autonomy in sectors critical for the twin transitions via for instance, the work of the EU Obser vatory of Critical Technologies.*
2. *Stepping up green and digital diplomacy, by leveraging the EU's regulatory and standardisation power, while promoting EU values and fostering partnerships.*
3. *Strategically managing supply of critical materials and commodities, by adopting a long-term systemic approach to avoid a new dependency trap.*
4. *Strengthening economic and social cohesion, by for instance, reinforcing social protection and the welfare state, with regional development strategies and investment also playing an important role.*

5. *Adapting education and training systems to match a rapidly transforming technological and socio-economic reality as well as supporting labour mobility across sectors.*
6. *Mobilising additional future-proof investment into new technologies and infrastructures – and particularly into R&I and synergies between human capital and tech –with cross-country projects key to pooling EU, national and private resources.*
7. ***Developing monitoring frameworks for measuring wellbeing beyond GDP and assessing the enabling effects of digitalisation and its overall carbon, energy and environmental footprint.***
8. *Ensuring a future-proof regulatory framework for the Single Market, conducive to sustainable business models and consumer patterns, for instance, by constantly reducing administrative burdens, updating our state aid policy toolbox or by applying artificial intelligence to support policymaking and citizens' engagement.*
9. *Stepping up a global approach to standard-setting and benefitting from the EU's first mover advantage in competitive sustainability, centred around a 'reduce, repair, reuse and recycle' principle.*
10. *Promoting robust cybersecurity and secure data sharing framework to ensure, among other things, that critical entities can prevent, resists and recover from disruptions, and ultimately, to build trust in technologies linked to the twin transitions.*

The number 7 draws the boundaries of author's work thesis, that will exactly propose a framework to access the effects of the enabling technologies of I4.0 on the achievement of some SDGs targets. In this framework the KETs have a double enabling power: they enable both some paradigms of I4.0, but also green transition principles.

In Figure 2 a brief recap of the main European and Italian policies about the Digital, Green and Twin Transition that characterize the scenario in which this study is collocated:

Figure 2: European and Italian policies of the Twin digital&green transition, Source: [2]

1.4. From the theoretical background to the work thesis idea

All this theoretical introduction was important to clarify the starting point of this work thesis. At first, it should be stressed out that SDGs targets are permeated by Lean and CE principles that will be presented in Chapter 3. Then, it should be kept in mind the idea which this work is based on: on one side it has started by the seventh area of "Towards a green and digital future" EU research and on the other, it has started by the fact that some multinationals and big companies in the last years, formally selected one or more SDGs and engaged some of their targets as a reference for their strategic choices, by beginning their Twin Transition. Big companies use SDGs as guiding principles to understand what the world needs action on and try to direct their innovation process in that direction. This is possible because large companies have the knowledge and the volumes to give a significant contribution to the ecosystem around them: for hundreds of employees, for the environment and for their customers all over the world.

An example is Danone, which selected targets 8.5, 8.7 and 8.8 of SDG8, "Decent Work and Economic Growth", as the most relevant for its business strategy, the main theme are Employment, Economic Inclusion, Non-discrimination, Capacity Building, Availability of a Skilled Workforce, Elimination of Forced or Compulsory Labor. Different initiatives show their commitments in these themes, such as ensuring decent work in an inclusive way for more than 100,000 employees in over 57 countries and promoting responsible social practices in their supply chain to eradicate forced labour. They also have a couple of social innovation funds, Danone Ecosystem Fund, that strengthen vulnerable economic partners in the value chain and Livelihoods Impact Investment Funds that supports disadvantaged rural communities in developing countries [11].

On the contrary, SMEs don't have enough resources (human, time and financial) to settle up campaigns, funds, global projects. It doesn't mean they cannot start their own Twin Transition. The twin transition of SMEs indeed, is sustained by 2030 Agenda aligned with the European Green Deal that pave European SMEs the way to a more sustainable production paradigm prioritize. Hence, in this work it has been proposed a model, called **TwinSME**, that puts in light the relationships between the digital paradigms of 4.0 and some sustainable elements of 5.0, by showing that an SME that has invested up to now in the enhancement of digital dimensions with the goal to increase its competitiveness can also start a Twin journey, by addressing specific SDGs targets and adopting LM and CE principles to reach a sustainable competitiveness. The author would like to show that some enabling technologies of I4.0 can play an important role also in an Industry 5.0 scenario, the adoption itself of specific technologies can be a proof of commitment in sustainability of the SMEs, because specific KETs mixed with the use of some Lean and CE principles can let SMEs achieve particular SDGs targets.

One well known example of intermediary that works as glue between the different stakeholders of I5.0 ecosystem is the Digital Innovation Hub (DIHP), in which the author made her internship experience.

1.5. Digital Innovation Hub Piemonte (DIHP)

It is a no profit organization that has been founded in 2017 with the other Digital Innovation Hubs, after "INDUSTRIA 4.0" Italy's National Plan for Industry by Calenda [12]. Almost one DIH for each region has been created, with different financing structures, some of them sell services on the market, some others are financed by territorial Industrial Unions, but they all have the same mission to sustain SMEs of the reference region in the digital transformation journey.

Today, the DIHP supports the digital transformation of the SMEs of Valle D'Aosta and Piedmont territory, with a recent particular attention to cyber-security and sustainability, as well. Its mission is to support the SMEs in the digital transition, by starting from the **Digital Readiness Assessment** (DRA). It is an instrument, created by the partnership from Polytechnic of Milan, Polytechnic of Turin and Confindustria to measure the digital maturity level of a firm, according to the evaluation of 4 dimensions of analysis, Execution, Monitoring and Control, Technologies and Organization for each of the 8 macroprocesses that let an organization create value: Engineering, Production, Logistic, Quality, Maintenance, Human Resources, Marketing and Supply Chain. The output of this assessment is a mark from 1 to 5 for each one of the listed dimensions and macro-areas, these evaluations are very useful for the entrepreneurs to check the level of digital maturity of their business compared to the territorial benchmarks. Another crucial output is a roadmap with several lines of intervention (project proposals) that could sustain the digital transformation of the firm, by starting from the areas that resulted to have the lowest marks. Project management, prioritization of the proposal and digital matchmaking are three of the most common follow ups.

DIHP is always in contact with the other stakeholders of the Italian digital network, in such a way to direct the SMEs toward the entity that can better fulfil its needs.

Other national bodies that support the digital transformation of the different industries are: "Il Sistema Poli" and the 8 Italian Competence Centres. The former pool is composed of 7 innovation poles that represents network of SMEs, large enterprises and innovative startups, that are actives in a specific technologic area and they are indeed divided into 7 thematic areas: MESAP (Smart Products and Manufacturing pole), AGRIFOOD (Agroalimetary), BioPmed (Health), CGreen (green and new materials), CLEVER (energy and green technologies), Pointex (textile) and Polo ICT.

The Competence Centres have instead the role of supporting the test before invest phase of the SMEs thanks to pilot lines that they have at their disposal and they are entitled of delivering upskilling and reskilling courses. There is one centre for each main thematic of I4.0: CIM 4.0 - Manufacturing 4.0 and AM, CYBER 4.0 – Cybersecurity Competence Center, MADE-Competence Center I4.0, BI-REX - Big data Innovation-Research Excellence, ARTES 4.0 – Industry 4.0 Competence Center on Advanced Robotics and enabling digital TEchnologies &

Systems 4.0, SMACT – Social networks, Mobile Apps and Advanced Analytics, MedITech Competence Center of Health care technologies, START 4.0– Safety and CyberSecurity.

In addition, in 2022, the EU adopted European program DIGITAL and created the European Digital Innovation Hubs Network, by assigning the title of European Digital Innovation Hub (EDIH) to 37 entities all over the Europe to give always more opportunities and support European SMEs in the digital transformation journey.

By coming back to the DIHP, it played a very important role for this work thesis, the Digital Readiness Assessment questions and evaluations have been used to select the digital paradigms that are included in the Fuzzy DEMATEL matrix. In addition, the results of the DRA of the last years have been analysed to choose the technologies of reference for the Canva sessions of Chapter 4, according to their rate of adoption. Thirdly, it should be noticed that the vendors who joined them have been selected from the Partner Relationship Management (PRM) of DIHP, a database dedicated to technology providers.

CHAPTER 2

2. Systematic Literature Review

This is the chapter about the Systematic Literature Review (SLR), which is considered as an optimal research method for this work, because of the nature of its goal, namely to analyse the cause-effect relationships between factors of The Twin Transition. The SLR is able to put in evidence the research gaps about such an innovative theme that will be filled by this work.

2.1. Methodology

This study follows the guidelines provided by Lagorio, Zenezini, Mangano and Pinto (et al., 2020) to devise a robust protocol divided into four main steps (Figure 3). The first one is the definition of inclusion/exclusion criteria, the second, a triple filtering protocol of the resulting papers, consisting in the reading of the title, the abstract and at last, of the whole text. Backward and Forward Snowballing phases are then applied to papers that outpaced the three filters. The "Backward Snowballing" phase consists in going through the reference list of the selected papers, among which only the ones that fulfil the inclusion criteria will be added to the pool of results that will be considered for the SLR. In the last passage, a "Forward Snowballing" is conducted, it refers to identifying new contributions based on the papers citing the selected ones.
In Figure 3 the list of steps that led to final corpus:

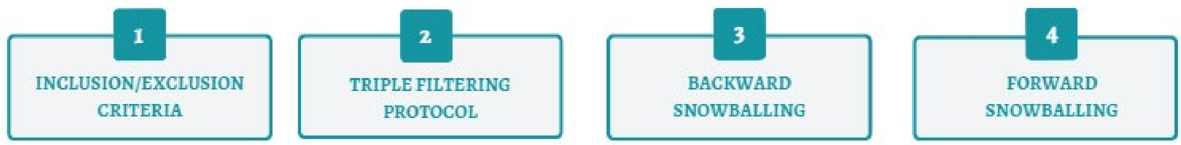


Figure 3: SLR steps

A Literature Review is considered "systematic" when it is based on clearly formulated questions (Tranfield, Denyer, and Smart et al., 2003). In the following, the two research questions of this thesis: *(1) May digital enabling technologies play a role in the twin transition of SMEs? (2) Which are the proposed models to study and mapping the interactions and interdependencies between digital and sustainable dimensions in pursuing the SDGs targets?*

2.1.1. Inclusion/exclusion criteria

The most used multidisciplinary database was Scopus at international level. The subject areas that were taken into consideration were "engineering", "environmental science", "business management and accounting" and "social sciences". In the study, the keywords were applied along with Boolean logical operators ("AND" and "OR"). The Boolean combinations are "Keyword of A AND Keyword of B OR Keyword of C". Only the articles with Open Access for PoliTo Students have been considered.

At the start, the search string was "Industry 4.0" OR "digital transformation" AND "sustainability" OR "sustainable management" in the fields "Article title, Abstract, Keywords". This first run resulted into 101 scientific papers. As inclusion criteria have been considered the ***publishing year, the document type and the English language*** (Figure 4). The *publishing time interval* was a fundamental inclusion criterion, because the crucial governmental papers about the Green Transition and the European Action Plans were published only in 2019, before of them no European agreed definition and directions exist about Twin Transition. Hence, papers published before 2019 could refer to legislations based on different principles and goals from the last ones and may not be coherent with this study.

Inclusion Criteria	Description
Publishing Year	From 2019 to May 2023
Document Type	"Articles" and "Conference papers"
Language	English

Figure 4: SLR Inclusion Criteria

The second admission criterion, the *document type*, has been considered important to limit the admission to "Articles" and "Conference Papers" in such a way to maintain homogeneity among the definitions of the different contributions, enhancing consistency across the themes. In addition, this choice gives relevance on one side to the academic research on these topics and on the other to the conference contributions. The open conferences indeed, are one of the means to mitigate the structural and cultural inhibitors between academic and industrial players, because it is a channel of communication between the two parties.

The third criterion, related to English *language*, was obliged, due to the fact that the author knows in a professional way only English and Italian and the work thesis is written in English to let the thesis be globally comprehensible.

2.1.2. Papers selection

In order to reduce the pool of found articles, more stringent researches have been performed, by using as "TITLE-ABS-KEY" the following strings of keywords "**enabling AND technologies AND of 4.0 AND twin AND transition",** "**enabling AND technologies AND of 4.0 AND sdg**, "**Industry AND 4.0 AND sdg**", **"twin AND digital AND green AND transition".** The reason behind the choice of the syntax of the search strings corresponds to the strategy chosen to write this paper, the SLR indeed, focused on two research's axis: digital and green, more precisely, on the study of the effects of the key enabling technologies of Industry 4.0 in the achievement of SDG targets in the twin transition ecosystem. That is the reason why all the search strings start with a term connected to the digital transition and end with the words "twin transition" or "sdg".

It should be stressed out that the study does not include all the articles published on the topic indeed, but only the one that outpaced the 3 filtering rounds ("Title Filtering", "Abstract Filtering", "Full Text Filtering") and have been considered useful to answer the previous research questions (1) and (2) and define a research gap.

All the selected articles have been listed in the excel file "**SLR – DB**", included as an Appendix to this thesis work. The papers were categorized according to Title, Keywords, Authors, Publishing year, Source, Country, Methodology of analysis. Only the papers that overcame the first filter, "Title Filtering" are present in the register file and for each one of them in the last column the key takeaways of the paper have been written down to justify their importance for the redaction of the literature state-of-art or to justify their exclusion form the coherent pool of articles.

The papers that overcame the first filter "Title Filtering" are 25 and they are listed in the first sheet "1st filter" of the excel file.

A second screening ("Abstract Filtering"), implying the reading of the abstracts of the papers has been done to identify their relevance to the topic. 7 articles were then excluded and they are identified by the word "NO" in the column "Abstract" of "SLR-DB" excel file.

Thanks to the last screening of the protocol ("Full Text Filtering"), another paper has been excluded and so the start set for the snowballing procedure was of 17 papers. The start set is shown in the first section of the second sheet of the register file, namely "Snowballing".

In the second section of this sheet the results of the Backward Snowballing procedure have been shown. The author read titles, abstracts and full papers if necessary of the references of the start set of papers and then decided whether to include them in the final corpus. Other 8 papers have been considered coherent after the three screening steps. They come from Elsevier, Wiley platform of University of Messina, Ijmens, Tailor and Francis Online Database and Production Planning & Control online journal.

Then, it was the time of the Forward Snowballing that resulted into other 7 contributions to this SLR. These papers are listed in the last homonymous section of the register file.
In total, the final set of papers considered for this SLR is of 34; the peculiar result is the fact that the search string that perfectly depicts the boundaries of this study "mapping AND industry 4.0 into AND sdg" showed only one result, the article "Mapping industry 4.0 enabling technologies into united nations sustainability development goals" by Mabkhot international team that will be analysed in the successive sections.
In Figure 5 a scheme of the adopted systematic search process:

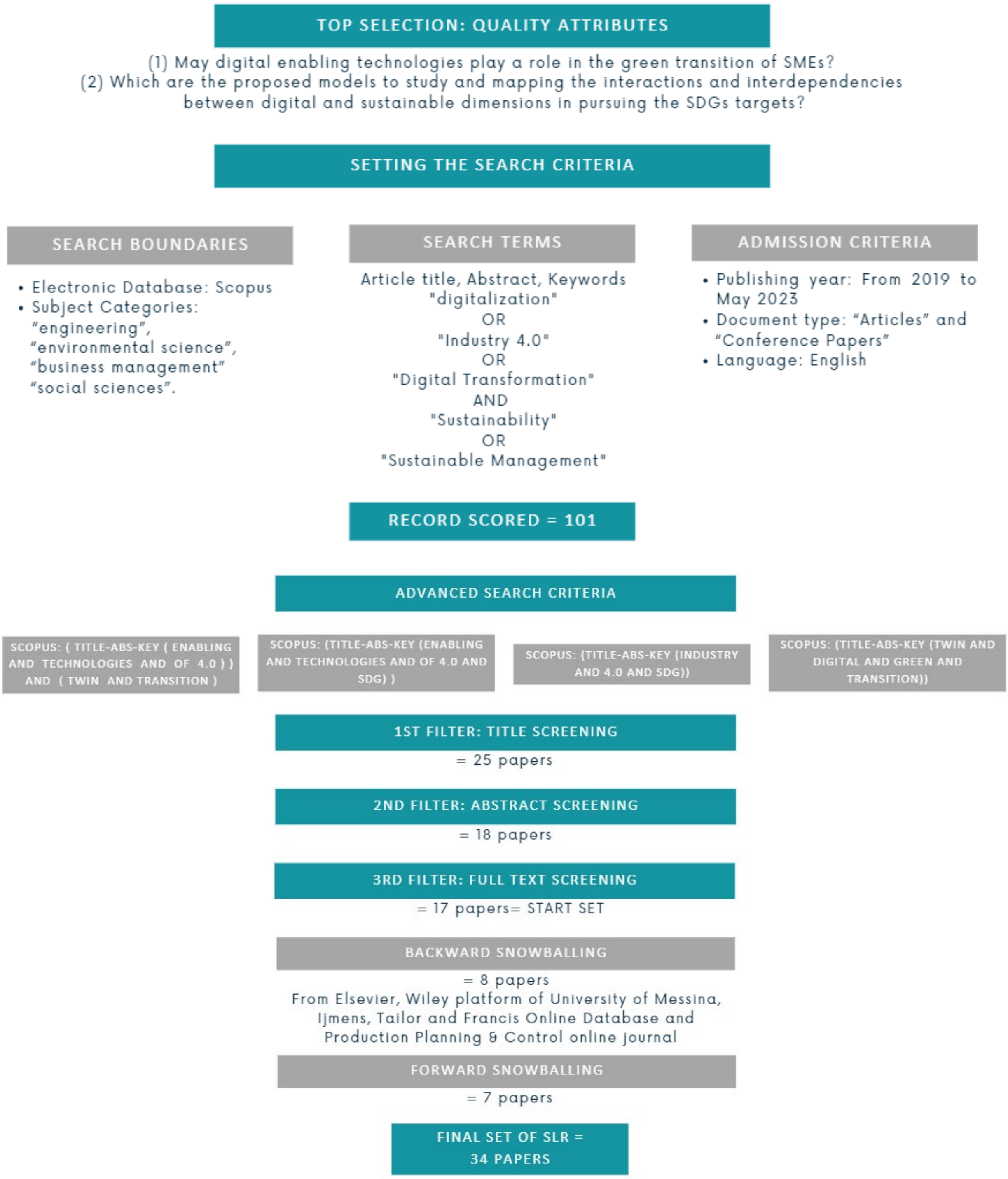


Figure 5: SLR results

2.1.3. Papers distribution

The country-wise visualization of the final set of papers, represented in Figure 6, shows the high level of attention that the developed economies countries have toward Twin Transition and the leadership role of Europe emerges clearly.

Country-wise visualization		
China	5	9,62%
Croatia	1	1,92%
Denmark	1	1,92%
France	2	3,85%
Germany	3	5,77%
Greece	1	1,92%
India	2	3,85%
Italy	7	13,46%
Malaysia	1	1,92%
Mexico	1	1,92%
Nigeria	1	1,92%
Pakistan	2	3,85%
Poland	2	3,85%
Portugal	5	9,62%
Russia	1	1,92%
Saudi Arabia	1	1,92%
Slovenia	1	1,92%
South Africa	2	3,85%
Spain	4	7,69%
Sweden	2	3,85%
Turnkey	1	1,92%
UK	3	5,77%
United Arab Emirates	2	3,85%
USA	1	1,92%

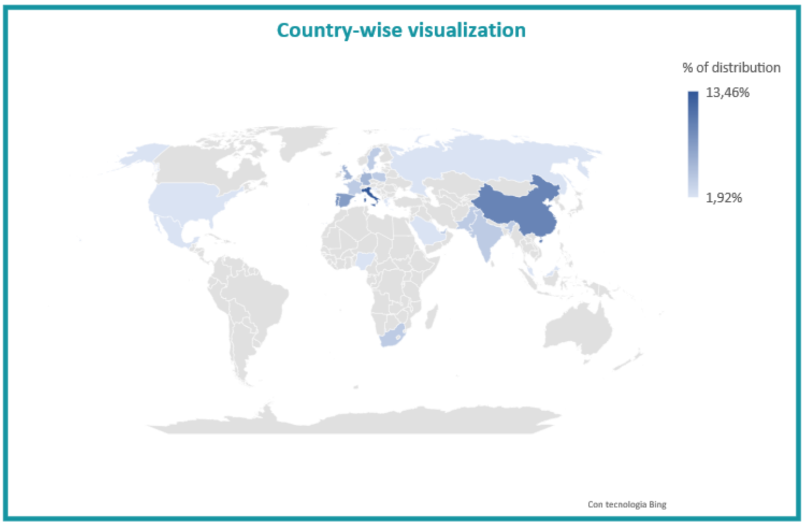


Figure 6: Country-wise visualization

The year-wise distribution, shown in Figure 7, stresses out again how much the interest about Agenda 2030 has incredibly increased in the last years, and probably Covid-19 pandemic has boosted it, by remembering to people the importance of a good life style and care of environment.

Year-wise distribution		
2019	2	5,88%
2020	3	8,82%
2021	9	26,47%
2022	8	23,53%
2023	12	35,29%

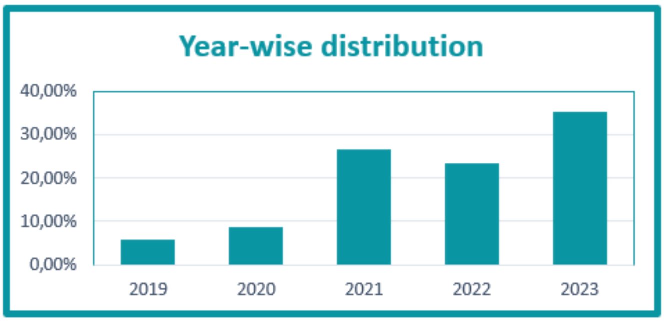


Figure 7: Year-wise visualization

The SDG-wise distribution shows in Figure 8 for each SDG how many authors of the final set worked on it, by showing that the so called Industrial SDG by Confindustria Piemonte, namely number 8, 9 and 12 are actually of great interest of academics that try to find correlations between technologies adoption and SDG targets achievement.

SDG-wise distribution		
1	1	1,45%
2	1	1,45%
3	1	1,45%
4	3	4,35%
5	1	1,45%
6	1	1,45%
7	6	8,70%
8	6	8,70%
9	17	24,64%
10	2	2,90%
11	1	1,45%
12	9	13,04%
13	7	10,14%
14	1	1,45%
15	1	1,45%
16	2	2,90%
17	9	13,04%

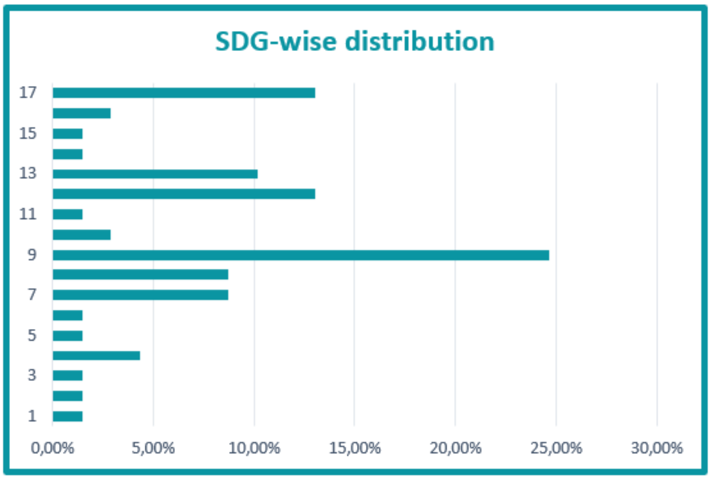


Figure 8: SDG-wise visualization

In Figure 9, it is instead possible to see the categorization of the different methodologies used by the authors to conduct the research on the selected articles. It is evident that the case study analysis and the creation of qualitative models have been two of the predilected models of analysis so far. It shows instead how the quantitative models on this topic are in a very embryonal stage.

Methodology-wise distribution		
case study	8	20,51%
Delphi panel	1	2,56%
desk research analysis	1	2,56%
Fuzzy TOPSIS	1	2,56%
IPAT framework	1	2,56%
ISM	1	2,56%
linear regression	5	12,82%
MCDM	4	10,26%
qualitative model	6	15,38%
quantile regression	1	2,56%
RESOLVE framework	1	2,56%
SLR	7	17,95%
taxonomy	1	2,56%
TOPSIS	1	2,56%

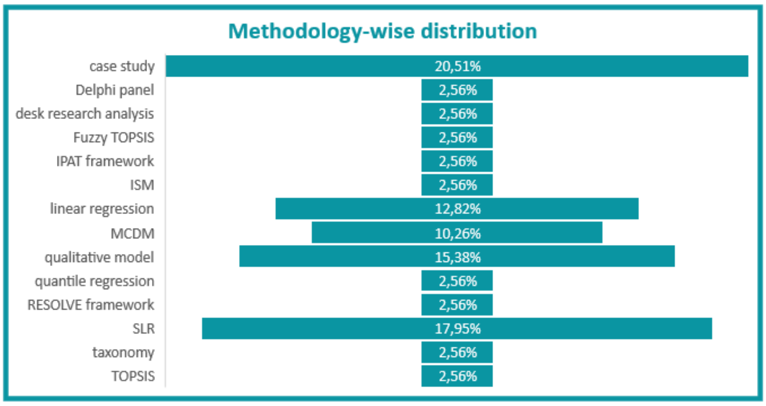


Figure 9: Methodology-wise visualization

2.2. Literature State of Art

The Section 2.2 is divided into two Subsections 2.2.1 and 2.2.2, respectively related to the first and the second research question: (1) May digital enabling technologies play a role in the green transition of SMEs? (2) Which are the proposed models to study and mapping the interactions and interdependencies between digital and sustainable dimensions in pursuing the SDGs targets ?

2.2.1. The role of KETs in the Green Transition of SMEs

After years of slightest attention to the environment and inefficient allocation of resources, the ongoing ecological and digital transition opens to new opportunities connected to the implemental policies of Industry 5.0 and related enabling technologies (Lauria et al., 2023). Industry 5.0 extends the tech features of I4.0 and complements the CE and Lean paradigm that prospers beyond jobs and growth while respecting the environment and the fifth one is the industrial revolution in which the study is collocated. In short, I5.0 leverages I4.0 technologies through human-machine collaboration and interaction to follow CE principles and drive optimal outcomes (Sehrish, et al, 2023).

I4.0 and sustainability have gained momentum in the academic, management and policy debate. However, this relationship between I4.0 and sustainability are still unclear, and the literature is fragmented, with different views on this relationship (Tavarez., et al., 2022). In any case, understanding the nature and effect of the relationship between sustainable impact and enabling technologies adoption is of major importance to help decision makers allocate countries' resources and formulate appropriate policies (Dabbous, et al., 2023).

Effectively managing the Green and Digital twin transitions is a cornerstone of achieving sustainability (Muench et al., 2022). The EU report "Industry 5.0: Toward more sustainable, resilient and human-centric industry" strongly affirms the need to speed up the underway digital and ecological transformation to deeply restore environment, economy, and communities (Lauria, et al., 2023). In order to reach Green Deal objectives, Key Enabling Technologies (KET) are considered of crucial importance by Juan-José Ortega-Gras paper (et al., 2021) and de Miranda one (et al., 2021), that enhances smart manufacturing to protagonist role in Industry 5.0 ecosystem.

It should be considered that despite the strategic relevance, digital and sustainability transformation are often considered separately in corporate practice, even though Europe intent. Corporations should understand that successfully linking digitalization and sustainability may create long-term competitive advantages in the market for example by developing smart and sustainable products (Kürpick, et al., 2023).

It is important to stress out that in the Twin digital&green Transformation, for the first time, technology is not seen simply as a new means to promote economic growth, but also as a pivotal element that will enable a more sustainable future (Mabkhot et al., 2021), by contributing in generating a series of new mechanisms to preserve and enhance natural resources, well-being, and health (Dabbous, et al., 2023). On the other hand it is important to stress out that there is empirical evidence about the fact that the local development of digital technologies has a negative effect on the environment, while adoption of green digital technologies has the potential to reduce green-house gas (GHG) emissions (Bianchini et al., 2023).

Talking about SDGs, it is clear that I4.0 have a significant impact on their achievements and this influence is explicitly stated in the 8 targets of SDG9 "Industry, innovation, and infrastructure" (Mabkhot et al., 2021) and in other 6 SDGs that are considered in the area of middle-high influence of I4.0 on social targets, which are the number 3, 4, 7, 8, 11 and 12. The importance of technological innovation for achievement of SDG9 is remarked into Ahmad paper (et al., 2023), where it is underlined the difficulty in fostering a sustainable production in countries where basic human needs granting is still the first goal to be reached and then human work conditions are preferred over the environment. SDG number 8 is fundamental right for the maintenance of good working conditions on one side and productive efficiency on the other, the taxonomy by Pan (et al., 2023) demonstrates the importance of resilience and human rights to reach a sustainable supply chain.

Another proof of the importance of manufacturing digitalisation to reach sustainable goals and give a sustainable footprint to the old manufacturing business models, is furnished by Bio-economy, presented in the study by Aquilani (et al., 2018). It can be considered part of the green eco-system, which is centered on the use of renewable raw materials and application of research, development and industrial biotechnology. It states that no important steps ahead can be made without digital innovation and firms are seen as "the locus of innovation in the economy".

By shifting the attention to other factors of Twin Transition panorama, it should be stressed out that several authors worked on empirical research linking either Lean or CE with I4.0 (John, et al., 2021). By all of them, digitalization has been presented as an enabler of environmentally sustainable development (Isensee, et al., 2020) and this triple integration can lead also to higher operational excellence, as resulted from monitoring studies by Tripathi (et al., 2021). Both digitalization and sustainability have been considered fundamental for an SME to create and sustain a competitive advantage. The interplay between the two unfolds bright opportunities for shaping a greener economy and society, paving the way towards the SDGs (Del Rio Castro, et al., 2020). In all of the selected papers the main message is the following: Digital Technologies (namely Smart Embedded Systems, IoT, Data, AI and Edge-to-Cloud Technologies) are enabling drivers for a Twin Digital&Green Transition, as well as

foundations for human centric, safe, comfortable and inclusive workplaces (Salis, et al, 2022). In these studies the Industry 5.0 has been defined as a socio-technical revolution that goes beyond CPS and covers the entire value chain of manufacturing, and faces economic, environmental, and social challenges (Yao, et al., 2022).
The World Economic Forum as well sustains sustainability can be enabled by digital technologies, for instance it states that KETs could reduce global emissions of 20% in 2050 in the three most pollutant industries: energy, materials and mobility [2].
To wrap up, many resulting articles from the SRL present theoretical frameworks with the aim to manage and monitor the two transitions (digital and green) for the achievement of sustainability and at the basis of each one of them there is the concept that Industry 4.0 power is not limited to the enhancement of the efficiency and responsiveness of the manufacturing system, but it can also positively affect the environmental impact of the company that adopt it (Rehman, et al., 2023).

2.2.2. Mapping digital and green dimensions in pursuing SDGs targets

The research on the Twin Transition factors is for the major part at academic level, a high percentage of the papers indeed, have little industrial evidence, with no contributions or validity demonstration from industrial players. Only few studies focused on mapping the contribution of I4.0 technologies for monitoring SDGs indicators in real business cases and they are related to specific projects in particular industries, there is no generic mapping. As Ghobakhloo (et al., 2020) states, there exist sophisticated precedence relationships among various sustainability functions of Industry 4.0, but they still should be deeply studied to better understand the opportunities that the digital revolution could offer in the sustainability field. Nevertheless, all the obtained results show growing expectations about the added value brought by digitalization for pursuing the SDGs (Del Rio Castro, et al., 2020) and indicate that Industry 4.0 can have a great impact all other the supply chains in an organized approach (Chauhan, et al., 2023).
In the following, some theoretical models that show correlations between digital and green transition. As common denominator of the different proposed models there is the concept of "sustainable production", that was born in 1994 by Elkington that reconsidered the value creation concept in an integrated way. A classic in the economic management of industries is the measuring of the created value through economic metrics and profit generation, Elkington integrated environmental and social dimensions as well in a framework called "Triple bottom line" (TBL) (Ciliberto et al., 2021), that is the basis of many other articles.
One of the few frameworks that imply the contribution of managerial figures is the DISEL one (Digitalization Supports Environmental Sustainability through Lean principles) that states that the digitalized lean implementations improve environmental sustainability (Chen et al., 2022).

This model combines the concept of lean manufacturing with I4.0 technologies to reduce environmental impact. Four industrial players were interviewed to collect input data, two CEOs and two logistic and production managers. This study shows in a qualitative way that ES is improved thanks to digital technologies' role as accelerators and lean principles' role as bridges.

Another interesting model, it is the one by Amjad (et al., 2020), that generalises the concept of Lean, by coining the acronym LARG (Lean, Agile, Resilient and Green) Manufacturing studying its relationship with the facets of Industry-4.0, through the adoption of smart production control, cyber-physical, systems and energy monitoring. LARG Manufacturing has been seen as a way to reach the Sustainable Production that is strongly linked to circular economy (CE). The latter can be considered as an industrial economy that is oriented to sustainability (Ciliberto, et al., 2021).

The third presented model is the Quintuple Helix innovation one, which is focused on the relationships between academia, industry, government, media and natural environments and could be the basis of twin innovative industrial models. A cooperative work of all these stakeholders let an advanced and sustainable manufacturing be possible by enabling the improvement of productive capacity on one side and increasing efficiency of energy and materials on the other (de Miranda et al., 2021). This is explained in the model RESOLVE, an acronym for regenerate, share, optimise, loop, virtualise and exchange. Such a framework shows through Ordinary least squares (OLS) estimations a positive correlation between CE and I4.0 (Findik, et al,. 2023). The Findik study demonstrated that I4.0 technologies help SMEs in 3 of the 7 analysed areas of the framework: first of all, adoption of KETs let Regeneration level be higher, thanks to renewable energy sources installation. In addition, it facilitates asset sharing among SMEs (Share) and enables SMEs to optimise their production processes, reducing waste and increasing efficiency (Optimise).

Keeping the focus on SMEs market, the econometric study by Chatzistamoulou (et al., 2023) on 23,464 European Small-Medium Enterprises, is an important starting point for this paper, thanks to its analysis of firm-level and country-level variables affecting a firm’s decision to adopt a green business strategy. The analysis indicates that digital transformation fosters sustainability transition and the speed of the transition is boosted by public intervention.

2.3. Research Gap

In this Section the answers to the two research questions have been discussed in such a way to put in evidence the research gaps at the basis of this study.

The answer to the question *(1) May digital enabling technologies play a role in the twin transition of SMEs?,* is affirmative according to the Systematic Literature Review results presented in Subsection 2.2.1. It is indeed evident that all over the world, especially around Europe, the connection between sustainable manufacturing and I4.0 has been identified and the governments are providing guidelines and policies to implement new 4.0 solutions. Their intervention is particularly important for the small enterprises that need formation and financial help for innovation, with consequent positive impact on all the sustainability dimensions (Machado et al., 2020). However, as the review shows due to the novelty of these topics, multifaceted nature and extreme complexity of the 2030 Agenda, research is still incomplete and fragmented, lacking confirmation from the industrial world and open debates (Del Rio Castro, et al., 2021). On one hand the SLR about this first question shows the growing attention of academic and governmental players about innovative approaches to enhance the Twin digital and green Transition on the whole supply chain, with particular attention to the fragile suppliers, but on the other it is evident a lack of formalized studies and structured results on how KETs could support the green transition towards a smart and sustainable industry and the response of the industrial players of the territory has not been accessed yet.

The results about question *(2) Which are the proposed models to study and mapping the interactions and interdependencies between digital and sustainable dimensions in pursuing the SDGs targets?* put in evidence a significant research gap about quantitative analysis on cause and effects relationships between digital technologies adoption in real industrial organizations and SDGs targets. The majority of the already proposed models are indeed of qualitative type. The manufacturing industries are characterized by superficial understanding of the interlinkages between the two worlds, they lack suitable indicators to monitor twin transition and assessment methodologies and they don’t have assigned clear responsibilities yet.

The influence of I4.0 technologies on the achievement of the Sustainable Development Goals (SDGs) has not been conclusively or systematically investigated, except by the academic experts of Mohammed M. Mabkhot’s international team (Mabkhot, et al. 2021), whose study results were very clear: the majority of the I4.0 technologies can contribute positively to the achievement of the UN agenda, but no industrialists have confirmed it yet.

As in the discussion about question (1), also in the mapping models shown in Subsection 2.2.2 about question (2), is evident the magnitude of the structural inhibitors between academic research world and industrial one on the Twin Transition topic. The SRL puts in light the significant involvement of academic experts in the research but the low involvement of industrial players. No evidence of the commitment of the technological providers and manufacturing SMEs in twin transition missions have been recorded. Academics and politicians consider digital&green transition crucial for the world, but the involvement of the industrialists in this challenge is still very limited. The misalignment of interests is evident: while the twin transition and TBL metrics are the present in the academic world, profit remains the main driver in the industrial field, particularly in the SMEs one, therefore, the implementation of adequate governmental policies plays a strategic role as a support to eco-innovation, promoting continuous pro-active collaborations between industrial companies and specialized intermediaries. (Aquilani et al., 2018).

The discrepancy between the interest of governments and academics about Twin Transition topic and the knowledge level of practitioners can be well explained by introducing the concept of Technology Readiness Level (TRL). It is an ordinal scale from 1 to 9 originally developed by NASA in the 1970s for space exploration technologies, that measures the maturity level of a technology throughout its research, development and deployment phase, to access its readiness to market launch. The industrial market works with technologies with high TRL while the majority of the papers are focused on simulations or very low TRL technologies.

To wrap up, there is no evidence of the magnitude of effects that the KETs that have been actually adopted by SMEs of the territory could have on the SDGs targets. Additionally, there are no clues of what the players that daily work with very high TRL in the SMEs and introduce KETs on the real market (the technological providers) know about the Twin Transition and Lean and CE approaches on which SDGs are based on.

In Table 1 a schematic recap of the research gaps that this thesis aims to cover:

Table 1: Research Gaps

Research gaps
From SLR related to Research Question (1): 1.1 No evidences of the Twin Transition interest and readiness of the SMEs structures and technological providers (Salis, et al, 2022; Rehman, et al., 2023) 1.2 Very low rate of industrial players involvement (Del Rio Castro, et al., 2021).
From SLR related to Research Question (2): 2.1 Very few quantitative models for mapping KETs contributions to SDGs targets achievement (Mabkhot et al., 2021; Findik, et al,. 2023; Chatzistamoulou et al., 2023;) 2.2 No evidence of the cause-effects relationships between the digital paradigms of 4.0 and the Lean and CE principles imbedded in some SDGs.

CHAPTER 3

3. TwinSME Model's Factors Identification

In Chapter 3 the elaboration of the Fuzzy DEMATEL quantitative matrix has been presented step by step, by starting from the explanation of how the thesis fills the identified research gaps (Section 3.1). It follows the description of the chosen methodology in Section 3.2 and the choice of the factors to fill the matrix, that are explained one by one in Section 3.3, up to showing the complete matrix in Section 3.4.

3.1. Filling the gaps with the TwinSME Model

To wrap up, the aim of this thesis is to show that the adoption of specific technologies in the SMEs can enable not only digital paradigms, but SDG targets as well, which are permeated by CE and LM principles. If it is true, the entrepreneurs that invest in the technological innovation of their firms may choose some digital solutions instead than others, by considering not only the digital potential of these technologies, but also the green one. By knowing which are the KETs that can positively impact the SME SDGs targets, they can make conscious decisions: the choice to invest on the empowerment of one digital function that has also a green enabling power can be a proof of the firm commitment in sustainability and a way to make SMEs contribute to the green transition of the territory.

Table 2 shows in a schematic way the research gaps that resulted from the SLR, presented in Chapter 2, the table is divided into two rows one for each research question. For each one of them there is a brief explanation of how the analysis run for the thesis work can fill them. For clarity, the gaps and the corresponding analysis have been classified with the following notation: "i.j", with i,j = 1,2. Then, for instance, it is indicated as 2.1 the first identified gap in the SLR referred to research question 2 and the dedicated thesis analysis to fill it.

Table 2: Schematic overview of the analysis conducted to fill the research gaps

Research Gaps	Filling the gaps
From SLR related to Research Question (1): 1.1 No evidences of the Twin Transition interest and readiness of the SMEs structures and technological providers (Salis, et al, 2022; Rehman, et al., 2023) 1.2 Very low rate of industrial players involvement (Del Rio Castro, et al., 2021).	1.1 Analysis of the KETs that have been largely adopted by **the SMEs of Piedmont and Valle d'Aosta** and involvement of their technological suppliers for the research work 1.2 Canva applicative sessions with 14 managers of **technological provider** organizations of the territory to fill the model's matrix
From SLR related to Research Question (2): 2.1 Very few quantitative models for mapping KETs contributions to SDGs targets achievement (Mabkhot et al., 2021; Findik, et al,. 2023; Chatzistamoulou et al., 2023;) 2.2 No evidence of the cause-effects relationships between the digital paradigms of 4.0 and the Lean and CE principles imbedded in some SDGs	2.1 **TwinSME quantitative model** based on the Fuzzy DEMATEL technique 2.2 Analysis of the **cause-effect relationships** between the **digital and sustainable** dimensions, permeated by LM and CE principles

As stated in the point 2.1, this paper contributes to the literature by exploring the relationships between Industry 4.0 paradigms, SDG 8, 9 and 12 targets, LM techniques and 9R of CE through the construction of an IDEF0 model called **TwinSME,** that is articulated into two nodes: the Digital Transition block and the Twin one. The cause and effect relationships between the factors are analysed through **the Fuzzy DEMATEL technique** that relies on the opinion of experts about the direct influence of one factor i on other factors j. In Section 3.2 there is a formal description of this technique and an explanation of the reasons at the basis of the choice of this model for the thesis. The constructed model studies the **points of convergence between digitalization and sustainability** from a managerial perspective, more precisely it shows the **cause effect relationships** (bullet point 2.2) analysed with rigorous matrixial calculations, between the digital paradigms, the LM and CE principles and the targets of the three selected sustainable development goals, namely SDG number 8, 9 and 12 that will be deeply analysed in the specific Subsection 3.3.2 and that from now on will be defined "SME SDGs" for reasons that will be explained in the same subsection. The results got at the end of the Fuzzy DEMATEL application will be presented in Chapter 5 through an IDEF0 representation.

In order to partially mitigate the structural inhibitors between academic and industrial world, the study has been conducted by interviewing production directors (1.2), logistics and IT managers and commercial area managers of **technological providers of the territory**, by giving them the chance to confirm or reject the results got by academic studies, analysed in the SLR in Chapter 2. Their point of view is indeed the one that reflects the most the real situation of the **Piedmont and Valle d'Aosta SMEs** (1.1), because they personally follow the desiderata of SMEs and the academic innovations in such a way to create a bridge between the two realities. The reason why the chosen territory has been Piedmont and Valle d'Aosta is the fact that, as anticipated in Chapter 1, they are the reference regions of the Digital Innovation Hub in which the author made the internship experience. DIHP supports SMEs of the territory in the digital transformation journey, then the data at disposal of the author were about SMEs in these areas. In addition, when DIHP enters a digitalization project with a firm and it has to propose a supplier for a certain project, the precedence is given to the technological providers of the same region. Hence, for this thesis the data about the digital maturity level presented in Section 4.1 will be about SMEs in Piedmont and Valle d'Aosta and for coherence with the DIHP area of action, the selected providers for this work have at least a seat in the same two regions and know the competitive factors and market logics of this market.

For the selection of the technology providers a filtering process consisting in three filters has been constructed: by technology, by territory and by expertise; it will be explained in detail in Section 4.1. In general, it should be stressed out that their job includes the production or the selling of machineries or software that fulfil the users' needs through the new application of academics discoveries. Between the participants there are developers and sellers of vertical and supply chain integration software that apply trend analysis on production and selling data to make forecasts, producers of AR visors and automated solutions for material handling that move materials thanks to optimization of the trajectories. On one side, the

involved suppliers are perfectly conscious of what the KET that they produce or sell can enable, in terms of digital paradigms. This model will give them the chance to reason about the digital&green potentiality of their KETs, defined in this thesis as enabling power, through the application of a mathematical rigorous methodology and the usage of governmental and academics agreed terms of the Twin Transition framework.
Enhancing the awareness of how I4.0 technology development impacts the SDGs is one of the most powerful tools to help future engineers to work towards a sustainable world (Mabkhot et al, 2021) and not only, what is important is to close the gap between what academic people consider important and what industrial technology vendors introduce in the SMEs market, by following the desiderata of the entrepreneurs themselves.

3.1.1. The TwinSME Model - Forward and Backward pass

In this Subsection, a deep dive on the logic of the TwinSME model, that will be used to schematize the results of the thesis that fill the previously discussed Research Gaps. For sake of clarity the terminology used to describe the model has been introduced in this Subsection.
The filling and the consequent interpretation of the proposed TwinSME model have been codified with the following two labels, “Forward Pass” and “Backward Pass”. The “Forward Pass” (Figure 10), codified with FP, consists in Canva applicative sessions, presented in Chapter 4, with the selected technology providers. These discussions are articulated in two phases: a preliminary reasoning about the digital enabling power of the KET produced or commercialized by the interviewed vendor and a generalised analysis of the influential links between digital, SDG, CE and LM factors of the model, through the filling of the Fuzzy DEMATEL matrix. The output of the FP is the Influential Relation Map (IRM), a graph that enlightens the cause-effect relationships between the previously listed factors.

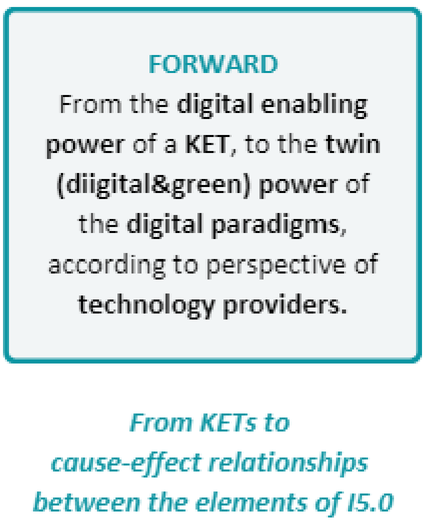


Figure 10: Forward Pass of the model

The "Backward Pass" (Figure 11), codified with BP, presented in Chapter 5, includes the backward interpretation of the cause-effects relationships, through the help of the IDEF0 representation of the TwinSME Model. For what regard the Digital part of the model, with BP, it is meant the possibility for an entrepreneur to start from the desire to enhance one digital paradigm to arrive to individuate the digital factors that affect it and the KETs that should be adopted to enable it. For what concerns the Twin section instead, BP means to start from targeting one of the selected SDGs and associating some Lean and Circular approaches and one or more KETs that should be adopted to reach the chosen targets. It could be done by going through the cause-effect relationships from the end to the beginning of the model, this backward reading is facilitated by the IDEF0 representation.

Figure 11: Backward Pass of the model

3.2. Fuzzy DEMATEL

This Section is dedicated to the explanation of the reasons at the basis of the choice of the Fuzzy DEMATEL method as quantitative technique of analysis for this thesis. Its results will be represented in the IDEF0 TwinSME Model.

DEMATEL, namely Decision Making Trial and Evaluation Laboratory, is considered as an effective Multi-criteria decision making (MCDM) method for the identification of cause-effect chain components of a complex system and exploration of the relationships between them. The name is the same as the original project it was developed for, implemented by Emilio Fontela and Andre Gabus at the Batelle Geneva Research Centre, aka Batelle Research Institute, Geneva, Switzerland, in the early 1970s. It was dedicated to the identification of the structure of the main problems of the contemporary world and it was conducted thanks to the participation of representatives of diverse cultural, social, economic, political, religious, etc., circles from all over the globe (Kwartnik-Pruc, et al., 2022). The generic aim of the

DEMATEL technique is the development of a map to reflect relative relationships within different factors that are put in the matrix of the model, by converting interdependency relationships into a cause and effect group via matrixial calculations (Muhammad, et al., 2017).

Over the recent decade, the DEMATEL procedure has grasp a significant level of attention and a certain number of variants have been put forward in the literature (Si, et al., 2018). Among the several existent versions, the Fuzzy one has been chosen for this work, because of study conditions and novelty of the topic. The **Fuzzy DEMATEL** version has been introduced due to the fact that in many real-world applications, human judgments are often unclear and they could lead to inexact numerical values and inadequate estimates (Akyuz, et al., 2015), exactly like in the case of this thesis, where the inputs for the model come from human evaluation, more precisely from Canva sessions with industrialists. In the psychology, the graded structure of the human concepts has been theorized from 1970, it means that when a limited group of people is selected for an evaluation, the answers of these people will be a matter of degree, rather than a yes-or-no question. This type of evaluation is commonly defined in a logical sense as “fuzzy”, it means that the characteristics of analysis apply to the concept "to a certain degree or extent", not in an absolute way [13]. Each participant will have differences in perception arising from the way of thinking and from the personal experiences, their subjective behaviors are explained by the concept of blurriness, which is defined as the application of fuzzy mathematics to the real world. In fuzzy logic indeed, there are linguistic variables (Zileli, et al., 2023).

In short, Fuzzy DEMATEL technique makes use of imperfect information based on the personal experience of experts to access direct influences between factors of different nature (Kwartnik-Pruc, et al., 2022). This is precisely the case of this work, where fourteen managers of technology providers firms have been involved to make pairwise comparisons that will be used to derive the complete picture of the direct influence of distinct factors (digital and green ones), through a rigorous procedure. The results of their applicative sessions have been presented in Chapter 4. The population of interviewed experts is usually limited, it is common to find groups between eight and sixteen participants, according to the number of dimensions put in the matrix (Muhammad, et al., 2017; Prakash, et al., 2022; Kwartnik-Pruc, et al., 2022; Abdullah, et al., 2023; Wang, et al., 2023; Zileli, et al., 2023).

In the following paragraph, it has been explained step by step how fuzzy DEMATEL methodology has been applied to this study and in Figure 12 the different phases have been clearly schematized.

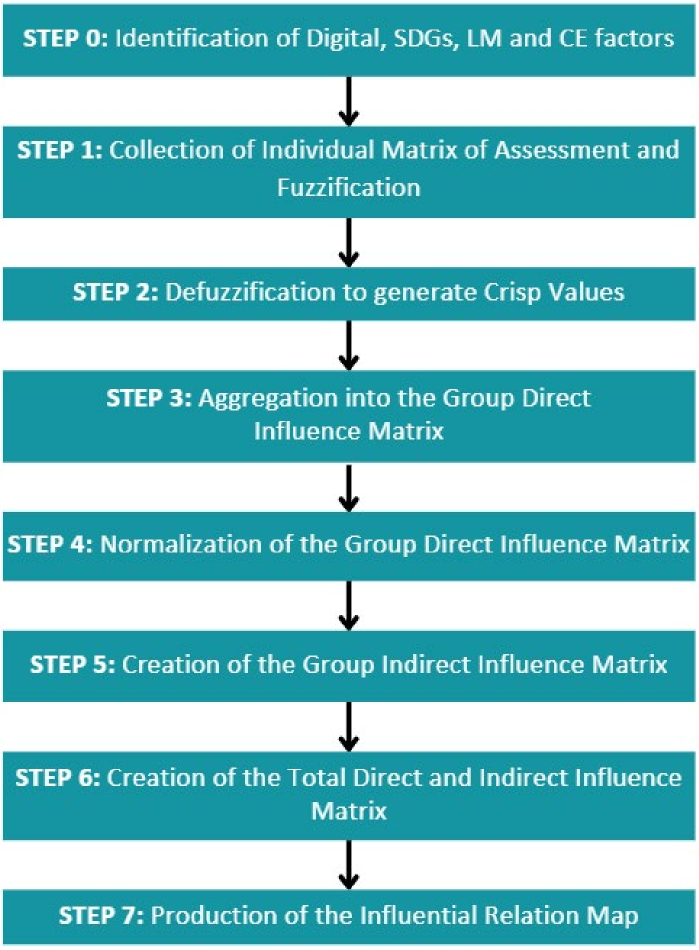


Figure 12: Flowchart of fuzzy DEMATEL methodology

Step 1 (*collection of the Individual Matrix of Assessment and Fuzzification*): First of all, it is necessary to establish a fuzzy linguistic scale that will be used by each expert to evaluate the pair-wise effects. In order to tackle the vagueness and imprecision in human assessments, the linguistic terms "No, Very Low, Low, High, Very High" followed by the linguistic variable "influence", can be used for the experts evaluation. This is then converted into a triplet, called triangular fuzzy number, that can be expressed in the following way, a = (l, m, u), graphically represented in Figure 14, where l, m and u denote respectively the lower, medium and upper numbers of the fuzzy sets (l ≤ m ≤ u) (Akyuz, et al., 2015). The fuzzy linguistic scale represented in Figure 13 *(Muhammad, et al., 2017)* has to be interpreted in the following way:

Linguistic Terms	Description	Fuzzy Triangular number	Explanation
No influence	0	(0; 0; 0.25)	Represents that two factors are not related to each other
Very low influence	1	(0; 0.25; 0.50)	Represents a low correlation between the two factors
Low influence	2	(0.25, 0.50, 0.75)	Represents a moderate correlation between the two factors
High influence	3	(0.50, 0.75, 1)	Represents a high level of correlation between the two factors
Very high influence	4	(0.75, 1, 1)	Represents a ver strong dependance between the two factors

Figure 13: Fuzzy linguistic scale

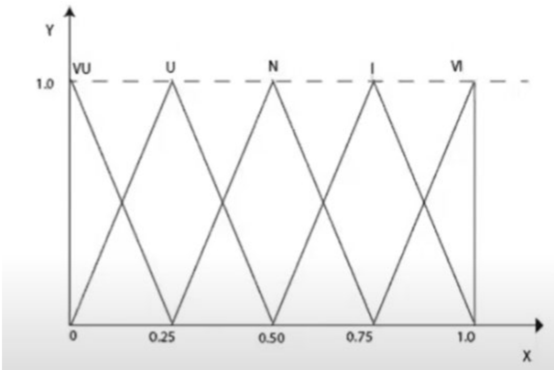


Figure 14: Triangular Fuzzy Numbers

The number of levels of the numerical scale adheres to standard psychological rules at the basis of human meaningful pairwise judgements, that are facilitated by an odd scale [13]. Each expert E_p (p = 1,2,…,12, with P=?) fills a quadratic n-by-n matrix, called *Individual Matrix of Assessment*, composed by n Factors, presented one by one in Section 3.3. The individual direct-influence matrix of the expert p is denoted by $\hat{A}^p = [\hat{a}_{ij}^p]_{n*n}$, where $\hat{a}_{ij}^p = (a_{lij}^p, z_{mij}^p, z_{uij}^p)$, according to the triangular fuzzy notation. All the principal diagonal elements will be equal to zero, because all cells on the diagonal indicate the effect of F_i on itself and each a_{ij}^p represents the judgment of decision maker E_p on the degree to which factor F_i affects factor F_j (with j != i). It is important to underline that, in the assessment, it is assumed that two opposite aspects have independent effects, in other words, the relation F1 to F2 and F2 to F1 has different influential effect.

Step 2 (*defuzzification of the Individual Matrixes to generate crisp values*): the generation of crisp scores is got through four sub-steps (Prakash, et al., 2023):

2.a. Normalization of each Fuzzified Direct Influence Matrix according to system of equations (1):

$$n_{lij}^{p} = \frac{\left(a_{lij}^{p} - mina_{lij}^{p}\right)}{\Delta_{min}^{max}};$$

$$n_{mij}^{p} = \frac{\left(a_{mij}^{p} - mina_{mij}^{p}\right)}{\Delta_{min}^{max}};$$

$$n_{uij}^{p} = \frac{\left(a_{uij}^{p} - mina_{uij}^{p}\right)}{\Delta_{min}^{max}};$$

$$where\ \Delta_{min}^{max} = maxa_{uij}^{p} - mina_{lij}^{p} \quad (1)$$

2.b. Calculation of left (nl) and right (nr) normalized values through system of equations (2):

$$nl_{ij}^{p} = \frac{n_{mij}^{p}}{(1+n_{mij}^{p}-n_{lij}^{p})};$$

$$nr_{ij}^{p} = \frac{n_{uij}^{p}}{(1+n_{uij}^{p}-n_{mij}^{p})}; \quad (2)$$

2.c. Acquisition of the crisp values through equation (3):

$$x_{ij}^{p} = \frac{nl_{ij}^{p}*\left(1-nl_{ij}^{p}\right)+nr_{ij}^{p}*nr_{ij}^{p}}{(1-nl_{ij}^{p}+nr_{ij}^{p})}; \quad (3)$$

2.d. Calculation of total normalized crisp values through equation (4):

$$z_{ij}^{p} = mina_{lij}^{p} + x_{ij}^{p} * \Delta_{min}^{max}; \quad (4)$$

For each respondent p there is now a matrix Z^{p}composed of crisp values z_{ij}^{p}

Step 3 (*aggregation of the different matrixes constituted of total normalized crisp values into the Group Direct-influence Matrix):* All the total normalized matrixes are then aggregated through a mathematical average to form the *Average Direct-influence Matrix,* Z* = $[z_{ij}^{*}]_{n*n}$, where $z_{ij}^{*} = \frac{1}{P}\sum_{p=1}^{P} z_{ij}^{p}$, got by equation (5):

$$Z^* = \frac{1}{P} \sum_{p=1}^{P} (Z^p) \tag{5}$$

This unweighted average includes the difference in credibility and quality of the different experts opinions.

<u>Step 4</u> (*normalization of the group direct-influence matrix):* Z* is then normalized through the transformation (6) to become the Normalized Direct Influence Matrix, Zn = $[zn_{ij}]_{n*n}$, where $zn_{ij} = zn_{ij}/\alpha$:

$$Zn = \frac{Z^*}{\alpha} \tag{6}$$

where α is the scaling factor which lets the limit (7) be a quadratic null matrix denoted by ∅, which is compatible with the Zn matrix:

$$Zn^e = \emptyset \tag{7}$$

The scaling factor α can be more simply approximated by finding the maximum between the largest row-wise and column-wise sum of Z* matrix components (Kwartnik-Pruc, et al., 2022).

<u>Step 5</u> (*creation of the Group Indirect-influence Matrix):* In the matrix Z the direct influences between the analysed dimensions are showed, while the indirect influences which result from the transmission of influence through intermediate factors are expressed in the matrix ΔZ = $[\Delta z_{ij}]_{n*n}$, deriving from Equation (8):

$$\Delta Z = Zn\,(I - Zn)^{-1} \tag{8}$$

<u>Step 6</u> (*creation of the Total Direct and Indirect Influence Matrix):* The Total Influence, which includes both the direct and indirect influences between the n Factors, is expressed by the n-by n quadratic matrix of Total Influence T = $[t_{ij}]_{n*n}$, depicted in Equation (9):

$$T = Zn + \Delta Z \tag{9}$$

Each component t_{ij} of the matrix T component represents the total influence of the i-th factor on the j-th one.

<u>Step 7</u> *(production of the Influential Relation Map (IRM)):* The summation of the values on the rows of the defuzzified T is denoted as r_i for each row i and the matrix that comprehends all these summations results is denoted by R in Equation (10). The same reasoning is applied to each column j to get the matrix C, represented in Equation (10) as well.

$$R = [r_i]_{n*1} = [\textstyle\sum_{j=1}^{n} t_{ij}]_{n*1} \;,\; C = [c_j]_{1*n} = [\textstyle\sum_{i=1}^{n} t_{ij}]_{1*n}^{T} \tag{10}$$

The analysis of data about total influences should be classified in two indices. Let i = j and i, j ϵ {1,2,…, n}, the first index is called *Prominence* or *Position* and it is denoted as s_i^+ for each i-th factor F_i and it indicates the strength of influence links with the other dimensions, in other words it stands for the degree of importance of the role that F_i plays in the system. The Prominence of each F_i is got by the sum of the correspondent r_i and c_i, as expressed in Equation (11):

$$s_i^+ = r_i + c_i \tag{11}$$

The second index, s_i^-, is instead called the *Relation* and it expresses the causal or effective role of the i-th factor. If it results to be positive, it indicates that F_i is a cause, meaning that it has a net effect on the system. If it is negative instead, it provides evidence that it is an effect, hence, it is influenced by other factors. The value is got by Equation (12), where it is present the difference between the same summations of Equation (11):

$$s_i^- = r_i - c_i \tag{12}$$

The classification of factors could be clearly expressed by points in a two-dimensional diagram, called Influential Relation Map (IRM), represented in Figure 15, where the Prominence (R+C) will be on the x-axis and the Relation (R-C) on y-axis. The elements with positive Relation are the most influential dimensions, their improvement indeed may positively influence the other factors that are influenceable by them, they are then considered “causes”. In addition, higher the Prominence, higher their influence. The points with negative Relation instead, are instead considered effects, because they are influenced by a change in one or more of the cause factors. As before, higher the Prominence, stronger the effect they feel by the causes (Si, et al., 2018).

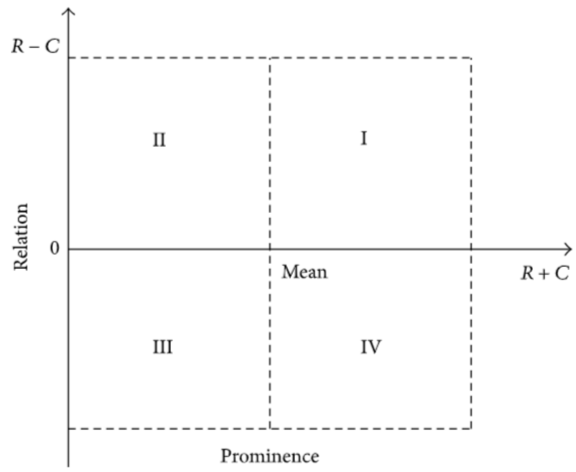


Figure 15: Influential Relation Map (IRM)

3.3. The Fuzzy DEMATEL Factors identification

As the first Step of the procedure states (Section 3.2), the DEMATEL matrix should be constructed by selecting the factors whose cause-effect relationships will be studied. The construction needed two phases, a digital and an SDG one. The Subsection 3.3.1 is about the selection of digital functions, defined as **Digital Paradigms or Digital Factors**, also called principles, functions or drivers. In the second part of the matrix creation phase instead, the focus shifts on the **Sustainable Development Goals number 8, 9 and 12**. In the Subsection 3.3.2, one target for each SDG has been selected, they will fill three positions of the matrix. In Subsection 3.3.3 instead, the **LM and CE Factors** will be introduced to conclude the model, in which there will be present Factors for each element of Industry 5.0 panorama, in such a way to study direct and indirect influences in this new scenario.

3.3.1. Digital Factors

The first seven positions of the matrix are filled by Digital Factors ($F_1, F_2, F_3, F_4, F_5, F_6, F_7$)*. They refer to the paradigms of I4.0, meaning that they are functions that are enabled by the introduction and usage of enabling technologies 4.0.*

As stated in Section 1.1, Industry 4.0 is a new philosophy of manufacturing and it is not a synonym of KETs. It is better to say that the realization of I4.0 is supported by a portfolio of KETs, that as the name states, have the power to enable one or more of the functions and paradigms that differentiate Industry 4.0 from the previous industrial philosophies (Mabkhot et al., 2021). These digital paradigms define the deliverables that Industry 4.0 technologies have gifted to the industrial world [14].

For sake of clarity, the Figure 16 schematizes the I4.0 scenario, by showing that I4.0 is not only KETs, but that they are fundamental to enable the digital paradigms, distinctive characteristics of the Fourth Industrial Revolution. It is possible to see a column dedicated to the so called Key Enabling Technologies (KETs) (Rüßmann et al., 2015; Saucedo, et al., 2018; Alcácer, et al., 2019) and another one that presents the list of the Digital Factors used in the Fuzzy DEMATEL matrix of this thesis, that will be explained one by one in the following paragraphs.

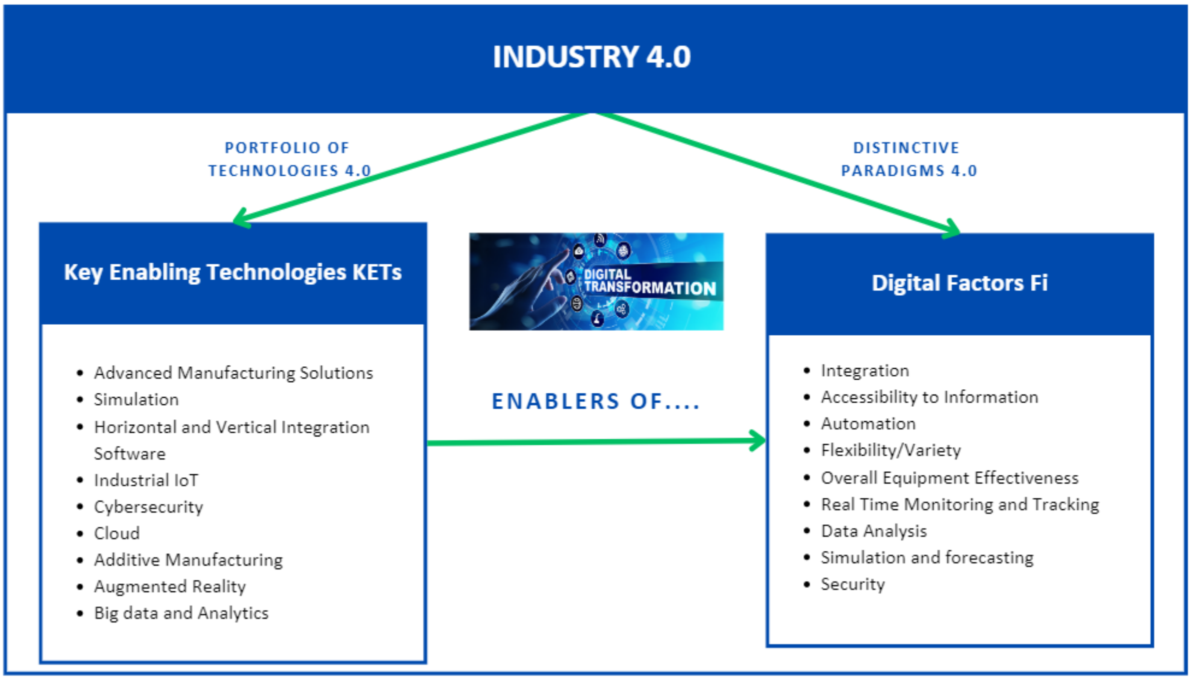


Figure 16: KETs and Digital Factors in the I4.0 scenario

This list of digital paradigms was born through the author analysis of **Digital Readiness Assessment** (DRA) questionnaire (described in Section 1.5), used by DIHP to measure the Digital Maturity Level (DML) of SMEs of the territory. The importance of each digital factor has been confirmed by the **SLR** (Section 2.2). In order to explain the process of identification of each digital F_i, it should be stressed out that the DRA is organized into eight parts that have the aim to analyse the eight macroprocesses of an organization, namely: Engineering, Production, Logistic, Quality, Maintenance, Human Resources, Marketing and Supply Chain (Figure 17). For all of them four dimensions are evaluated: Monitoring and Control of the information flux, Technologies level, Execution of information and the Organization of the Structure (Figure 17). For each one of the eight macroprocess there are a series of questions which the managers of the specific departments answer to, with the help of DIHP team. The tool gives as result of the analysis the Digital Maturity Level of the SME in each one of the eight divisions, according to a scale from 1 to 5. Level 1 is denominated as *Initial* and it indicates a poor management of the processes and the presence of not advanced technologies with no interconnection one with the other. Level 2 is called *Managed,* while Level 3 is called *Defined* and it depicts a discrete organization, automation and monitoring of the processes, but still with a low percentage of integration between different resources. The level of maturity number 4 is called *Integrated and Interoperable*, while the optimal one is defined *Oriented to Digitalization* and it is assigned to a firm where all the processes are monitored in real time, the technologies are advanced and both the horizontal and vertical integration are total. It means that the higher the final marks the closer the SME is to Industry

4.0 philosophy. This is the reason why the analysis of DRA is so important for this work thesis, from the questions of the different sections indeed, it is possible to extrapolate the elements that the group of DRA creators considered important for an SME to be classified as a firm 4.0. Hence, the digital factors used in this matrix are in indirect way validated by the professors of Politecnic of Turin and Politecnic of Milan and Confindustria experts that joined the creation of DRA in 2017.

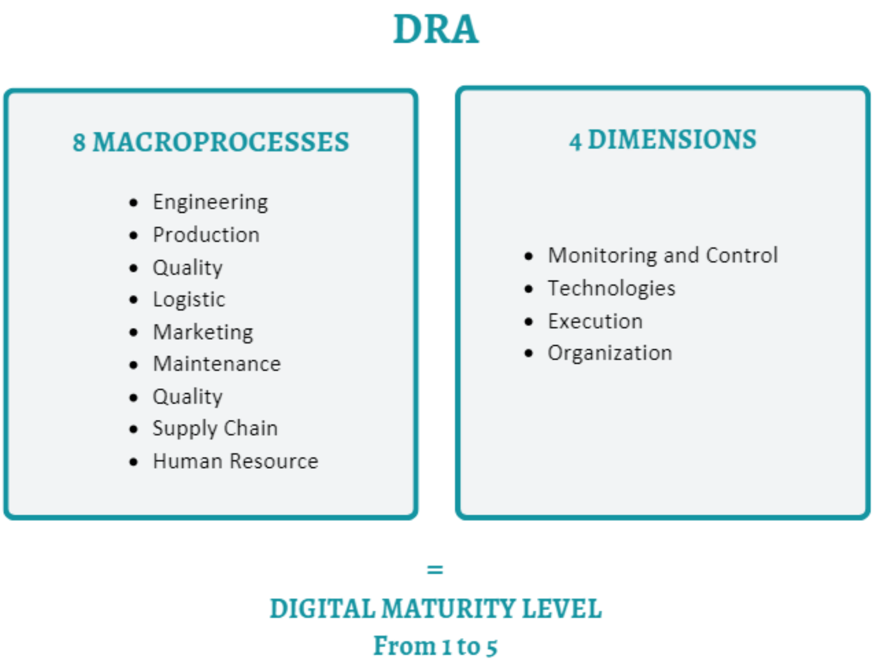


Figure 17: Digital Readiness Assessment structure

In the following paragraphs there are listed the digital factors that the author obtained from DRA analysis and that will occupy the first seven positions of the Fuzzy DEMATEL matrix and an explanatory table is present for each one of them. They are codified as F_i, with i from 1 to 7. For all the selected paradigms there is reported the reference, in the right-hand column of the table, "DRA Reference", to the macroprocess of DRA from which it was got. It puts in evidence the role that it is played by the specific factor in the digital maturity level (DML) calculation of that macroprocess. Obviously, not all the factors are cited in each macroprocess of the questionnaire, because each F_i assumes a different importance in each department. In addition, for each driver the author has reported in the first column of the table, "SLR References", one or more definitions taken directly from the SLR of Chapter 2, in such a way to depict the function that each factor plays in the I4.0 panorama, according to the analysed academic papers.

Horizontal and Vertical Integration and Interoperability (F1)

Table 3: F1 References

SLR References	*DRA References*
Interoperability between all the types of resources, machineries and human is one of the main feature in the scenario 4.0, where the typologies of integration are two: vertical and horizontal and both of them are fundamental to let factories be smart (Machado et al., 2020). Vertical Integration concept represents the connection between machines, devices, sensors and people [14] and it indicates the flattening of the company pyramid, from field level to production level, passing through the operations level and the enterprise planning one. Horizontal Integration instead, regards the interconnection of different stakeholders along the value chain, in such a way to make information flow freely from suppliers toward the production company up to the final users. The integration of the whole Supply Chain increase the likelihood to achieve success in a sustainable production [14].	The two typologies of integration are crucial for digital maturity level (DML) calculation in all the macroprocesses of DRA, in different measures: Engineering: in this first macroprocess of DRA, the DML of an organization increases if there is a good vertical integration between the design engineers and the different CAE software like CAD, CAM. In I4.0 panorama indeed, the planning phase of a product is vertically integrated (Chauhan, et al, 2023) [1]. Production: it is again the vertical integration to play an important role, in DRA it is evaluated the degree of interconnection of machineries along the production line and the information flows between management of procurements, planning activities and WIP monitoring. Quality, Maintenance, HR and Marketing: the DML in these four macroprocesses increases in parallel with the level of vertical integration between human resources, machines and monitoring software, because all of them contribute to optimization of failures number, anticipation of downtimes and study of customers desiderata. Supply Chain (SC) and Logistic: in these two macroprocesses what is important for the DML computation is instead the horizontal level of integration. In a SC 4.0 indeed, the information should flow freely between all the stakeholders, thanks to integration of KETs like Warehouse Management System (WMS), Enterprise Resource Planning (ERP) and Supply Chain Management Systems (Reyes, et al, 2021).

Accessibility to information/Transparency (F2)

Table 4: F2 References

SLR References	*DRA References*
In Industry 4.0 paradigm, F2 indicates the possibility to access to information everywhere and every time, with a series of advantages for the firm efficiency. Some examples are reduction of searching time and costs and mitigation of information asymmetry between the different players inside the organization and along the whole SC (Ciliberto, et al., 2021).	Engineering and Production: accessibility to information increases the DML of an SME, because monitoring makes sense if the collected data are then easily accessible in such a way to improve the decision making. According to the DML scale, the control of the operations is fundamental to pass from one level to the other and it is right the transparency of information that let the processes be monitorable and more efficient, by decreasing the downtimes of both human and not human resources. Between the portfolio of technologies 4.0, Enterprise Resource Planning (ERP) and Manufacturing Execution System (MES) are fundamental for access velocity and transparency of information [14]. Maintenance: in the DRA it is underlined the importance for a maintainer to have access to a significant volume of data about machineries exactly in the time he/she needs to mitigate the intensity of the damages and the faster the access to information, the higher the chances to reduce downtimes and dangerous situations. Supply Chain: in the nowadays dynamic markets the easiness in information access along all the SC is considered a key success factor (Reyes, et al, 2021).

Automation (F3)

Table 5: F3 References

SLR References	*DRA References*
This factor indicates the independence of machines from humans (Mabkhot et al., 2021). It implies reduction of complexity (Ciliberto, et al., 2021) and it is important to stress out that it is one the main functions of I4.0 that companies are adopting (Chen et al., 2022).	Production and Quality: the automation concept is of great importance in the computation of DML of these two macroprocesses, because time, cost and quality can benefit from an increase in automation level. It can indeed lead to an increase of throughput and decrease of cost per piece, thanks to economies of scale [14]. Maintenance: automation in maintenance macroprocess is crucial to measure the level of digitalization, by considering how much failures and anomalies are autonomously signalled by the machines thanks to integration of technologies like Computerized Maintenance Management System (CMMS) and Enterprise Resource Planning (ERP) (Lauria, et al, 2023). Logistic: in a warehouse 4.0 the whole system of picking and packing should be automatized, thanks to barcode RFID for the identification of the charge units and the integration of physical resources with Warehouse Management System (WMS).

Flexibility/Variety (F4)

Table 6: F4 References

SLR References	*DRA References*
Flexibility is entailed as the chance for a producer to use a miscellaneous of materials and as the opportunity to create a variety of different geometries to increase the customers' needs satisfaction, by offering a higher level of customization (Ciliberto, et al., 2021). Customized product delivery is one of the key factors for manufacturing industries in hyperdynamic markets (John, et al., 2021).	Engineering and Production: Flexibility in Engineering and as consequence in the following Production phase has been enhanced in I4.0 by introduction of Addictive Manufacturing tools, like 3D Printing. In the DRA, the DML computation passes also through the ability of an SME to project and produce small batches of customised and lighter products, reducing logistics costs and stock volumes (Machado, et al. 2019). Marketing: An higher flexibility in the materials that could be worked and in the geometries that could be offered to customers means also satisfaction of more desiderata and enhancement of customer experience, one point that is considered in DML computation of Marketing macroprocess (Machado, et al. 2019).

Overall Equipment Effectiveness (F5)

Table 7: F5 References

SLR References	*DRA References*
OEE is a percentage that is considered the gold standard for measuring manufacturing productivity, it is got through Equation (10): $OEE = A * P * Q$ (10) A stands for "availability" of the machineries and production lines to grant business continuity and reduction of downtimes. P stands for "production per time/throughput" and Q for "quality", meaning satisfaction of customers' requirements. OEE is an indicator of efficiency and productivity of an organization (Ciliberto, et al., 2021). In general, 4.0 KETs are expected to bring a performance improvement by definition, in terms of productivity, flexibility and resource efficiency (Machado, et al., 2020).	Production, Maintenance and Quality: as the name of the indicator suggests, the macroprocesses of DRA in which OEE takes part to DML computation are Production, Maintenance and Quality, respectively in terms of availability of machines, reduction of defective pieces and increase of average quality per produced batch.

Real Time Data Collection/Monitoring and Tracking (F6a)

In such a way not to let the Fuzzy DEMATEL matrix be too heavy, this factor "Real Time Data Collection, F6a" and the following one, namely "Data Analysis, F6b" have been incorporated in a unique Factor, F6, denominated "Real Time Data Collection and Analysis", whose acronym is RTDCA.

Table 8: F6a References

SLR References	*DRA References*
Monitoring a process means collecting data through sensors from each working centre to track its performance and analyse past trends to try to forecast future ones. The importance of collecting data was clear also in the 3rd Industrial Revolution, but only thanks to technologies of I4.0 was possible to incredibly increase the volume of collected data. According to academic papers this digital paradigm is strongly correlated with LM and CE principles (John, et al., 2021), for instance digital technologies can enable the monitoring of emissions, ecosystem statuses, and material flows. In a circular economy indeed, digital tracking is an enabler for reuse and recycling and the combination of smart and communicating sensors, with data analytics, may provide a nearly real-time understanding of the environment state [2].	Production, Maintenance, Quality and Supply Chain: Monitoring and control is one of the four dimensions of DRA and the majority of questions about it are concentrated in the previously listed macroprocesses. This underlines one of the main distinctive factor of Manufacturing 4.0, the collection of great volumes of data to monitor in real time the production lines, the status of the machineries, the trends of failures and the needs of the different players of the SC [14].

Data Analysis (F6b)

Table 9: F6b References

SLR References	*DRA References*
The extraction of knowledge from data is crucial to design an information-based knowledge model. Data analysis makes it possible to gain insights into the industrial process, by enabling a Data Driven Decision Making [14]. Between a company with the only goal to increase its competitiveness in the industry and a company with sustainability targets to be reached, there is the data management. The term "analytics" is crucial for I4.0, where enormous quantity of data are collected. Analytics includes various methods for discovering meaningful patterns in data; it uses data science to support making right decisions (Mabkhot et al., 2021).	In the DRA there are questions about Data Analysis/Management in each one of the eight sections. The data curation is a challenge in each department: cleaning up unwanted data, analysing the collected one to grasp information about past trends and forecast the future is fundamental in each macroprocess of DRA. Having the chance to make conscious decisions thanks to information extrapolated from data is one of the distinctive factors of I4.0 (Mabkhot, et al., 2021).

Virtualization (F7)

Table 10: F7 References

SLR References	*DRA References*
It is a close and virtual imitation of a machinery, process or system operation that is already working or that still does not exist, considering its real or potentials characteristics, behaviour and/or physical properties. In the first case it allows real time monitoring though IoT sensors, while in the latter it allows digital simulations. They can give access to the knowledge of the whole life cycle of products, before investing in its construction. This enables the identification of options to improve the environmental footprint, reduce the carbon footprint and increase the useful life [2]. Simulations can support improvements in the factory to reduce energy consumption, and to optimise and add value to operations by simulating all activities within the entire supply chain (Machado et al., 2021)	Engineering, Maintenance and Logistics: the computation of DML of these three macroprocesses takes into account the ability of an organization to simulate products before actually realizing them, simulate production processes before investing into new machineries and layouts and/or simulate the deterioration state of a working tool to predict its useful life and anticipate the failure mode. Technologies 4.0 that can allow these activities are simulation systems and digital twins (Hassani, et al., 2022).

3.3.2. SDGs Factors and core elements of I5.0

Section 3.3.2 is dedicated to the presentation of the three SDGs that could be targeted by an SME of the territory and that are related to the Economical DImension [16]. For the selected goals a deep analysis of the targets and indicators agreed by the United Nations [15] will lead the author to the Sustainable Factors that will take the position 8, 9 and 10 of the Fuzzy DEMATEL matrix.

The Sustainable Development Goals are seventeen (Figure 18) as already anticipated in Section 1.3, but most of them have targets that are directly linked with the introduction of I4.0 technologies in an SME and indicators that can be measured only on a global scale.

Figure 18: Sustainable Development Goals, Source: [15]

Hence, only three of them have been selected for this study, following the division of the SDGs proposed at the Stockholm EAT Food Forum on the 13th June 2016 by the Stockholm Resilience director Johan Rockström and the board member Pavan Sukhdev. They framed a new way of viewing Sustainable Development Goals (SDGs), by classifying them according to three axes of action, economy, society and environment, thereby introducing the SDGs wedding cake format [16], shown in Figure 19. This scheme conveys the idea of how economies and societies should be seen as embedded parts of the biosphere, moving away from the common approach based on a net separation of the three areas. The same model has been presented by Confindustria Piemonte in the “SDG Action Manager plan” (2022). In this work thesis the author decided to focus on three out of four SDGs of the “Economical Dimension” (Figure 19), in such a way to maintain the coherence with the aim of this thesis: the study of relationships between the digital paradigms of I4.0 enabled by KETs (Section 3.1.1) and SDG targets, in an SME context. It should be remembered that I4.0 KETs increase economic competitiveness [14] of an SME, then the author wanted to focus on the SDGs that have as aim an economic growth as well, but this economic goal doesn’t end in itself, as in the previous case. In a Twin Transition context, the economic sustainability of a firm is necessary to be able to target the social and environmental dimension. It is at the center of the Cake Model, then activities, projects, investments that target one of the SDGs in the Economical Dimension don’t have to damage what is around, the social and the environmental dimension.

This thesis focuses on 3 over 4 Economy SDGs, more precisely, the number 8, “Decent Work and Economic Growth”, the ninth one, namely “Industry, Innovation and Infrastructure” and the number 12, “Responsible Production and Consumption”. These three have been defined for sake of clarity, from now on, “SME SDGs”, to indicate the chance for an SME to target them with its commercial and industrial strategies, to reach a sustainable competitiveness. Among all the targets of the 3 selected SDGs, only the ones that could be affected by the adoption of enabling technologies and that could be targeted by a structure with size, economical dimension and number of resources such an SME should be taken into consideration.

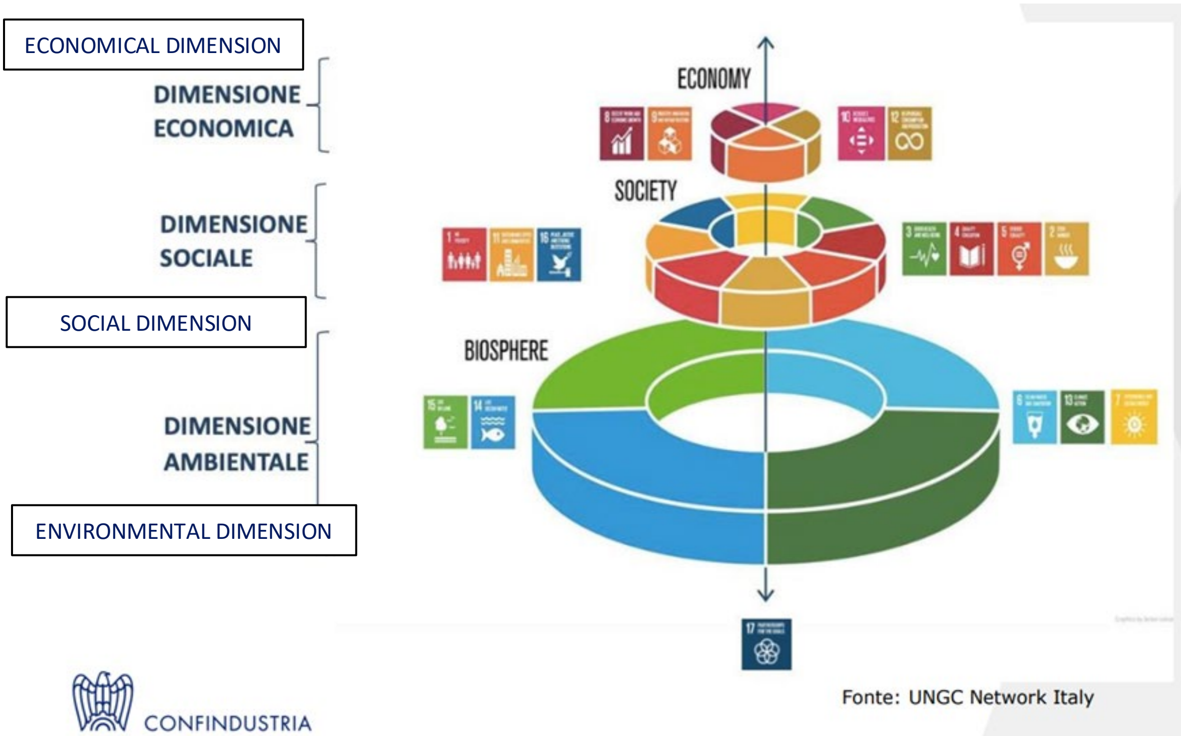


Figure 19: SDGs classification by Confindustria. Source: [3]. The titles have been translated by the author

Each one of the “SME SDG” is presented in the dedicated Subsections, respectively called “SDG 8: Decent Work and Economic Growth”, “SDG 9: Industry, Innovation and Infrastructure” and “SDG 12: Responsible Production and Consumption” . In this respect, the so-called SDGs Targets are the ones of Agenda 2030, visible on the United Nations website in Sustainable and Development section [15]. For each one, it is indicated the correlation with one of the core elements of Industry 5.0, human-centricity, sustainability and resilience, according to “Industry 5.0: Towards a sustainable, human-centric and resilient European industry”, publication in 2021, by Research and Innovation center UE [B4].

SDG8 : Decent Work and Economic Growth

It is the SDG (Figure 20) inherent to the Green Human Resource Management (GHRM), higher degrees of productivity and a stronger competitive advantage are two of the organisational benefits that are normally associated with it (Rehman, et al 2023).

Figure 20: SDG number 8 – United Nations presentation, Source: [15]

This type of management fosters a business organization in which employees are educated to a sustainable and ecological culture and they are motivated and inspired in making their part in the improvement of their firm sustainable impact (Shirin, et al., 2018). GHRM incentivizes also the policies of Diversity Management to educate each level of the organizational hierarchy to inclusion. The majority of the targets of this SDG are inherent to the fact that the work is a human right that donates independence to families and enhances the economical and psychological welfare of each person. In addition, it should be stressed out that enterprises are a fundamental element for the creation of new workplaces, so they play an important role in SDG8 scope [17]. Hence, the point of interest of this goal is not the simple creation of work, but the novelty is the focus on conditions on the workplaces and inclusion in the hiring phase. It is possible to verify these aspects in four selected Targets (Figure 21) out of the original ten:

Target

8.2

Achieve higher levels of economic productivity through diversification, technological upgrading and innovation, including through a focus on high-value added and labour-intensive sectors

Target

8.3

Promote development-oriented policies that support productive activities, decent job creation, entrepreneurship, creativity and innovation, and encourage the formalization and growth of micro-, small- and medium-sized enterprises, including through access to financial services

Target

8.5

By 2030, achieve full and productive employment and decent work for all women and men, including for young people and persons with disabilities, and equal pay for work of equal value

Target

8.8

Protect labour rights and promote safe and secure working environments for all workers, including migrant workers, in particular women migrants, and those in precarious employment

Figure 21: Target 8.2, 8.3, 8.5 and 8.8 of SDG number 8, Source: [15]

This goal stresses out the fact that economic productivity is not connected only to performance factors, but it is measured also in terms of diversity of workforce, as stated in Target 8.2 and 8.5, the concept of productivity is then connected to inclusion of women, youngsters and differently abled people. Such a competitive inclusion can be enabled by technological upgrading and innovation by starting from small and medium sized enterprises as confirmed in Target 8.3. The term “decent” that is used in number 8.5 is connected to the pay and to the security (Target 8.8) granted to the worker on the workplace and to suppliers along the supply chain [17].

It is straightforward to notice a connection between SDG 8 and the core element of I5.0, Human centricity, that means to adapt technologies to workers needs, rather than asking industry workers to adapt their skills to the adopted technologies [B4]. In the listed targets indeed, the economic growth through technological development is promoted, but it described as a sustain for decent job creation, for human creativity enhancement, for

everyone inclusion and for the creation of safe workplaces. SDG8 promotes a “Human centric economic growth”.
F8 will be the factor dedicated to the SDG number 8, it will be considered a cause in the case in which attempts and policies to achieve one of the targets presented in the previous paragraph generate benefits for other factors of the matrix. It will be interpreted as an effect instead, if the pursuing of other factors will play a positive role in the achievement of one or more of these targets, by putting technology at the service of human operators. The same cause-effect reasoning to fill the matrix will be used also for F9 and F10, respectively related to SDG9 and SDG12, presented in the correspondent Subsections.

SDG9 : Industry, Innovation and Infrastructure

SDG 9 (Figure 22) seeks to promote sustainable industrialization, technological innovation, and resilient infrastructure. This goal is crucial for advancing technological progress and promoting sustainable production processes, which can help reduce the negative impacts of industrialization on the environment (Dinis-Carvalho, et al., 2023). It is strongly connected with the Resiliency core element of I5.0, as the tile of goal suggests, that refers to the ability to change and adapt to the changes [B4]. According to academic literature it is the most impacted SDG by KETs development (Mabkhot, et al., 2021), particularly by Industrial Internet of Things implementation, Cloud Computing and Horizontal and Vertical System Integration.

Figure 22: SDG number 9 – United Nations presentation, Source: [15]

There is a strong interrelationship and interdependence between goal 9 and the concepts of 4th industrial revolution and sustainable development. Small industrial enterprises are more vulnerable than larger firms to economic downturns owing to their limited financial resources and greater supply chain dependencies. In general, industries that are well diversified and with innovative infrastructures suffer less from damages in recession periods, as it is shown in Figure 23, result of a United Nations statistic about goal 9 [15]. Higher technology industries result then to be more resilient.

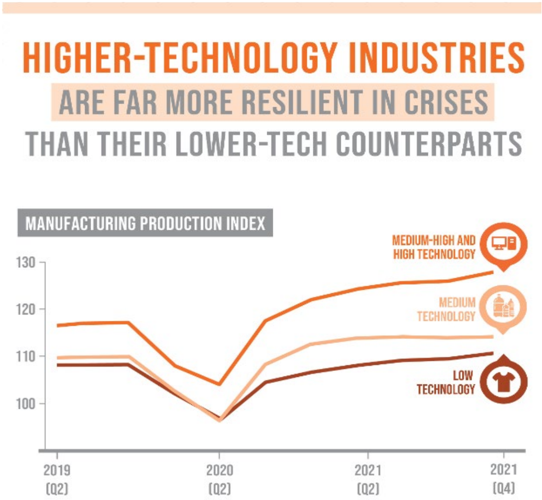


Figure 23: SDG 9 overview – United Nations presentation, Source: [15]

In Figure 24, the list of the four targets that have been considered in this study:

9 INDUSTRY, INNOVATION AND INFRASTRUCTURE

Target

9.2

Promote inclusive and sustainable industrialization and, by 2030, significantly raise industry's share of employment and gross domestic product, in line with national circumstances, and double its share in least developed countries

9 INDUSTRY, INNOVATION AND INFRASTRUCTURE

Target

9.3

Increase the access of small-scale industrial and other enterprises, in particular in developing countries, to financial services, including affordable credit, and their integration into value chains and markets

9 INDUSTRY, INNOVATION AND INFRASTRUCTURE

Target

9.4

By 2030, upgrade infrastructure and retrofit industries to make them sustainable, with increased resource-use efficiency and greater adoption of clean and environmentally sound technologies and industrial processes, with all countries taking action in accordance with their respective capabilities

9 INDUSTRY, INNOVATION AND INFRASTRUCTURE

Target

9.5

Enhance scientific research, upgrade the technological capabilities of industrial sectors in all countries, in particular developing countries, including, by 2030, encouraging innovation and substantially increasing the number of research and development workers per 1 million people and public and private research and development spending

Figure 24: Target 9.2, 9.3, 9.4 and 9.5 of SDG number 9, Source: [15]

The effects of digitalization and industrialization are not always positive in terms of sustainability (Lekan et al., 2022; Estevao, et al., 2023), this is why there is Target 9.2 that fosters a sustainable increase of GDP. It means that the plants and the technologies adopted in the organizations should be environmentally sustainable and buy only high quality materials in such a way to grant the security of workers and consumers, it is not a trustful KPI the simple increase of the work places and/or GDP. It is repeated again in Target 9.4, where it is underlined the interest of United Nations in upgrading the old infrastructures to reduce their CO_2 emissions and increase their energetic efficiency. It can be done with new technologies adoption (Target 9.5) and formation of workers about their efficient usage. In hyperconnected industrial fields, it is not anymore sufficient to focus on the single production plant, all the supply chain should start a sustainable journey through innovation, by including in the process all the small suppliers (Target 9.3).
The ninth position of the matrix will be dedicated to SDG9 and the Resiliency element of I5.0, denoted with F9.

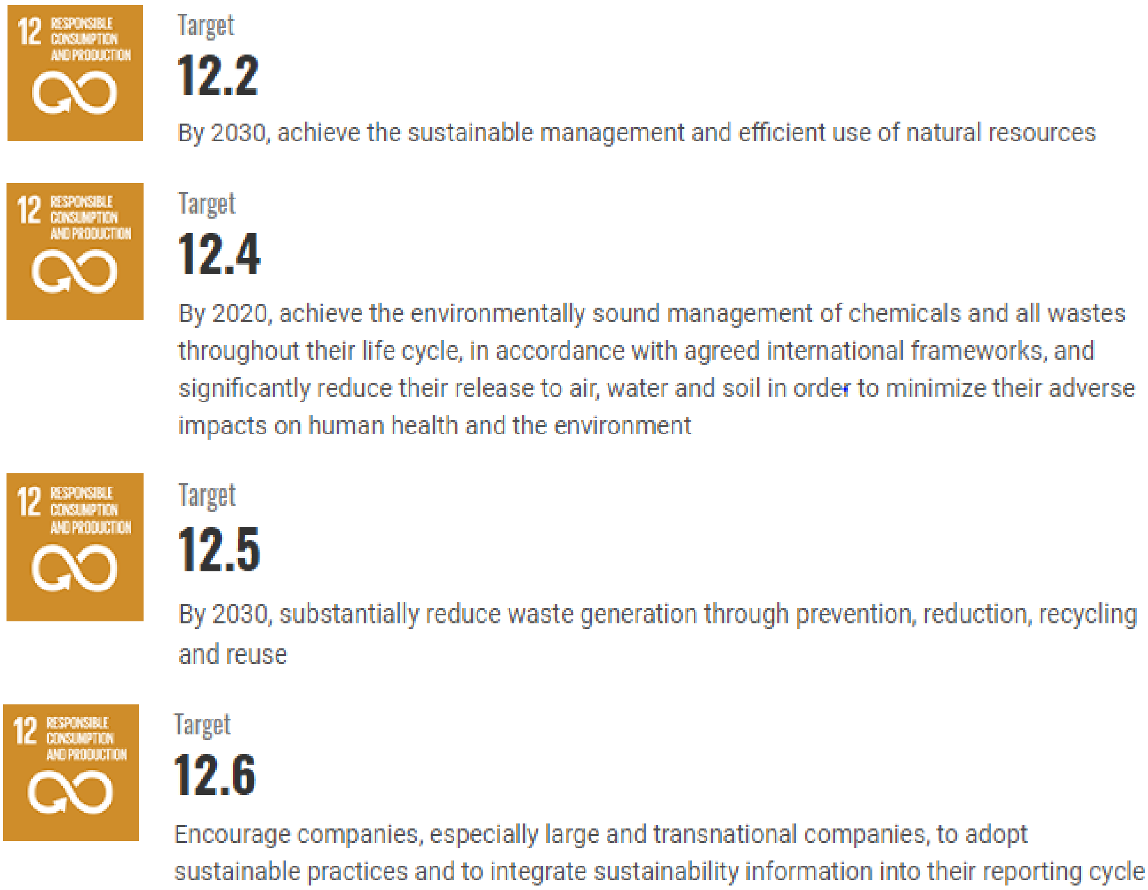
SDG12 : Industry, Innovation and Infrastructure

Another SDG which is crucial to reach a sustainable production and a sustainable supply chain is the number 12 (presented in Figure 25), which focuses on responsible consumption and production, aiming to reduce waste, increase resource efficiency, and promote sustainable practices in production and consumption (Dinis-Carvalho, et al., 2023). It underlines again the importance in I5.0 not only to increase the production, but to let it be sustainable. Sustainability is indeed the third core element of I5.0 [B4].

Figure 25: SDG number 12 – United Nations presentation, Source: [15]

The parameter of the matrix referred to SDG12 and to the Sustainability element 5.0 is F10 and it is strictly connected to the 9R of the Circular Economy theory, described one by one in Subsection 1.2.2, namely Recover, Recycle, Repurpose, Remanufacture, Refurbish, Repair, Reuse, Reduce, Rethink and Refuse.
Factor 10 will be considered a cause or an effect of other factors respectively in the case in which the pursuing of the four targets listed in Figure 26 brings or receives benefits to or from

other F_i. F10 includes the following four targets, considered the ones which an SME can target to.


12 RESPONSIBLE CONSUMPTION AND PRODUCTION

Target

12.2

By 2030, achieve the sustainable management and efficient use of natural resources

12 RESPONSIBLE CONSUMPTION AND PRODUCTION

Target

12.4

By 2020, achieve the environmentally sound management of chemicals and all wastes throughout their life cycle, in accordance with agreed international frameworks, and significantly reduce their release to air, water and soil in order to minimize their adverse impacts on human health and the environment

12 RESPONSIBLE CONSUMPTION AND PRODUCTION

Target

12.5

By 2030, substantially reduce waste generation through prevention, reduction, recycling and reuse

12 RESPONSIBLE CONSUMPTION AND PRODUCTION

Target

12.6

Encourage companies, especially large and transnational companies, to adopt sustainable practices and to integrate sustainability information into their reporting cycle

Figure 26: Target 12.2, 12.4, 12.5 and 12.6 of SDG number 12, Source: [15]

The Targets 12.2, 12.4 and 12.5 underline the centrality of the efficient use of resources. The symbol agreed upon by United Nations Commission for this goal is explicative of the main point of attention of SDG12: the circular economy and the R strategy. This sustainable goal is strictly connected to KETs, particularly to Horizontal and Vertical Integration systems and Data Management, Target 12.6 indeed, underlines the importance of collect information to enhance the sustainability of a business. It is an evidence of the fact that the relationships in the model both with the digital factors and with CE dimensions are expected to be strong. CE itself is considered the enabler of economic, environmental and social benefits. CE is seen as a way to redefine the corporate business model, thanks to adoption of recovery, reuse and recycling practices (Moktadir et al., 2020). The connection between the adoption of technologies 4.0 and the circular economy and as consequence SDG12 is explained by the incipit of the European «Circular Economy Action Plan» . It states that *«Building on the single market and the potential of digital technologies, the circular economy can strengthen the EU's industrial base and foster business creation and entrepreneurship among SMEs. Innovative* *models based on a closer relationship with customers, mass customisation, the sharing and collaborative economy, and powered by digital technologies, such as the internet of things, big data, blockchain and artificial intelligence, will not only accelerate circularity but also the dematerialisation of our economy and make Europe less dependent on primary materials» [5].*

3.3.3. LM and CE Factors

As presented in the Section 1.3, in the Industry 5.0 framework, Lean Manufacturing and Circular Economy principles collaborate with Industry 4.0 technologies in reducing waste, increasing efficiency, and minimizing environmental impact (Dinis-Carvalh et al, 2023). They all take part to the journey that an organization has to do to reach a sustainable competitive advantage. In such a way not to let the matrix be too complicated to be filled by interviewed suppliers, only the last two factors, F11 and F12 will be dedicated to the topic of this Subsection number 3.3.3.

Factor 11, that is simply called Lean Manufacturing (LM), includes all the elements presented in Table 11 and described in Subsection 1.2.1.

Table 11: Lean Manufacturing principles and techniques

JIT production and continuous improvement philosophy	● *Just-in-time (JIT)* ● *Kaizen*
Industrial flows analysis and Data Visualization	● *Value Stream Mapping (VSM)* ● *Bottleneck Analysis* ● *Kanban*
Process standardization	● *Poka-Yoke* ● *Jidoka* ● *5S Method: Sort, Straighten, Shine, Standardize, Sustainment*
Waste Reduction	● *excess inventory* ● *over-production* ● *defects that require costly correction* ● *waiting time* ● *resources motion with no value added* ● *unused talent* ● *over-processing*

Then, the meaning of this factor will be the following: if the pursuing of another driver has also a positive effect on one of the listed elements in Table 11 the former will be considered cause of F11. An example could be an investment on the improvement of a digital factor that let a Lean techniques be more precise and efficient or one of the Seven Wastes be reduced.
Factor 12, is named Circular Economy (CE) and it implies the 9R Strategy (Subsection 1.2.2): *Recover, Recycle, Repurpose, Remanufacture, Refurbish, Repair, Reuse, Reduce, Rethink*. A digital or SDG driver can have a relationship with F12, if its pursuing can enhance one or more of the Rs, in this case that dimension will be a cause of CE factor. On the contrary, F12 will result a cause if the application of the 9R brings benefits to the achievement of another factor.

3.4. The Fuzzy DEMATEL Matrix

In this Section, the Fuzzy DEMATEL Matrix has been filled with all the Factors presented in the Section 3.3, by reporting the same list of dimensions both on the columns and on the rows, according to the model construction described in Section 3.2.
The Figure 27 represents the *Direct Influence Matrix of Assessment* that has been proposed to each technological provider (E_p) interviewed for this thesis, whose answers are reported and analysed in the following Chapter 4. It is possible to see how the main fields of Industry 5.0 ecosystem (Section 1.3) are represented by one or more Factors: from F1 to F7 the dimensions are inherent to Industry 4.0 and they are called Digital Factors (Subsection 3.3.1), from F8 to F10 included there are the SDGs Factors and their correlation with the 5.0 core elements, human centricity, sustainability and resiliency (Subsection 3.3.2) and the last two places are filled respectively by the dimensions related to LM and CE principles (Subsection 3.3.3).

Fuzzy DEMATEL *Matrix*			Digital Factors							SDGs Factors			LM & CE Factors	
			H/V Integration	Data Access	Automation	Flexibility/ Variety	OEE	RTDCA	Virtualization	SDG8 - Human Centricity	SDG9 - Resiliency	SDG12 - Sustainability	LM	CE
			F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12
Digital Factors	H/V Integration	F1												
	Accessibility to_Information	F2												
	Automation	F3												
	Flexibility/ Variety	F4												
	OEE	F5												
	RTDCA	F6												
	Virtualization	F7												
SDGs Factors	SDG8 - Human Centricity	F8												
	SDG9 - Resiliency	F9												
	SDG12 - Sustainability	F10												
LM & CE Factors	LM	F11												
	CE	F12												

Figure 27: Fuzzy DEMATEL Matrix

CHAPTER 4

4. Canva applicative sessions

This is the chapter dedicated to the "Forward Pass" of the model, codified with FP, consisting in Canva applicative sessions with the fourteen selected technology providers according to the filtering process described in Section 4.1. The list of the participants is presented in Section 4.2, while the structure of the Canva supporting material used in the sessions is described in Section 4.3. These discussions are articulated in two phases: a preliminary reasoning about the digital enabling power of the KET produced or commercialized by the interviewed vendor, which is the topic of the Section 4.4, and a generalised analysis (Section 4.5) of the influential links among the factors of the TwinSME model, through the filling of the Fuzzy DEMATEL matrix.

4.1. Technology providers selection process

The selection process of the technology providers that joined the Canva sessions consisted of three filters: by technology, by territory and by expertise. It is schematized in Figure 28.
First of all, it has been made a filter "by technology", filtering between the various enabling technologies of the Industry 4.0. The list of KETs at which both DIHP and this thesis makes reference, as presented in Section 3.3.1, is the following: Additive Manufacturing, Advanced Manufacturing Solutions, Augmented Reality, Big Data & Analytics, Cloud systems, Cybersecurity, Horizontal and Vertical Integration software, Industrial IoT, Simulation software (Rüßmann et al., 2015; Saucedo, et al., 2018; Alcácer, et al., 2019).
In order to choose the technological areas to focus on, the author made a quantitative analysis of the DIHP Digital Readiness Assessment (DRA) data, which are collected in a dedicated Excel file, of DIHP ownership, containing 388 SMEs with an operative seat in Piedmont or Valle d'Aosta regions that have made the DRA from the 1st January 2017 and the 1st January of 2023. For each one of them, the DIHP team reported the town in which it is located, the number of employees, the annual revenues, the industry, the digital maturity level obtained at the end of the DRA for each macroprocess and for each dimension and the answer to each question of the assessment. Thanks to these data, the author has been able to detect which were the technologies in phase of adoption by the assessed SMEs and the ones that have been suggested as intervention lines by DIHP team in the digitalization

roadmap to improve the Technological dimension. In the following, it has been discussed KET by KET its inclusion or dismissal in the selection process. For the sake of clarity, it has been maintained an alphabetic order between the technological areas.

- The 5% of the 388 firms that made a DRA in 2022 belongs to the Industry of plastic materials and rubber transformation. The 100% of them evaluated the adoption of Additive Manufacturing (AM) solutions. In addition, the Metals industry constitutes the 24% of the whole set, and its 50% considered Additive manufacturing as well. Hence, the AM has been considered as an area of interest for a significant percentage of the SMEs of the territory and as a consequence for the work thesis.
- Advanced Manufacturing and Logistics Solutions (AMLS) have been included in the thesis. To understand their employment rate on the SMEs of the territory is sufficient to say that the totality of the enterprises in Industry of the machines and equipment, also called Automation industry, which is the 11% of the total, had at least one element among automated warehouses, cobots, AGV.
- Augmented Reality (AR) is the third KET to be selected, because between the adopted technologies or among the proposed intervention lines to the SMEs that must make maintenance or provided safety service directly at customers plants (13%), there is always an AR digital solution. An example is a visor to enable the field operators in accessing virtual maintenance manuals and maintaining a constant and online contact with the technical office during the intervention.
- Horizontal and Vertical Integration software are the privileged technologies by the SMEs, they can be adopted by every industry indeed and the regional and national calls for fundings of the last years, financed their adoption. Then, at all the firms that didn't have already adopted an ERP (39,13% of the assessed SMEs) DIHP suggested to introduce it. In particular the marketing and customer care module have been proposed to the 78,26% of them, while supply chain integration software have been requested by the 100% of the firms producing alimentary products, that transforming a perishable good, need an end-to-end collaboration along the Supply Chain (SC) to maximize the value creation. Same reasoning for the commodities producers in the metal industry (24%), where the margins are so thin, that SC productivity is a differentiator factor with the competitors.
- It has been decided not to dedicate specific Canva sessions to the following four KETs, IoT, Big Data Analytics, Simulation software and Cloud Computing, because in the SME scenario, analysed through DRA data, the investments in these areas are made in parallel with integration software adoption, so it has been chosen to find technology providers that offer intelligent supply chain platforms including also modules managing these aspects, in such a way to discuss with them the potentiality of the adoption of a digital solution including all of them.

- No supplier in the field of Cyber Security has been involved, for a reason of coherence with the tool used for the Fuzzy DEMATEL matrix creation. The digital factors derive from the analysis presented in Section 3.3 of the Digital Readiness Assessment questions, that measures the digital maturity level of the assessed SME. There is another Assessment dedicated to the measurement of the cyber security readiness, that hasn't been considered for the selection of the dimensions put in the matrix, in such a way not to let the model be too heavy to be presented to the suppliers during the Canva sessions.

To wrap up, as it is showed in Figure 28, the technological areas that have been selected after this first step of filtering are: Additive Manufacturing, Advanced Manufacturing Solutions, Augmented Reality and the field of Horizontal and Vertical Integration software with modules dedicated to Data Analytics of data collected from Industrial IoT sensors and Simulation.

The second filter applied in the selection process is "by territory". For each typology of technology indeed, DIHP had many providers in its PRM, Partner Relationship Management. It has been given the precedence to the suppliers with at least one operative seat in the region of Piedmont and Valle d'Aosta. On one hand, it is likely that they have supported at least once the SMEs assessed by DIHP. On the other hand, they have a quite homogeneous perception of the needs of the market and they all are in the network of at least one of the following entities, being always informed of the new academics research to mirror them on the working field: Politecnico of Turin, Competence Centres and Poles of Innovation of the territory.

The third filter is called "by expertise". Between the selected organizations after step 1 and 2 , this filter has been used to select the representatives for each provider to be involved in the Canva session. There were accepted people with more than 5 years of experience in the technological field of reference, profiles of Responsible of Production or Marketing and Communication of one business unit and founders or co-founders of the activities. All the participants know very well the digital potential of their technological solution and the sensitivity of the market to the different features of the KET and the penetration of the different versions. Hence, they have also an idea of the future evolution of these products to continue in satisfying the requests of the SMEs. It is right this deep knowledge of the market and the hands-on day-by-day experience on real business cases that has been fundamental to fill the matrix.

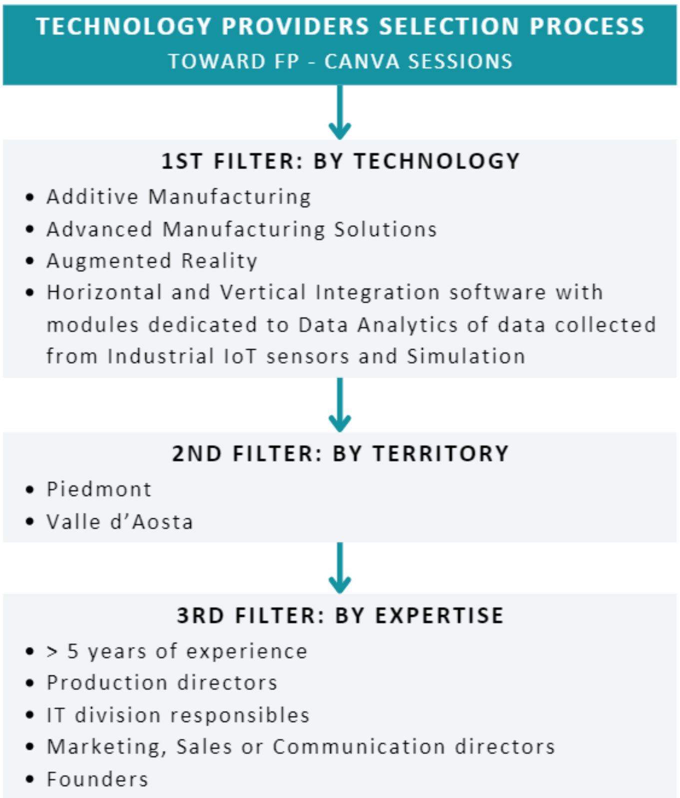


Figure 28: Selecting Process of technology providers

4.2. Technology providers presentation

In this Section, the technology suppliers that have been selected with the process detailed in the Section 4.1, have been described one by one. They are grouped for KET of reference. For sake of clarity, each Canva session has been codified with the notation [CVi] with i from 1 to 14. The codification [CVi] has been used in the following sections to refer to statements and results of the Canva session i. For each provider it is reported the name of the organization and the division of reference of the manager that joined the session. Then, it is written down the name and the role of the interviewed person followed by a brief presentation of the business core and history of the firm, in the case in which the manager signed down the written permission for the author to publish it. For confidentiality reasons some providers didn't give such a permission. In any case, for all the sessions it is stressed out the reasons why the specific vendor has been selected for this thesis.

4.2.1. Additive Manufacturing (AM)

[CV1] Overmach SpA – Additive division

Gabriele Marletta – IT specialist

Overmach operates in the field of Machine Tools since 1817 and it has four reputable divisions: Overmach Engineering, Overmach Tools, Overmach Service and Overmach Additive. The manager that joined the Canva session belongs to the latter, he was chosen because he is the expert of the 3D printings that the structure commercializes. Overmach is a master in the Additive manufacturing field, it proposes indeed solutions that allow different combinations of materials and technologies, by supporting the customers SMEs in a continuous improvement of the precision, flexibility and efficiency of the printing process. In their portfolio there are 3D printers with polymer powder casting technology, with photopolymers and some others with laser fusion of metallic powders. The producer of many of them is Stratasys [18].

[CV2] AM supplier 2

Project manager in AM adoption projects

For reasons of confidentiality, it is not possible to publish the name of the expert that joined the session and his organization. It is important to stress out that it has been chosen for the important role it has on the territory in customizing the AM solutions according to the needs of the customers SMEs.

[CV3] AM supplier 3

Additive Manufacturing system integration responsible

This third provider has been selected because of its AM unique solution, based on a Large Format Additive Manufacturing system, constituted by a robotized head with continuous feeding of polymers, its expert put at disposal his experience in the integration of the specific software platform to manufacture advance industrial parts.

4.2.2. Advanced Manufacturing and Logistics Solutions (AMLS)

[CV4] AMLS supplier 1

Area manager

The name of the organization cannot be reported, but it should be specified that the manager who joined the Canva session has an experience of 20 years as commercial manager in intralogistics solutions industry. The discussion was about advanced solutions for material handling.

[CV5] AMLS supplier 2

Project manager in AMLS development projects

The name of the firm cannot be published for reasons of confidentiality, but it should be reported their role in the study of the Production and Logistics flows of their customers with the aim to start with them customized projects of new technologies adoption, like cobots and AGV, to increase the Overall Equipment Effectiveness of the structure.

[CV6] AMLS supplier 3

IT expert

It is a provider with a global experience in the development of industrial automation products and inspection equipment. Their portfolio of products include code readers, laser markers, machine vision systems, measuring systems, microscopes, sensors, and static eliminators. Their offer is in constant evolution in such a way to fulfil as much as possible the technical requests of the market in terms of precision, velocity and flexibility.

[CV7] *AMLS supplier 4*

Production responsible

The fourth AMLS provider has been chosen for its experience in the advanced production robotics, its automated solutions are integrable with MES and ERP and collect data in real time through IIoT sensors about throughput, quality and generated waste in the production operations.

4.2.3. Augmented Reality

[CV8] Kiber, VRMedia Srl

Corrado Vesentini – Sales Director

Denise Amadei – Marketing Director

Kiber is powered by VRMedia, spin-off company of the Scuola Superiore Sant'Anna, which is in the top global ranking of Higher Education for applied sciences. Kiber produces AR solutions providing the "Instant Expertise" to accomplish hard or dangerous tasks in challenging conditions, by enhancing the interaction between people and promoting safety and efficiency. It has two seats in Italy, one in Pisa and the other in Cagliari, but it has important contacts and partners in North Italy too, thanks also to the numerous technological fairs at which they take part. The outstanding solution is Kiber K3S, an AR helmet which integrates technical tools, cross reality, and Android apps to bring Instant Expertise Everywhere. It is thought to connect field technicians to company systems, or line operators to office leaders through real time audio and video documentation to reduce error rates, let peer learning be easier and let production be faster. It provides workers with visual and voice instructions for assembling or repairing equipment, with no limits of distance and time. It had a sales boost during Covid-19 pandemic period, because like many other digital solutions, it has been considered fundamental for business continuity [19].

[CV9] AR supplier 2

Area manager

For reasons of confidentiality, the name of the organization cannot be revealed, but it should be stressed out their important experience in AR solutions, that brought advantages in the customers SMEs in terms of enhancement of operators training and remote inspection of plants. Their applications include 3D models of the machines with virtual attachments, like manuals and maintenance registers for each component. It is very useful to reduce travel hours and learning time.

4.2.4. Horizontal and Vertical Integration software

This Subsection is dedicated to producers and resellers of integration software including modules of IoT sensors data collection, Data Analytics and Simulation software.

[CV10] OSL Overmach Group

OSL expert

OSL Srl is a software house specialized in providing IT solutions for the production management of metalworking companies, software of machine interconnection and production plant monitoring. In 2019, OSL became part of the Overmach S.p.A. Group with the goal of creating a synergy by products offerings and services delivering in the engineering world [18].

[CV11] Digitalsoft

Giulia Ruffatto – Head of Product Marketing and GTM

Digitalsoft is a software house with five seats all over the world with the goal to make smart factories achievable for manufacturing companies, thanks to their digital solution, namely d-one. It is a supply chain integration platform enabling an end-to-end connected value chain, obtained by the optimization of industrial software. This platform is the reason why this vendor has been selected for the work thesis, it is indeed composed of four main modules with an easy ERP connection. It includes first of all d-oneplan, which is an integrated business planning, that has features like demand management, production planning, simulation tools, inventory management. The second unit is d-onefactory, that enables a smart execution and control of operations, managing logistics, material handling, predictive maintenance. The third one is d-oneiot, that as the name suggests it is dedicated to data collection from IoT sensors, digital twins management, factory data analysis. The last module is the supplier collaboration one, called d-onenext, that simplifies collaboration with vendors and supports a supplier portal for supply data management [20].

[CV12] rsAutomazione Srl

Francesco Santoro – Sales and Marketing Manager

It is a software house that develops integrated solutions to create a perfect mix between engineering and creativity. It overcomes the selection process because it is both a user and a reseller of the most famous CAM in the world, Mastercam, that sees its main application in guiding CNC tools. In addition, they commercialize rsMES for Industry 4.0, a Manufacturing Execution System easily integrable with ERP and able to analyze the data collected from IoT sensors on the production lines about throughput, cycle time, production orders, quality controls, warehouse management. The masterpiece is the 100% compatibility between rsMES, CNC and Mastercam [21].

[CV13] Tesisquare – Fondazione DIG421

Elio Becchis – Senior Solution and Delivery Manager

Tesisquare has 28 years of experience in the Information Technology field and 6000 enterprises in its network, with seats in 40 countries around the globe, with 8 ones only in Italy. The Canva session was hold on by Torino division. Their mission is to support firms in the digitalization of the supply chain, by having as final target an end-to-end operative excellence, which is perfectly coherent with what was requested by HVIS providers filtering process. Its masterpiece in integration software is TESISQUARE Platform that supports customers in the development of an interconnected SC ecosystem with a complete integration of the data flows. It is a scalable solution, that includes four main modules, one of all is TESI SRM, dedicated to the optimization of the suppliers relationships, passing through sourcing management, procurement, replenishment and work order management. The second and the third modules are respectively TESI MAKE, that allows product traceability and TESI TMS, that digitalizes the transportation in and out, by integrating monitoring systems of the carriers and simulating the costs. The last section is TESI SALES, that includes functionalities like consumer engagement, customer orders planning and simulation for a rapid orders execution. In particular, the Canva session was settle up with an expert of TESI Control Tower, the suite software of TESISQUARE Platform, that constitutes a central hub for the visibility, analysis and management of the whole supply chain, through systems of proactive notification, KPIs and dashboards [22].

[CV14] PlaNet Srl Information Systems

Domenico Bernardo – Innovation Manager

They pool their experience in the IT field, with an emphasis on Internet services, database design, CRM and e-commerce development. Their aim is to realize design solutions for the integration of new technologies and optimization of the IT environment, by taking care of training, technical help, trouble-shooting, maintenance and up-dating of the products.
It has the operative seat in Firenze, but it follows many important projects in Turin as well. It has been selected in such a way to have feedbacks also from a player that supports firms and associations of the territory in the communication enhancement and in the IT management system integration [23].

4.3. Forward Pass steps

Each of the selected technology providers went through the two steps of the Forward Pass, joining a Canva session, organised in a first part dedicated to a preliminary reasoning with the vendor on the digital enabling power of the commercialized KET and a second one, where the focus shifts on the relationships between digital and sustainable factors. In this section the logic at the basis of the Canva support material is presented in a detailed way and it is schematized in Figure 29.

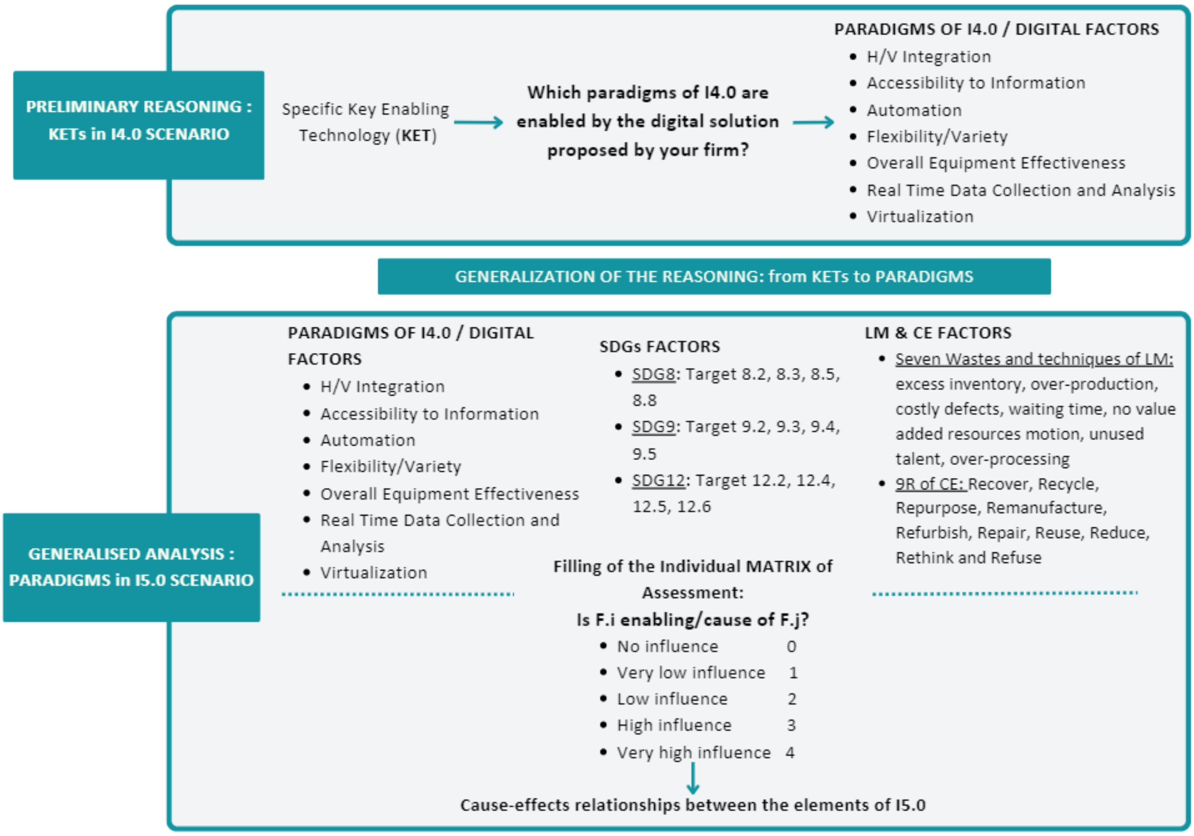


Figure 29: Forward Pass steps

The Canva applicative session has been chosen as methodology of acquisition of the evaluations from the suppliers for the FP, because of the novelty of the topics about Twin Transition. Canva discussions have been managed through Microsoft Teams meetings. One call has been settled up for each supplier, with the participation of the author and the enterprise tutor. A Canva presentation was used as support during the meetings and it was filled directly by the author. The title of the presentation is explicative of the topic of reference, "Twin Transition for SMEs". The first slides are dedicated to the first step of the FP, described in the upper part of Figure 29, in which the author introduces the digital paradigms, listed in Figure 30, and describes the role that they play in the Industry 4.0 scenario. The main message of the first part of the session is the fact that I4.0 is not a synonim of KETs, the latters are enablers of the paradigms that characterize the Fourth Industrial Revolution, as it was explained in two different Sections, 1.1 and 3.3.1.

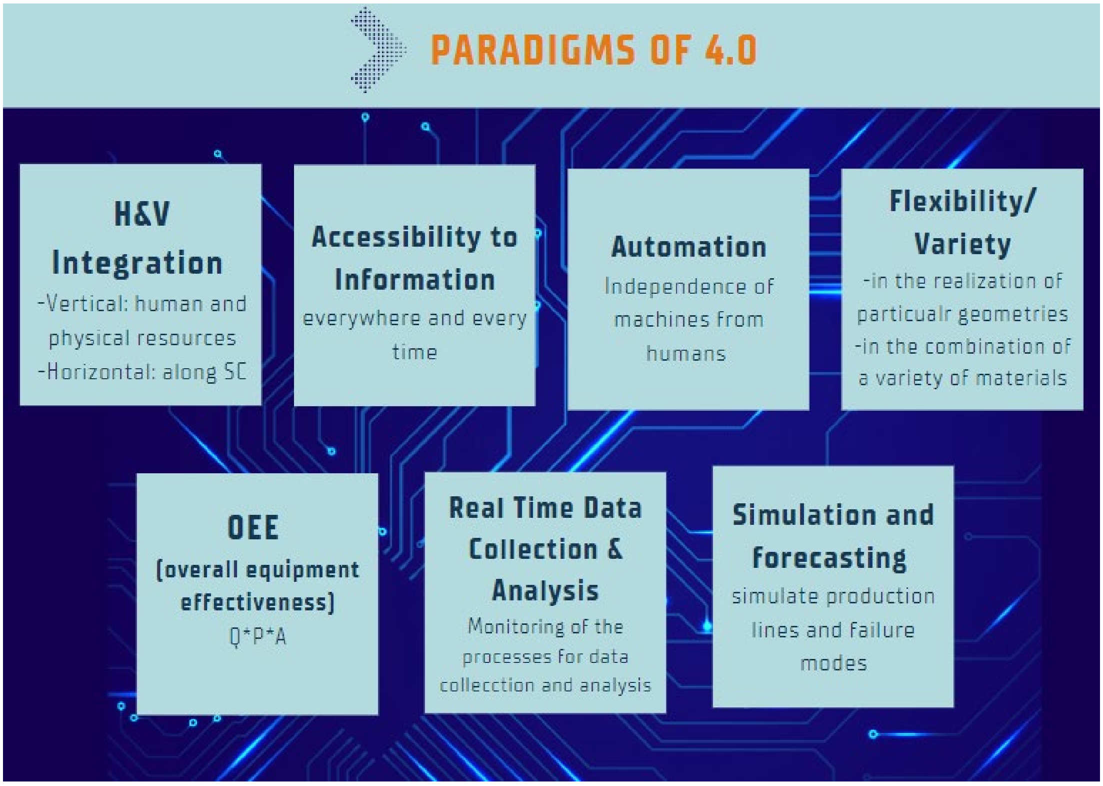


Figure 30: Paradigms of Industry 4.0

Then, the author asks to the supplier to express the digital potential of his/her technological solution in forms of digital paradigms, by answering the question of Figure 31:

Figure 31: Digital enabling power of the KET

The answer was quite straightforward for all the vendors, because each one of them knows very well the characteristics of his/her product. The digital profile of a technology indeed, is a key success factor in the IT industry, then, all the production directors and area managers with a certain amount of years of experience can easily point out the digital factors that let his/her organization win a market positioning in an Industry 4.0 scenario.

In the second part of the Canva presentation, there was instead an introduction to the Twin Transition scenario, by adding to the previously analysed digital paradigms, the sustainable factors. Each additional element is explained by a specific slide, to clarify the meaning of all the factors that will be present in the Fuzzy DEMATEL Matrix. Hence, there are three slides dedicated to the presentation of the "SME SDGs", that are present in the matrix in the form of three Factors, more precisely F8, F9 and F10. In Figure 32 it is shown the SDG8 and the four chosen Targets (Subsection about "SDG 8"), in Figure 33 it is visible the SDG9 and the respective selected Targets (Subsection about "SDG 9") and Figure 34 is instead dedicated to SDG12 description (Subsection about "SDG 12").

Figure 32: The selected targets of SDG8

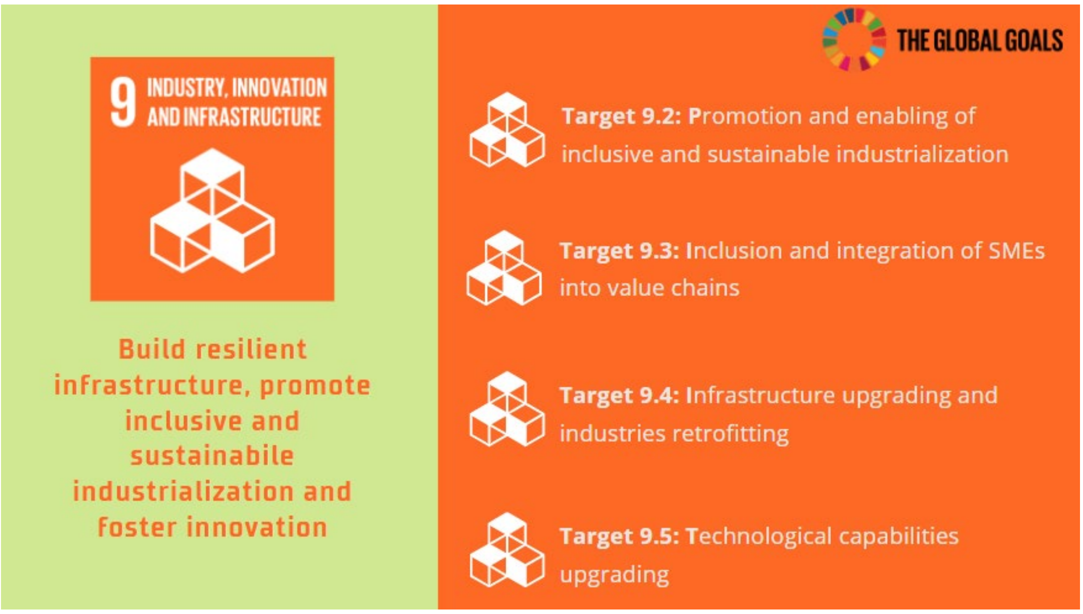


Figure 33: The selected targets of SDG9

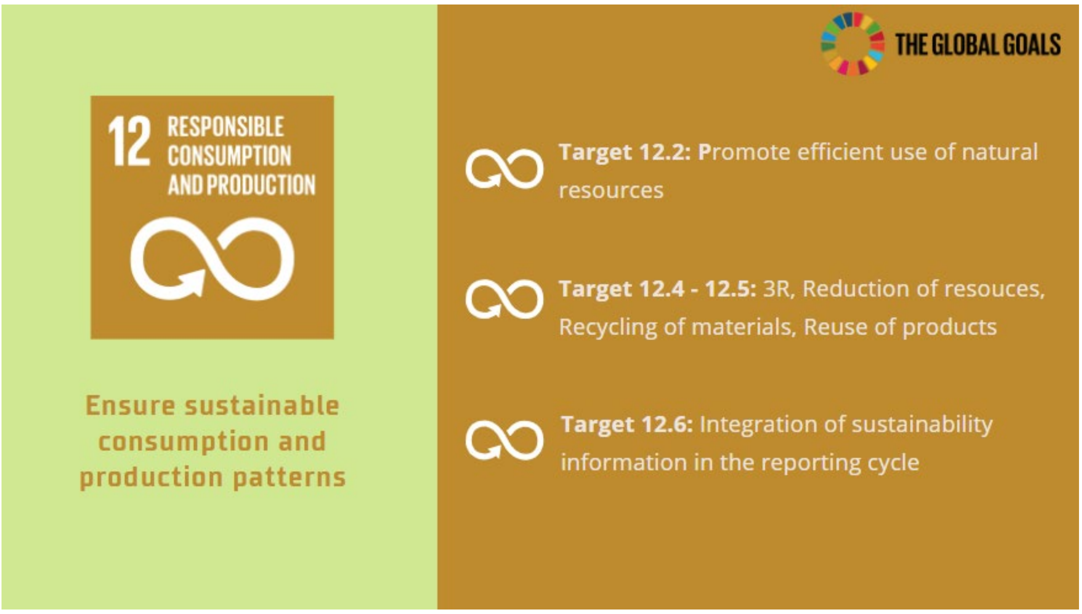


Figure 34: The selected targets of SDG12

The last two factors, F11 and F12, respectively the selected LM principles and techniques and the Nine R of the Circular Economy are presented in the dedicated slide of Figure 35.

Figure 35: LM and CE principles presentation

If in the first part of the session the focus was on the digital paradigms of Industry 4.0, in this second part the scenario enlarges, by including crucial elements of the Industry 5.0. In the first slides indeed, the attention was on the digital enabling power of a specific technological solution, in this second section the focus is on the paradigms themselves. At the beginning the aim was to reason with the vendor about the digital effects of the adoption of a specific KET, now it is asked a generalization of the discussion. The analysis is indeed conducted in terms of functions, by thinking about the effect on a Twin SME of a whatever investment to enhance the level of one of the 4.0 paradigms. It was quite clear to everyone that an upgrade of one or more digital factor have also a positive influence on at least one sustainable element. In other words, a strategical digital investment, corresponding at an operative level to the introduction of one or more KETs, have some influences on sustainable targets. More precisely, the attention on some digital aspects can help the entrepreneurs get closer to some targets of the three selected SDGs, by fulfilling some LM and CE principles. In order to collect the perceptions of the technology providers in a structured way, at the end of each Canva applicative session it has been filled a Fuzzy DEMATEL matrix (Figure 36).

Fuzzy DEMATEL Matrix			Digital Factors							SDGs Factors			LM & CE Factors	
			H/V Integration	Accessibility to_Information	Automation	Flexibility/ Variety	OEE	RTDCA	Virtualization	SDG8	SDG9	SDG12	LM	CE
			F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12
Digital Factors	H/V Integration	F1												
	Accessibility to_Information	F2												
	Automation	F3												
	Flexibility/ Variety	F4												
	OEE	F5												
	RTDCA	F6												
	Virtualization	F7												
SDGs Factors	SDG8	F8												
	SDG9	F9												
	SDG12	F10												
LM & CE Factors	LM	F11												
	CE	F12												

Figure 36: Fuzzy DEMATEL matrix

In order to fill the matrix, at each provider has been asked the following question "*Based on your expertise and perception, how much high is the influence of F.i on F.j* ?" (with i != j), in other words it is asked to evaluate the influence of one factor on the other, by thinking whether the improvement and/or pursuing of the i-th Factor in an organization has a positive impact in the enabling of j-th Factor as well. The dimension whose effect is analysed is always the one in the row by choice of the author, hence for each i-th Factor (with i from 1 to 12) in the i-th row is checked its influence on all the j-th Factors in the j-th columns (with i != j). The influence power can be indicated with a number from 0 to 4, as stated in Section 3.2. The cell that contains the intensity of the effect of F_i on F_j will be the cell (i, j), with i referred to the row position and j to the column one. The number of questions to fill the whole matrix is:

$$\text{Number of questions} = n * n - n = n * (n - 1) \tag{11}$$

In this precise case the quantity of questions is 132, due to the fact that the effect of each criteria on itself is considered to be the maximum by default and it will be indicated for sake of simplicity with this symbol " * ", that will be present in all the cells (i, j), with i=j.

4.4. Canva applicative sessions – Preliminary reasoning in I4.0 scenario

This Section presents the output of the first part of the Canva applicative sessions, which is about the first step of FP, the preliminary reasoning on the digital enabling power of the KETs of the interviewed managers in an Industry 4.0 scenario. As Section 4.2, also this one, it is divided into Subsections, one for each key enabling technology. It means that, the Subsection 4.4.1, dedicated to Additive Manufacturing, reports the results of the sessions [CV1], [CV2]

and [CV3], while the Subsection 4.4.2, Advanced Manufacturing and Logistic Solutions, makes references to [CV4], [CV5], [CV6] and [CV7]. Then Subsection 4.4.3, Augmented Reality, is linked to [CV8] and [CV9], while the Subsection 4.4.4, dedicated to software of Horizontal and Vertical Integration, with modules of IoT sensors data collection, Data Analytics and Simulation software, shows the outputs of the last five Canva sessions.
For each Subsection, it is reported the definition of the Key Enabling Technology with reference to the SLR and to the one given by the corresponding vendors. Then, there is a table showing the digital factors that, according to the technology providers of that area, are enabled by the KET. For each enabled paradigm, the argumentations given by the interviewed managers are reported.

4.4.1. Additive Manufacturing

Definition

Additive Manufacturing (AM), also called 3D printing, is a process that creates a physical object from a digital design. Additive Manufacturing (AM) is the term used to refer to a group of production technologies that contrapose to traditional subtractive or mass-conserving manufacturing techniques. AM technologies are natively digital (Mabkhot et al., 2021).

KET Digital Enabling Power

From the Canva session [CV1], AM solutions resulted to be enablers of the digital factor 3, Automation, in the meaning that they are able to automate production operations that should otherwise be done by human resources.
In addition, they are clearly enablers of F4, Flexibility and Variety, thanks to them indeed, SMEs can produce small batches of customised and lighter products, with more complex geometries. 3D printings let engineers create shapes and fulfil customer needs, without the limits of the traditional methods of modelling. With the AM machines of last generation, every colour spectrum and whatever combination of opacity, rigidity, elasticity and translucency can be obtained [18].
It should be also considered that 3D printing is typically associated with productivity enhancements in product design [CV2, CV3], quality improvement (Matt et al., 2023) and amount of waste for piece reduction [CV1]. Hence, F5 is considered to be enabled.
In addition, AM machines are able to collect data (F6) during operation cycles, but the elaboration may be possible only with integration software [C3], that can enhance also F3 and F5. The enabled digital factors are summarized in the Table 12.

Table 12: Digital Factors enabled by Additive Manufacturing solutions

F3 - Automation	F4 - Flexibility	F5 - OEE	F6 - RTDCA

4.4.2. Advanced Manufacturing and Logistics Solutions

Definition

For the scope of this work, the expression "Advanced Manufacturing and Logistics Solutions" includes different technologies: collaborative robots (cobots), automated guided vehicles (AGV) and production machines that thanks IoT sensors can increase OEE . The former "are intelligent machines capable of performing tasks in collaboration with human operators, by respecting their times" (Mabkhot et al., 2021), thanks to advanced sensors, control algorithms, data communication channels and the crucial data processing abilities. The AGV instead, are machines without a human driver, that are used to move semifinished or finished products around the plant. The difference with a vehicle with autonomous guide, is the fact that they follow only predefined trajectories by humans, thanks to navigation and guidance systems.

KET Digital Enabling Power

From the Canva sessions [CV4, CV5, CV6, CV7], it was clear that Advanced Manufacturing and Logistic solutions enable the Digital Factors listed in Table 14. An SME that adopts these KETs is characterized first of all by Automation (F3) of production operations or components movements and by a good OEE (F5) level. The enhancement of these digital factors goes in parallel with the increase of digitalisation level of robots. With the advancement in machine vision techniques [CV5, CV6], they are able to keep tracked all the movements of objects in real-time and perform visual assignments such as identifying and removing defective parts from the production line, without interrupting the production and reducing as consequence the downtimes (Ortega, et al., 2021).
In addition, these solutions are set up to collect real time data (F6) of the operations they perform and conduct some rapid analysis on them [CV7]. However, the level of the three digital factors increase if the digital solutions are Integrated with ERP, MES and/or WMS and if the Access to Information is possible, otherwise their potential is limited [CV4].

Table 13: Digital Factors enabled by Advanced Manufacturing solutions

F3 - Automation	F5 - OEE	F6 - RTDCA	

4.4.3. Augmented Reality

Definition

Virtual Reality (VR) immerses users into a completely virtual world where they can interact with the environment, Augmented Reality (AR) instead, adds virtual entities and information to a user viewport, combined with images of the real world (Mabkhot et al., 2021). Augmented reality (AR) is a technology capable of combining virtual elements with information from the real world, by enhancing human perception [CV8].

KET Digital Enabling Power

In Table 14, the digital functions that are enabled by the adoption of an AR solution according to the same AR providers. The factor Accessibility to Information (F2) is strongly effected by AR adoption, gone are the days when physical access to devices was necessary to assess their status, according to [CV8]. AR visors indeed, can be used to let workers access a big volume of information thanks to remote access, for instance technical manuals, guides or important documents could be accessed directly on the field or along the production lines [20]. This functionality is enhanced by ERP integration.

Level of Automation (F3) is positively influenced by AR devices introduction as well. In this specific case for Automation, it is meant the chance to allow operators accomplish a task with lower time and higher quality, for instance through the autonomous analysis of the images, granted by an AR helmet [CV8].

Also factor OEE (F5) is positively affected by this KET. More precisely, AR can be used to reduce downtime, setup times and improve equipment performance, by enhancing availability level [CV9]. It doesn't have to be forgotten the fact that these solutions save time to travel, by eliminating the need for costly international travels [20]. In addition, AR is also used to enhance the quality control and let troubleshooting process be faster, workers indeed, can more easily identify and correct failures, as consequence scraps may be reduced. AR solutions are also used to manage training remotely and cut the time spent in shadowing new workers [CV9], they will be operative and effective in the field faster. This can help to increase the overall efficiency of an SME.

The factor 7, Virtualization, is considered effected by such a technology, by considering the chance to let operators access virtual copies of technical manuals or virtual models of mechanical components to practice with production operations or make maintenance interventions faster.

Table 14: Digital Factors enabled by Augment Reality solutions

F2 - Accessibility to Information	F3 - Automation	F5 - OEE	F7 - Virtualization

4.4.4. Horizontal/Vertical Integration Systems

Definition

Integration in an Industry 4.0 context means to connect IT systems of different production lines, work stations and business units, through APIs, by granting that all of them work together as subsystems of a unique system. Systems are integrated when they can easily and quicky share uniform data and they have a meaning and a value in all the different modules [21], [CV11], [CV13]. For the scope of this thesis, the horizontal integration has been considered along the supply chain, while the vertical one, within the shop floor (i.e., machine to machine, machine to human), in such a way to flatten the silos data pyramid from field level to production one, from operations level to enterprise one [14].
The organizations that joined the Canva sessions for what regard the Integration Systems area have been chosen because their integration software have also modules referred to other three KETs, IoT data collection, Data Analytics and Simulation, for the reasons explained in Section 4.1. They are not alternatives to ERP, but add-on with additional vertical functionalities.
It should be specified that IoT module is a service of data collection from different information sources and machines, to create a real-time factory environment, while eliminating data compartmentalization. With modules of Data Analytics instead, the author refers to processing of collected data, data aggregating and computation of real-time insights to boost data visualization. While for Simulating modules, it is meant vertical application for forecasting, that is analysing the past data trends to build models for process, acquisition and sales simulations. At the basis of these modules there is the usage of heuristics, statistical methods and Machine Learning techniques [14,23].

KET Digital Enabling Power

Integration systems like the ones presented in [CV10, CV11, CV12, CV13, CV14] are enablers of all the seven digital factors, as presented in Table 15. More precisely, F1 and F2 are enabled by definition, connection to empower the business world is the aim of these technologies. More precisely modules like production planning, warehouse management, material handling, predictive maintenance are dedicated to vertical integration, including ERP and MES interoperation. While, the supplier relationships management sections (vendor, order and transport management) are about horizontal integration [14].

Integration allows Automation (F3) in smart fabrics, but not only, it can be also at the basis of an efficient collaboration between technologies and employees to enhance OEE level (F5) [CV11, CV13]. The higher the synchronization level, smarter and faster the decision can be to gain operation excellence.

About Flexibility, F4, from [CV10 and CV13] was possible to deduce that a value chain integrated network gives also the chance to access a certain variety of shapes and materials to produce a specific product, hence also flexibility is enabled by integration.

The Integration Systems are always to be studied in couple with IoT sensors that let them collect data from the integrated hardware, that are then elaborated to grasp past trends in terms of production, maintenance or sales. Factory data analysis tools (F6) can unblock intelligent modules, like sales prediction with machine learning, demand sensing, SC planning, predictive maintenance, what if analysis and scenario simulation (F7) [CV11].

Only through a complete view of the SC is possible to capture the whole value of the collected data, F1 and F6 are fundamental, according to all the providers to empower at 100% the first levels of analysis, the descriptive and the proactive ones, with the goal to reach the predictive and the prescriptive ones, where the information flow is not unidirectional anymore. The machines and the human resources indeed, continue to push data in the integration and analysis software, but on the other side the software themselves are able after having learnt the flow trends, to give predictive information and suggest decision makers how to anticipate and solve critical issues.

Table 15: Digital Factors enabled by HVIS

F1 – Horizontal/ Vertical Integration	F2- Accessibility to information	F3 - Automation	F4 - Flexibility
F5 - OEE	F6 – Real Time Data Collection and Analysis	F7 - Virtualization	

4.5. Canva applicative sessions – Paradigms analysis in I5.0 scenario

This Section presents the second part of the Canva applicative sessions, which is about the second step of the FP, the generalised analysis on the twin enabling power of the paradigms in I5.0 scenario.

In order to compare the perceptions of the four technological groups of vendors, the author grouped the evaluations of the providers belonging to the same technological area into aggregated matrixes, that present the averages of the factor to factor influences assigned by the four groups. This passage was propaedeutic to explain for each factor the reasons that led the participants give a mark instead than other. It could be noticed that similar marks come from providers of similar technological solutions, probably because of a common hands-on experience on the production or commercialization of the specific KET. Hence, it has been constructed the twelve matrixes, presented from Figure 37 to 48, that are visible in the dedicated Excel file “Fuzzy DEMATEL”, in the sheet named “Aggregates for KET”. More precisely, each matrix is referred to the influence level of a Factor Fi, with i from 1 to 12, on the other Factor Fj, with j from 1 to 12, according to the perception of the managers, aggregated for KET. The first row of each matrix presents the average of the marks given by the vendors of AMLS, that stands for Advanced Manufacturing and Logistics Solutions, the second one instead, reports the evaluations of providers of AM, Additive Manufacturing solutions. The third one is dedicated to Augmented Reality solutions suppliers, whose acronym is AR and in the last row, the KET of reference are the Horizontal and Vertical Integration Software, HVIS.

4.5.1. F1 – Horizontal/ Vertical Integration

In Figure 37, the matrix related to the levels of influence of F1 on the other factors shows the importance of this paradigm for enabling the others. The respondents agree on the fact that Integration is a base ground for the other factors.

H/V Integration	H/V Integration	Accessibility to Information	Automation	Flexibility/ Variety	OEE	RTDCA	Virtualization	SDG8	SDG9	SDG12	LM	CE
	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12
AMLS	*	4	4	3,25	3,5	3,75	2,5	3,75	4	4	3,5	2,5
AM	*	4	4	3,33	3,67	4	2,67	4	4	4	3	3
AR	*	3,5	3	2	4	4	4	3	4	3	3	3,5
HVIS	*	4	4	4	4	4	4	4	4	4	4	4

Figure 37: F1 – Horizontal/ Vertical Integration levels of influence

The impact of Integration on Accessibility to information, Automation, OEE and RTDCA has been perceived to be high, by all the technology providers. In particular, the participants to the HVIS Canva Sessions sustained that the biggest challenge in digital transformation is not the new technologies adoption, but the integration of old and new typologies of resources to

enable new functions, like the green ones. Also the impact on Virtualization has been considered quite high, due to the fact that a virtual imitation is powerful if it can consider in real time the characteristics of the twin machine or production line [CV8], [CV12].
It was straightforward for everyone the effect of F1 on the sustainable factors. The horizontal integration (along the supply chain) has been considered important enabler of industry innovation environment (SDG9). The other direction of integration, the vertical one instead, has been perceived as high on SDG8 on average. In particular, System integrators producers, stated that investments on the improvement of vertical integration in an organization could have a great effect on employees welfare and security on work places (Target 8.8), by favoring Human centricity in an SME.
Also SDG 12 has been perceived to be influenceable by investments on Integration, thanks to vertical integration indeed it is possible to monitor the energy consumption all over the production lines, the employment of natural resources and the amount of waste in the plant [14]. In addition, [CV13] put in light the effect of horizontal integration on the enhancement of the sustainability level of the whole supply chain. It's the end to end integration and the chance to have access to supply chain data that lead to sustainable transferring and production of products.
In addition, it has to be stressed out that the integration of digital technologies with sustainable principles can help companies reduce their environmental impact, by not losing their efficiency, through an optimization of the processes, energy consumption reduction, and resource utilization improvement (Dinis-Carvalh et al, 2023).
For all the respondents, the influence of Integration on Lean Manufacturing and Circular Economy was straightforward. In particular, from [CV11, 13 and 14] it is emerged the idea that an end-to-end visibility on the supply chain may reduce any form of inefficiency or waste, that by definition it is something that doesn't add value. In addition, techniques like JIT, VSM or Bottleneck analysis may become more precise thanks to the possibility to receive information from any step of the supply chain, by enabling LM principles of continuous improvement and waste reduction [CV13], [6], (Ciliberto, et al., 2021).

4.5.2. F2 - Accessibility to Information

The influences of this second factor on the others are showed in Figure 38 and they are quite high. The entire concept of the fourth industrial revolution indeed, is built around establishing a communication channel through the internet in such a way to create a bidirectional flow of data between machine-machine and human-machine that should be easily assessed for data analysis in support to data driven decision making (Santhi, et al., 2023).

Accessibility to Information	H/V Integration	Accessibility to Information	Automation	Flexibility/ Variety	OEE	RTDCA	Virtualization	SDG8	SDG9	SDG12	LM	CE
	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12
AMLS	1,25	*	2,75	1,75	3,25	3	3	3	4	2,5	3,5	2
AM	2	*	3	3	3	3	3	2	3,67	3	3	3
AR	1	*	4	3	3,5	3	3	2	3	2	3	2
HVIS	2,4	*	3,2	2,8	3,4	3,2	3	3	3,6	3	3,2	3

Figure 38: F2 – Accessibility to Information levels of influence

The influence of F2 on F1 is very low according to all the respondents that considered Data Access an effect of a good Integration and not vice versa. Only the H/V Integration systems providers assigned a medium mark to the specific cell, by considering that the higher the amount of easy accessible information, the higher the incentive to integrate the data sources to give a meaning to these data.

The effect on F3-Automation has been perceived to be quite high, due to the fact that decision making, products movements and production operations can be automized only if the machine PLC can have free and fast access to the useful data for the queries that have to been solved to perform the requested task. For the same reasons, it has been considered as an enabling factor of the Data Analysis (F6), because it is clear that if data are not accessible, the analysis cannot be done.

In addition, F2 has been perceived as a factor with an high impact on OEE. The effect is so strong for AR solutions producers, because AR can be used to provide workers with remote access to technical manuals, troubleshooting guides, and other information, which can help to empower line and field operators, reduce downtime and improve equipment performance [CV8].

Data access (F4) has been considered of average influence on SDG8 and SDG12 targets achievement, but of crucial importance for SDG9, in a particular way for what regards the promotion of innovative industrialization.

The level of influence of this factor on LM wastes reduction and 9R enhancement has been considered of average intensity, due to the fact that in Industry 4.0 the possibility to access to information everywhere and every time brings a series of advantages in terms of firm efficiency, like for instance reduction of searching time and downtimes and mitigation of information asymmetry between the different players inside the organization and along the whole supply chain (Ciliberto, et al., 2021).

4.5.3. F3 - Automation

The greatest effect of Automation has been felt to be on OEE (F5) and SDG9, because the ability of a machine or of a software to accomplish a task or take a decision without the human intervention contribute, according to all the interviewed managers, to the enhancement of the production throughput, reliability and sustainability of the processes, as well as to the scientific research (Targets 9.3, 9.4 and 9.5). All the other influences are considered to be lower and they are visible in Figure 39.

Automation	H/V Integration	Accessibility to Information	Automation	Flexibility/ Variety	OEE	RTDCA	Virtualization	SDG8	SDG9	SDG12	LM	CE
	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12
AMLS	3,5	3,75	*	1,5	4	3	1,75	3,25	4	3	3,5	2
AM	2,67	3	*	1	4	3	1	2	4	2	3,33	2
AR	3	3	*	1	3,5	3	1	3	3,5	1,5	4	2
HVIS	3	3	*	1	3,4	3	1	2,4	3,8	2,4	3,4	2

Figure 39: F3 – Automation levels of influence

It should be noticed that Automation has been perceived as important for SDG8 targets achievement, particularly by Advanced Manufacturing and Logistics solutions providers [CV4], [CV7], that sustained the significance of these technologies in granting safe and secure working environments (Target 8.8). Some investments in automation indeed, can lead to the introduction of production robots and AGV that can perform dangerous tasks and access unsafe places instead of humans [CV4] (Santhi, et al., 2023). In addition, it was underlined in [CV8] that the enhancement of Automation level could let people with disabilities make some operations that couldn't be accomplished without it (Target 8.5). Thanks to automation investments technology could be made as a service of Humans talents (Human centricity). The influence level assigned to SDG8 is not too high, because in different Canva sessions, it was underlined the possible contraposition between the creativity supported by Target 8.3 and the standardization of processes that can derive by investments in Automation.

Automation influence on SDG12 resulted to be only average, because on one side automation can unblock reduction of waste, downtimes and efficient use of resources, as supported in Target 12.2 (Ortega, et al., 2021), but on the other hand investments in automation doesn't sound mandatory environmental friendly (Target 12.4), because they imply more use of energy, sometimes water and CO2 emissions.

For what regard the influence of Automation on Lean Manufacturing it appears to be high, because both manufacturing automation and LM have the same aim: removing non-value-added activities, reducing waste and producing high quality products (Chen, et al., 2022).

4.5.4. F4 – Flexibility and Variety

As it visible in Figure 40, the enhancement of F4, Flexibility has not been considered a cause of a change in the other digital factors level, but as an effect.

Flexibility/ Variety	H/V Integration	Accessibility to Information	Automation	Flexibility/ Variety	OEE	RTDCA	Virtualization	SDG8	SDG9	SDG12	LM	CE
	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12
AMLS	1	0	0	*	0,75	1,5	0,25	3	3	2,75	1	3
AM	1	1,33	1	*	1,67	1,67	0	4	4	4	2,33	4
AR	1	0	0	*	1	1	0	2	2,5	2,5	2	3
HVIS	1	1	0	*	1	1,4	1	3,2	2,4	3	1	3

Figure 40: F4 – Flexibility levels of influence

The influence of F4 on SDG8 targets has been considered quite high, due to the fact that Target 8.2 promotes an high level of economic productivity through diversification and the number 8.3 the creativity and entrepreneurship. Through investments in the enhancement of Flexibility level of the organization, the SME can access the production of new shapes and components with a greater options of materials, in such a way to unblock side business and creative ideas [CV1, CV3].

Effect of F4 on SDG9 has been perceived to be high as well by all the suppliers, it is particularly true in the case of AM solutions providers [CV1, CV2, CV3], that sustain indeed the fact that the chance to get new geometries with a variety of materials, whose potential before I4.0 was undiscovered, like polycarbonates and photopolymers, may transform old manufacturing paradigms (Target 9.5). A more flexible production can give new oxygen to SMEs in the competitive supply-chains, by innovating consolidated productive processes and giving them the chance to produce more complex and innovative products, by upgrading the technological capabilities of the personnel (Target 9.4 and 9.5). It should be considered however, that it is not so easy to make radical changes to consolidated productive flows, that is why the effect of F4 on SDG9 is not the maximum [CV2].

The effect of this factor on SDG12 has been perceived only quite high by many KETs providers, but very high from AM experts, that sustain the power of a flexible and agile production in recovering old production wastes and/or products at the end of their life [CV1]. The powder that is not used for a certain printing indeed, can be reused for the following one, so nothing is thrown away. In addition, the number of unsold pieces that should be expensively stocked is practically zero, because it is printed only what is ordered, with just in time philosophy. For the same reason they assigned a 4 also to the influence to CE factor (F12), AM has been identified as facilitator of eco-design practices incorporating new sustainable materials (Ortega, et al., 2021).

It has to be stressed out that Flexibility is entailed as the chance for a producer to use a miscellaneous of materials and as the opportunity to create a variety of different geometries, then the set up times of the machines and the several changes of materials for the different operations could increase the no value-added times, this is why the effect on LM is low (John, et al., 2021). On the other hand, an higher flexibility can nurture the chances of Recovery, Repurpose and Rethink of a product (F12).

4.5.5. F5 - Overall Equipment Effectiveness

As it possible to see in Figure 41, the effect of an investment in OEE (F5) has not perceived to be direct on the other digital factors, that means that a change in the Availability of the production machines, in the Throughput level and in the Quality of the produced pieces has not been perceived as cause of the other paradigms, but as an effect.

OEE	H/V Integration	Accessibility to Information	Automation	Flexibility/ Variety	OEE	RTDCA	Virtualization	SDG8	SDG9	SDG12	LM	CE
	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12
AMLS	1,75	1,25	2	1	*	2	0,25	2,25	2,75	2	3	1
AM	1	1	1	1	*	1	1	2	2	2	3,67	2
AR	2	1	1	0	*	2	2	3	3	2	4	1
HVIS	1,2	1	1	1	*	1,8	1	2,8	3,2	2,8	3,6	2

Figure 41: F5 – OEE levels of influence

The effect of an investment on F5 on SDG8 has been considered high instead, due to the fact that an improvement on a whatever of the three factors of OEE let the SME achieve higher levels of economic productivity, as stated in Target 8.2 and 8.3. It wasn’t assigned the maximum level of influence, because an extreme focus on the OEE metrics may also lead to production levels so high to create stress between the operators in contrast with the promoted decency of the work expressed in Target 8.3.

For what regard the SDG9, also in this case the level of influence is medium, because this goal sustains the sustainable industrialization that is supported by an high production Quality and low percentage of downtime that can cause delays to all the supply chain, by employing energy and generating emissions not used to generate value. But on the other hand, higher the throughput, higher the employment of materials, energy and emissions (Joao, et al., 2023).

The same medium influence has been assigned to SDG12, because on one side higher the quality of produced units, lower the generation of waste and necessities of reworking (Target 12.5), but on the other hand, particularly in a structure like an SME, higher the throughput higher the probability of waste generation and unsold products, in contrast with Target 12.6. It’s not the level of throughput or downtime that let a production process be sustainable, as it is requested by SDG12 targets.

OEE level enhancement has been perceived as strongly connected to LM (F11), because it is straightforward to say that higher the OEE, lower the Seven Wastes of LM, in addition it should be kept in mind that Lean main motive is to lower lead time to increase productivity without compromising the quality (John, et al., 2021).

While there is no direct influence between OEE level and 9R strategy of CE system, because a firm can have an optimal level of availability and quality and an high throughput, but a very low attention to circularity, by not being environmentally concerned, OEE can be enhanced indeed, also through linear economy system (Kirchherr, et al., 2017; Findik, et al., 2023).

4.5.6. F6 - Real Time Data Collection and Analysis

The influence of RTDCA on the majority of the other factors appears to be strong for each respondent, both in terms of digital factors and sustainable ones, as it is visible in Figure 42. Systems integrators providers evaluations are higher than the ones of all the others. Their choice goes in parallel with the high marks assigned to F1-Integration, they stated indeed that the collection and elaboration of data is the basis of Industry 4.0 program and the integration of the different resources let to an higher volume of data and gives the opportunity to the top managers to see the big picture and capture the whole value of data [CV11, CV13]. For them, RTDCA is crucial to unblock intelligent modules, like maintenance prediction, intelligent planning and sales. It is only through consistent data lakes that machine learning algorithms can be trained and data trends can be analysed, with the aim to forecast future ones and suggest best practices toward process and decision optimization (Hassani, et al., 2022)[14].

RTDCA	H/V Integration	Accessibility to Information	Automation	Flexibility/ Variety	OEE	RTDCA	Virtualization	SDG8	SDG9	SDG12	LM	CE
	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12
AMLS	4	4	2,5	3	3,25	*	4	4	4	4	4	4
AM	4	4	2,67	3	2,33	*	4	3,33	4	4	4	4
AR	2	4	2	2,5	3	*	3	3	4	3	4	4
HVIS	4	3,4	3,8	3,4	4	*	3,6	4	4	4	4	4

Figure 42: F6 – RTDCA levels of influence

In general, for each supplier the collection of data and its analysis is fundamental for the digital transformation journey of any organization.

Investments in simulation and virtualization can add value to operations if they can have access to real time data (Machado, et al., 2021), this is why also the effect on Virtualization has been considered quite high.

Investments on RTDCA have been felt important for SDG8 targets achievements, like Target 8.2 and 8.8, that are about the promotion of safer workplaces and achievement of higher levels of economic productivity. In particular, from [CV4] resulted that the number of work incidents in warehouses reduce of 30-40% thanks to the continuous collection and monitoring of data through semi-automated forklifts, because the attention level of operators increase if they know their work is monitored and their performance data are controlled. An higher level of surveillance seems to lead to adoption of safer practices.

The so high influence on SDG9 has been justified by the fact that the innovation and Resiliency fostering of industries has to pass through data driven decisions (Estevao, et al., 2023).

Collection and Analysis of data of logistic and productive flows is fundamental for the material movements and fleet optimization, by sizing the fleet and allocating AGV and forklifts in the different departments, in such a way to create an homogeneous stress. This is a way toward efficiently and environmentally sound industrial processes (Target 9.4).
About SDG12 the Canva sessions put in evidence a strong correlation between the collection and analysis of data along the supply chain and a more sustainable management (Target 12.2) [CV7, CV13].
The evaluations of the influence of RTDCA on Lean Wastes Reduction and CE principles is very high, waste management sector indeed is being transformed rapidly through the application of different technologies (like Big Data and 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. (Ortega et al., 2021).
This factor influence on F11 and F12 has been perceived to be very high, data gathering indeed, is the crucial part to implement Lean and CE principles, by starting from collecting data in an I4.0 context from various sources and then applying analytics to streamline production processes (John, et al., 2021). Data collecting and data analysis enable flows analysis like Value Stream Mapping and Bottleneck detection (Chen, et al., 2023).

4.5.7. F7 - Virtualization

Influences of investments in virtual imitation of machineries and production lines and simulation processes weren't considered to be strong on digital factors, but on the other hand, as explained in the previous Subsections, F7 has been considered an effect of investments in the other digital factors enhancement, as it is visible in Figure 43.

Virtualization	H/V Integration	Accessibility to Information	Automation	Flexibility/ Variety	OEE	RTDCA	Virtualization	SDG8	SDG9	SDG12	LM	CE
	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12
AMLS	1,5	0,75	0,75	2,25	1	0,75	*	2,75	2,75	2,5	3	2,75
AM	1,5	1,5	1	2	3	2	*	3	4	3	3	3
AR	2	2	1	3,5	3	2	*	4	3,5	4	3	4
HVIS	1,6	1,8	1	1,6	1,8	1,6	*	2,6	3	3,2	2,8	3,2

Figure 43: F7 – Virtualization levels of influence

It has been registered a medium influence on Flexibility and OEE, due to the fact that digital simulations can let entrepreneurs try different scenarios in terms of production operations and components engineering, before investing, by optimizing the output during the simulations [2].
For the AR experts the influence of Virtualization on SDG8 is very high, because they underlined during the Canva sessions as the workers safety (Target 8.8) may be increased thanks to the chance to simulate an intervention before actually doing it, in addition the ergonomy of the working stations could be enhanced thanks to a prior virtualization of them.

It should be also considered that the power of virtualization is also of learning type, training times of new employees, included the youngsters and the ones that come from other industries, could be shorten up (Target 8.5).
Virtualization results indicate an average effect on SDG9, the upgrading of infrastructures and the resiliency of the supply chains can be fostered by virtualization methods. This influence is particularly felt by HVIS and AR providers that assigned a value of 4. This difference with the other suppliers can be due by the fact that they see directly on their customers the effects of investments in virtualization of products and simulation of processes and they sustain that these can lead to better understanding of business systems, by making industries more sustainable and usage of resources more efficient (Target 9.4).
It has also a great effect on SDG 12 and CE factor, the possibility to test different product lifecycles can give the chance to the entrepreneur to choose materials that are easier to be recycled, to choose operations that reduce the wastes and a concept that can be rethought for other markets [CV8] [20].
For what regard the influence on LM factor, the evaluation is quite high, simulation processes indeed can enhance the potentiality of Value Stream Mapping, Bottleneck Analysis and Poka-Yoke, by simulating the possible scenarios and standardizing errors before the real failure [6].

4.5.8. F8 - SDG8

In the previous Subsections it has been discussed the influence of the digital factors on F8, in this Subsection instead it is put in light in Figure 44 as the SDG8 targets achievement has been perceived as a factor which is influenced by the others and not vice versa. It is straightforward to understand that an investment for creativity enhancement (Target 8.2), decent job creation for everyone (Target 8.3 and 8.5) or in favour of safer working places (Target 8.8) couldn't have a direct effect on digital factors like Integration, Accessibility to Information, Automation or Virtualization, just a low one on Flexibility and OEE level.
It is visible instead, a discrete influence on the other two SDGs, because all of them supports the economic productivity, so an investment that enhances it, may positively influence all of them.

SDG8	H/V Integration	Accessibility to Information	Automation	Flexibility/ Variety	OEE	RTDCA	Virtualization	SDG8	SDG9	SDG12	LM	CE
	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12
AMLS	0,25	0,5	0,5	1,5	2,25	1	0,5	*	2	1,75	1	1,5
AM	0,33	0,33	0,33	0,67	1,67	1,33	1	*	1,33	0,67	0,33	0,33
AR	0,5	0	0,5	0,5	2,5	1	1	*	0,5	0,5	0	0,5
HVIS	1,2	0,4	0,8	1,8	1,4	1	1	*	1,8	0,8	1	1

Figure 44: F8 – SDG8 levels of influence

4.5.9. F9 - SDG9

As in the case of SDG8, also SDG9 targets have been perceived as influenceable by the digital factors but not vice versa. It should be stressed out that the influence of this SDG on digital factors is in any case slightly higher than the one of the other goals, because it should be remembered that Target 9.4 promotes upgrading and retrofitting of industries and number 9.5 the upgrading of technological capabilities in all the firms. On the other hand, Target 9.2 supports a sustainable industrialization that doesn't mandatory indicate an higher level of integration, automation flexibility or virtualization.

SDG9	H/V Integration	Accessibility to Information	Automation	Flexibility/ Variety	OEE	RTDCA	Virtualization	SDG8	SDG9	SDG12	LM	CE
	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12
AMLS	1,75	1,25	1,5	0,5	1,75	1,75	0	1	*	1	1,5	1
AM	1,67	1	0,67	0,33	0,67	0,67	0	0,33	*	0,33	2	0,33
AR	1,5	1	1,5	1	2	1	0,5	1	*	1	2	1
HVIS	1,2	1	2	0,6	1,8	1,6	1	1	*	1,6	0,8	1,8

Figure 45: F9 – SDG9 levels of influence

4.5.10. F10 - SDG12

As for the previous two SDGs, also the influence of SDG12 on the digital factors has been perceived as low, because investments for the improvement of natural resources use (Target 12.2), for reduction of waste generation (Target 12.4 and 12.5) and for integration of sustainable information (Target 12.6) are not directly connected to enhancement of one of the digital factors. It is instead evident from Figure 57, the high influence level on 9R strategy of CE framework [5] and to LM principles. Target 12.6 indeed encourage companies to adopt sustainable practices and to integrate sustainable information into the reporting cycle, then the Lean practices that reduce wastes and non-value added resource motion, excess inventory and reworkings could be positively influenced by investments toward the achievement of this target.

SDG12	H/V Integration	Accessibility to Information	Automation	Flexibility/ Variety	OEE	RTDCA	Virtualization	SDG8	SDG9	SDG12	LM	CE
	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12
AMLS	1,75	1,25	0,75	0,75	0,75	1,75	0	1,5	1,75	*	1,75	3
AM	2,33	1,67	0,67	0,67	0,67	0,67	0	0,67	1,67	*	2	2,67
AR	2	1	1	1	1	1	1	1	2	*	2	3,5
HVIS	1,4	1,2	1	1	1	1,4	0	1	1,6	*	2,4	3

Figure 46: F10 – SDG12 levels of influence

4.5.11. F11 - Lean Manufacturing

In order to better understand the argumentations of this Subsection, a wrap up of the considered elements of Lean Manufacturing is present in Table 16, that have been presented in Subsection 1.2.1:

Table 16: Lean Manufacturing principles and techniques

JIT production and continuous improvement philosophy	• *Just-in-time (JIT)* • *Kaizen*
Industrial flows analysis and Data Visualization	• *Value Stream Mapping (VSM)* • *Bottleneck Analysis* • *Kanban*
Process standardization	• *Poka-Yoke* • *Jidoka* • *5S Method: Sort, Straighten, Shine, Standardize, Sustainment*
Waste Reduction	• *excess inventory* • *over-production* • *defects that require costly correction* • *waiting time* • *resources motion with no value added* • *unused talent* • *over-processing*

The marks given to the power of influence of LM (Figure 58) on three digital factors over seven, more precisely F1, F4 and F7, are low, due to the fact that the respondents interpreted on average these digital dimensions as enablers of some Lean wastes reduction and flows analysis techniques, but not vice versa.
The digital paradigm that resulted to be most affected by LM principles is the F5, OEE, due to the fact that LM and I4.0 have similar objectives as both look for productivity efficiency, that could be reached through waste elimination and they are both customer-oriented (Reyes, et al., 2021).
An average level of influence has also been assigned to F2-Access to Information, F3-Automation and F6-RTDCA, because techniques as Value Stream Mapping, Bottleneck Analysis and Kanban boards support the analysis of data to detect the non-value added activities and enhance the access to the main information about the scheduling, the load and

the throughput of the planned activities (Chen, et al., 2023). For what regard F3-Automation, the level of influence has not been perceived as high, because on one side LM supports the waste reduction and the standardization of processes through 5S Method and Poka-Yoke technique, which is supported by Advanced Manufacturing Solutions introduction [CV4, CV7], but on the other hand the intervention of human operators is significant in an LM scenario and according to techniques like Jidoka, the automation is only partial, quality controls, decision-making, problem resolution and working stations organizations are still tasks that should be made by operators.

LM	H/V Integration	Accessibility to Information	Automation	Flexibility/ Variety	OEE	RTDCA	Virtualization	SDG8	SDG9	SDG12	LM	CE
	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12
AMLS	0,75	1,5	1,75	0	3	2	1	2,25	3,5	2,75	*	3
AM	1,33	2,33	2,33	1	3,33	2,67	1	3	3	4	*	3
AR	1,5	2	3	0	3	1,5	1	2,5	3	2	*	2,5
HVIS	1	1,8	2,6	0	3,6	1,8	0	2,8	3,2	3,2	*	3

Figure 47: F11 – LM levels of influence

The evaluations are completely different for what regard the sustainable factors, in general indeed, it can be seen that one of the highest evaluations has been given to the cell related to the influence of LM on SDG8. In particular, Target 8.2 sustains the economic productivity through a focus on high-value added and labour intensive sectors, this is perfectly in line with the aim of reduction of any form of no value-added activities in an LM scenario [CV3, CV9]. In addition, the focus on the 6th form of waste (Subsection 1.2.1), *unused talent* can have as consequence a good effect on the Target 8.5 that promotes productive employment and Human centricity. There is a strong correlation indeed, between the second S of the Lean 5S Method, *Seiton,* to grant a safe and ordered working station (Subsection 1.2.1) and the Target 8.8 that promotes safe and secure working environments. On the other side, the philosophy of reduction of a whatever waste, including the downtimes, could lead indeed to exclude operators whose learning times are longer than the average, being in contrast with the statement of Target 8.5 about the employment of young people and persons with disabilities. In addition, the 4th S of the 5S Method, is about *Standardization* of all the operations to get systematic procedures, it seems to negatively affect the Target 8.3, which promote decent and creative work.

For what regard SDG9 instead, it is possible to see that the average mark is 3, due to the fact that this goal promotes sustainable industrialization in Target 9.2 and an efficient use of resources in Target 9.4. Both the statements could be positively influenced by the reduction of the Lean Wastes, an example is the decrease of *excess inventory* and *over-production* that constitute an inefficient processing of materials and energy sources employment (Reyes, et al., 2021) or the diminishing of *resources motion,* with consequent reduction of employed energy for the fleet [CV4]. Also investments and practices for the *reduction of costly corrections* and products *reworkings* can positively influence a sustainable industrialization,

that thanks to an higher focus on production quality can lead to emission, energy and water employment reduction (Joao, et al., 2023).
Lean Manufacturing principles have been perceived as strongly impacting on the achievement of SDG12 Targets, Target 12.2, 12.4 and 12.5 are perfectly in line with the Muda of LM, by promoting respectively an efficient use of natural resources and a reduction of all wastes throughout the life cycle of a product. LM practices, by definition has the aim to reduce excess inventory and over-production, failures and downtimes by diminishing as consequence waste of materials, energy and water employment in the first part of the product lifecycle.
For what regard all the SDGs factors, the marks of the LM influence on their targets achievement is not the maximum, because according to the technology providers, LM techniques are not sufficient to enable them, digital investments are needed. This statement is strengthen by Chen (et al., 2023) paper that presents digital technologies as accelerators of sustainable approaches adoption and lean principles as bridges between the two worlds.

4.5.12. F12 - Circular Economy

For the sake of clarity of this Subsection, in the following, a brief recap of the 9R of CE framework, explained one by one in Subsection 1.2.2: Recover, Recycle, Repurpose, Remanufacture, Refurbish, Repair, Reuse, Reduce, Rethink and Refuse (Viles et al., 2022).
The evaluations of the influence levels of CE (Figure 48) on the digital factors are very low, because as in the LM case, the technology providers interpreted the digital dimensions as enablers of the 9R (Subsection 1.2.2). According to Industry 5.0 report by ESIR of the EU [B3], digital technologies are fundamental for a circular economic framework that points to the waste and pollution elimination in an 9R Framework. The only digital paradigm that has been felt as an effect of an investment in terms of CE is the number 4, Flexibility and Variety. Having indeed, the chance to *Recover* or *Remanufacture* discarded components enhances the flexibility level of an SME, while the product *Rethinking* and *Recycling* enable respectively a greater variety of marketing options and of employable materials.

CE	H/V Integration	Accessibility to Information	Automation	Flexibility/ Variety	OEE	RTDCA	Virtualization	SDG8	SDG9	SDG12	LM	CE
	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12
AMLS	0,75	0	0	3,75	1	1	0	1,5	2	4	3,5	*
AM	0,33	0,33	0,33	3,67	1	0,33	0,33	2	3	4	3,33	*
AR	1	0	1	3	1	1	1	1,5	3	4	3	*
HVIS	1	1	1	3,4	1	1	1	2,4	3,4	4	3,6	*

Figure 48: F12 – CE levels of influence

Also the level of influence on SDG8 targets resulted to be low, it has been perceived one unique connection with Targets 8.2 and 8.3, due to the fact that they promote decent jobs through diversification, creativity and innovation, which can be enabled by the flexibility of the CE principles.

For what regard the influence on SDG9 instead, the magnitude is higher, there is indeed a strong correlation with the CE principles adoption and the sustainable reorganization of SMEs. By applying practices of *Reusage* and *Rethinking* on production machines and tools, it is possible to make infrastructures upgrades (Target 9.4) and industry retrofitting, by promoting sustainable industrialization (Target 9.2) [5].

The highest influence has been perceived on SDG12, whose Target 12.2 is about the efficient usage of natural resources, hence it is affected by 7th R, that stands for *Reduction* of natural resources and materials employment and CO2 emissions [9]. The most influenced Targets are the 12.4 and 12.5, which promote reduction of all waste generation through prevention, *reduction*, *recycling* and *reuse*, which are a subset of the 9R theory of CE. Target 12.6 instead, refers directly to sustainable practices adoption in the industries, and a perfect example of green practices are exactly the CE ones [8].

CHAPTER 5

5. Fuzzy DEMATEL application and TwinSME Model

In this chapter the Fuzzy DEMATEL technique has been applied to each Individual Direct Influence Matrix (DIM) in such a way to get the Influential Relation Map (IRM) that enlightens the cause-effect relationships between the twelve factors of the TwinSME model.

The fourteen DIMs, obtained as output of the Canva sessions presented in Chapter 4, have been organised in a dedicated Excel file, called "Fuzzy DEMATEL", where there are fourteen sheets, one for each technology provider, as shown in Figure 49. The pages are named with the acronym of the technological area of reference, then for instance the DIM of the sessions of the vendors of Additive Manufacturing solutions are identified as "AM1", "AM2" and "AM3", while the sheets dedicated to Advanced Manufacturing and Logistic Solutions providers are identified with the labels "AMLS1", "AMLS2", "AMLS3" and "AMLS4". They are followed by the two pages referred to Augment Reality area, "AR1" and "AR2" and at the end, there are the five sheets of the Horizontal and Vertical Integrators suppliers, called "HVISi" with i from 1 to 5.

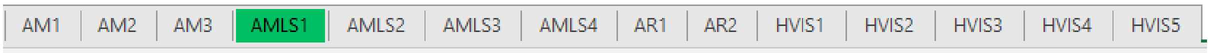


Figure 49: Sheets of the Excel file "Fuzzy DEMATEL"

In the first cell in the top left corner of each page there is the reference to the dedicated Canva Session, with the specific notation [CVi], with i from 1 to 14. In each sheet has been replicated the Fuzzy steps of the DEMATEL procedure, more precisely Step 1 and 2, according to the sequence described in Section 3.2. These first passages have been presented in Section 5.1, where all the figures that support the theoretical explanation of the different steps are screenshots of the matrixes present in the sheet AMLS1, highlighted in Figure 60. It has been chosen as a propaedeutic example, for a clear presentation of the calculations performed by the author in the dedicated Excel file for fourteen times. Each one of the fourteen sheets ended up with the corresponding DIM with total normalised Crisp Values.

Always in Section 5.1, there is the presentation of the calculation performed for the last five steps of the DEMATEL procedure that finishes with the showing of the Influential Relation Map. These final steps are performed in the same Excel File, in the dedicated sheet "DEMATEL"

(Figure 50). In order to try to explain in a detailed way the meaning of the obtained IRM, it has repeated the Fuzzy DEMATEL procedure other two times, by focusing first only on the digital factors (Section 5.2) and then on the LM and CE role (Section 5.3). The computations have been made again in the same *File described before, more precisely in the last three pages, called "Digital" and "SDG, LM, CE" and "no LM-CE", as it is shown in Figure 61.*

Figure 50: The last three sheets of the Excel file "Fuzzy DEMATEL"

In each section the results got by the Fuzzy DEMATEL Application have been presented in an IDEF0 model, a formal graphical way to schematize them and let their discussion be clearer. In addition, these graphical models are useful to perform in a rapid way the Backward Pass (BP) of the model, that has been presented in Section 3.1.
After a deep dive analysis of the relationships among all the twelve factors, the results have been put together in Section 5.4 in the TwinSME Model, the final IDEF0 representation.

5.1. Fuzzy DEMATEL Application steps

In this Subsection the results of the Fuzzy DEMATEL application are presented step by step, according to the sequence described in Subsection 3.2.
Step 1 (collection of the Individual Matrix of Assessment and Fuzzification):
In each sheet of the dedicated "Fuzzy DEMATEL" Excel file there is first of all, the Direct Influence Matrix DIM, got as output of the specific Canva Session, as example in Figure 51, it is possible to see the DIM present in the sheet AMLS1.

Direct Influence Matrix AMLS			Digital Factors							SDGs Factors			LM & CE Factors	
			H/V Integration	Accessibility to_Information	Automation	Flexibility/ Variety	OEE	RTDCA	Virtualization	SDG8	SDG9	SDG12	LM	CE
			F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12
Digital Factors	H/V Integration	F1	*	4	4	3	3	4	3	4	4	4	3	2
	Accessibility to_Information	F2	2	*	3	2	3	3	3	2	4	3	4	2
	Automation	F3	3	3	*	1	4	3	2	3	4	2	3	2
	Flexibility/ Variety	F4	1	0	0	*	1	2	1	3	3	3	1	3
	OEE	F5	1	2	2	1	*	2	1	3	2	2	3	1
	RTDCA	F6	4	4	2	3	3	*	4	4	4	4	4	4
	Virtualization	F7	1	1	1	2	2	1	*	3	3	3	3	3
SDGs Factors	SDG8	F8	0	1	1	1	3	2	1	*	2	1	1	1
	SDG9	F9	2	2	2	0	2	2	0	1	*	1	1	1
	SDG12	F10	3	3	1	1	1	2	0	1	2	*	1	4
LM & CE Factors	LM	F11	1	2	2	0	3	2	1	3	4	4	*	3
	CE	F12	1	0	0	3	1	1	0	2	2	4	3	*

Figure 51: Direct Influence Matrix AMLS1 of Canva Session [CV3]

At the right of the Influence Matrix, for each expert p, it is presented the Fuzzified Direct Influence Matrix (Figure 52), $\hat{A}^p = [\hat{a}^p_{ij}]_{12*12}$, where each influence level is substituted by the correspondent triangular fuzzy number, codifiable in the following way, $[a^p_{lij}; a^p_{mij}; a^p_{uij}]$, according to Fuzzification Table in Figure 53.

$\hat{A}^p = [\hat{a}^p_{ij}]_{12*12}$		H/V Integration	Accessibility to_Information	Automation	Flexibility/ Variety	OEE	RTDCA	Simulation	SDG8	SDG9	SDG12	LM	CE
		F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12
H/V Integration	F1	1;1;1	0,75;1;1	0,75;1;1	0,50;0,75;1	0,50;0,75;1	0,75;1;1	0,50;0,75;1	0,75;1;1	0,75;1;1	0,75;1;1	0,50;0,75;1	0,25;0,50;0,75
Accessibility to_Information	F2	0,25;0,50;0,75	1;1;1	0,50;0,75;1	0,25;0,50;0,75	0,50;0,75;1	0,50;0,75;1	0,50;0,75;1	0,25;0,50;0,75	0,75;1;1	0,50;0,75;1	0,75;1;1	0,25;0,50;0,75
Automation	F3	0,50;0,75;1	0,50;0,75;1	1;1;1	0;0,25;0,50	0,75;1;1	0,50;0,75;1	0,25;0,50;0,75	0,50;0,75;1	0,75;1;1	0,25;0,50;0,75	0,50;0,75;1	0,25;0,50;0,75
Flexibility/ Variety	F4	0;0,25;0,50	0;0;0,25	0;0;0,25	1;1;1	0;0,25;0,50	0,25;0,50;0,75	0;0,25;0,50	0,50;0,75;1	0,50;0,75;1	0,50;0,75;1	0;0,25;0,50	0,50;0,75;1
OEE	F5	0;0,25;0,50	0,25;0,50;0,75	0,25;0,50;0,75	0;0,25;0,50	1;1;1	0,25;0,50;0,75	0;0,25;0,50	0,50;0,75;1	0,25;0,50;0,75	0,25;0,50;0,75	0,50;0,75;1	0;0,25;0,50
RTDCA	F6	0,75;1;1	0,75;1;1	0,25;0,50;0,75	0,50;0,75;1	0,50;0,75;1	1;1;1	0,75;1;1	0,75;1;1	0,75;1;1	0,75;1;1	0,75;1;1	0,75;1;1
Simulation	F7	0;0,25;0,50	0;0,25;0,50	0;0,25;0,50	0,25;0,50;0,75	0,25;0,50;0,75	0;0,25;0,50	1;1;1	0,50;0,75;1	0,50;0,75;1	0,50;0,75;1	0,50;0,75;1	0,50;0,75;1
SDG8	F8	0;0;0,25	0;0,25;0,50	0;0,25;0,50	0;0,25;0,50	0,50;0,75;1	0,25;0,50;0,75	0;0,25;0,50	1;1;1	0,25;0,50;0,75	0;0,25;0,50	0;0,25;0,50	0;0,25;0,50
SDG9	F9	0,25;0,50;0,75	0,25;0,50;0,75	0,25;0,50;0,75	0;0;0,25	0,25;0,50;0,75	0,25;0,50;0,75	0;0;0,25	0;0,25;0,50	1;1;1	0;0,25;0,50	0;0,25;0,50	0;0,25;0,50
SDG12	F10	0,50;0,75;1	0,50;0,75;1	0;0,25;0,50	0;0,25;0,50	0;0,25;0,50	0,25;0,50;0,75	0;0;0,25	0;0,25;0,50	0,25;0,50;0,75	1;1;1	0;0,25;0,50	0,75;1;1
LM	F11	0;0,25;0,50	0,25;0,50;0,75	0,25;0,50;0,75	0;0;0,25	0,50;0,75;1	0,25;0,50;0,75	0;0,25;0,50	0,50;0,75;1	0,75;1;1	0,75;1;1	1;1;1	0,50;0,75;1
CE	F12	0;0,25;0,50	0;0;0,25	0;0;0,25	0,50;0,75;1	0;0,25;0,50	0;0,25;0,50	0;0;0,25	0,25;0,50;0,75	0,25;0,50;0,75	0,75;1;1	0,50;0,75;1	1;1;1

Figure 52: Fuzzified Direct Influence Matrix, AMLS1 of Canva Session [CV3], Expert 3

Score	Fuzzy	l	m	u
*	1;1;1	1	1	1
0	0;0;0,25	0	0	0,25
1	0;0,25;0,50	0	0,25	0,5
2	0,25;0,50;0,75	0,25	0,5	0,75
3	0,50;0,75;1	0,5	0,75	1
4	0,75;1;1	0,75	1	1

Figure 53: Fuzzification Table

In order to perform in a clear way the steps of the Fuzzy DEMATEL technique each Fuzzified matrix has been decomposed in twelve matrixes, one for each Factor, containing one array for each influence faced by a Factor j, from all the twelve Factors i, with i again from 1 to 12. The first three matrices of the total twelve, got by decomposition of the Fuzzified DIM, of [CV3] are visible in Figure 54.

	Step 1: Fuzzification $[\ a_{lij}^{p}\ \ a_{mij}^{p}\ \ a_{uij}^{p}\ ]$		
	F1	F2	F3
F1	[1,00 1,00 1,00]	[0,75 1,00 1,00]	[0,75 1,00 1,00]
F2	[0,25 0,50 0,75]	[1,00 1,00 1,00]	[0,50 0,75 1,00]
F3	[0,50 0,75 1,00]	[0,50 0,75 1,00]	[1,00 1,00 1,00]
F4	[0,00 0,25 0,50]	[0,00 0,00 0,25]	[0,00 0,00 0,25]
F5	[0,00 0,25 0,50]	[0,25 0,50 0,75]	[0,25 0,50 0,75]
F6	[0,75 1,00 1,00]	[0,75 1,00 1,00]	[0,25 0,50 0,75]
F7	[0,00 0,25 0,50]	[0,00 0,25 0,50]	[0,00 0,25 0,50]
F8	[0,00 0,00 0,25]	[0,00 0,25 0,50]	[0,00 0,25 0,50]
F9	[0,25 0,50 0,75]	[0,25 0,50 0,75]	[0,25 0,50 0,75]
F10	[0,50 0,75 1,00]	[0,50 0,75 1,00]	[0,00 0,25 0,50]
F11	[0,00 0,25 0,50]	[0,25 0,50 0,75]	[0,25 0,50 0,75]
F12	[0,00 0,25 0,50]	[0,00 0,00 0,25]	[0,00 0,00 0,25]

Figure 54: Columns F1, F2, F3 of the Fuzzified Direct Influence Matrix, AMLS1, of Canva Session [CV3], Expert 3

Step 2 (*defuzzification of the Individual Matrixes to generate crisp values*):

2.a. In each sheet it is then performed the *Normalization of the Fuzzified Direct Influence Matrix* according to the system of equations (1) (Section 3.2). The normalization of the level of influence assigned to the first three factors by expert 3 is shown in Figure 55.

$maxu_{ij}$	1
$minl_{ij}$	0
$\Delta\,(maxu_{ij}; minl_{ij})$	1

Eq (1)

$$n^p_{lij} = \frac{(a^p_{lij} - mina^p_{lij})}{\Delta^{max}_{min}};$$

$$n^p_{mij} = \frac{(a^p_{mij} - mina^p_{mij})}{\Delta^{max}_{min}};$$

$$n^p_{uij} = \frac{(a^p_{uij} - mina^p_{uij})}{\Delta^{max}_{min}};$$

$$where\ \Delta^{max}_{min} = maxa^p_{uij} - mina^p_{lij}$$

Step 2a: Normalization

[n^k_{lij} n^k_{mij} n^k_{uij}]

	F1	F2	F3
F1	[1,00 1,00 0,75]	[0,75 1,00 0,75]	[0,75 1,00 0,75]
F2	[0,25 0,50 0,50]	[1,00 1,00 0,75]	[0,50 0,75 0,75]
F3	[0,50 0,75 0,75]	[0,50 0,75 0,75]	[1,00 1,00 0,75]
F4	[0,00 0,25 0,25]	[0,00 0,00 0,00]	[0,00 0,00 0,00]
F5	[0,00 0,25 0,25]	[0,25 0,50 0,50]	[0,25 0,50 0,50]
F6	[0,75 1,00 0,75]	[0,75 1,00 0,75]	[0,25 0,50 0,50]
F7	[0,00 0,25 0,25]	[0,00 0,25 0,25]	[0,00 0,25 0,25]
F8	[0,00 0,00 0,00]	[0,00 0,25 0,25]	[0,00 0,25 0,25]
F9	[0,25 0,50 0,25]	[0,25 0,50 0,50]	[0,25 0,50 0,50]
F10	[0,50 0,75 0,75]	[0,50 0,75 1,00]	[0,00 0,25 0,50]
F11	[0,00 0,25 0,25]	[0,25 0,50 0,75]	[0,25 0,50 0,75]
F12	[0,00 0,25 0,25]	[0,00 0,00 0,25]	[0,00 0,00 0,25]

Figure 55: Normalization of the Columns F1, F2, F3 of the Fuzzified DIM of Canva Session [CV3], Expert 3

2.b. *Calculation of left* nl^p_{ij} *and right* nr^p_{ij} normalized values through system of equations (2). In figure 56 the left and right values of F1,F2,F3 of the example sheet.

Eq (2)

$$nl^p_{ij} = \frac{n^p_{mij}}{(1+n^p_{mij}-n^p_{lij})};$$

$$nr^p_{ij} = \frac{n^p_{uij}}{(1+n^p_{uij}-n^p_{mij})};$$

Step 2b: L and R normalized values

nl^p_{ij} nr^p_{ij}

	F1	F2	F3
F1	1,00 1,00	0,80 1,00	0,80 1,00
F2	0,40 0,50	1,00 1,00	0,60 0,75
F3	0,60 0,75	0,60 0,75	1,00 1,00
F4	0,20 0,25	0,00 0,00	0,00 0,00
F5	0,20 0,25	0,40 0,50	0,40 0,50
F6	0,80 1,00	0,80 1,00	0,40 0,50
F7	0,20 0,25	0,20 0,25	0,20 0,25
F8	0,00 0,00	0,20 0,25	0,20 0,25
F9	0,40 0,33	0,40 0,50	0,40 0,50
F10	0,60 0,75	0,60 0,80	0,20 0,40
F11	0,20 0,25	0,40 0,60	0,40 0,60
F12	0,20 0,25	0,00 0,20	0,00 0,20

Figure 56: left and Right normalized values of the Columns F1, F2, F3 of the Fuzzified DIM of Canva Session [CV3]

2.c. The following step applied again in each sheet, presents the *Acquisition of the Crisp Values* through equation (3), as it is shown in Figure 57.

Eq (3)

$$x_{ij}^{p} = \frac{nl_{ij}^{p} * (1 - nl_{ij}^{p}) + nr_{ij}^{p} * nr_{ij}^{p}}{(1 - nl_{ij}^{p} + nr_{ij}^{p})};$$

Step 2c: Crisp Values (CV) x_{ij}^{p}	F1	F2	F3
F1	1,00	0,97	0,97
F2	0,45	1,00	0,70
F3	0,70	0,70	1,00
F4	0,21	0,00	0,00
F5	0,21	0,45	0,45
F6	0,97	0,97	0,45
F7	0,21	0,21	0,21
F8	0,00	0,21	0,21
F9	0,38	0,45	0,45
F10	0,70	0,73	0,27
F11	0,21	0,50	0,50
F12	0,21	0,03	0,03

Figure 57: Crisp values of the Factor F1, F2, F3 of Canva Session [CV3]

2.d. Now, it is applied the last additional passage of the Fuzzy version with respect to the standard DEMATEL technique, which is the calculation of *Total Normalized Crisp Values* through equation (4), as shown in Figure 58. For each respondent p there is now a matrix Z^{p}, in the respective sheet, exemplified in Figure 59, composed of crisp values z_{ij}^{p}, which is the output of the fuzzification process of this Fuzzy version and the input of the standard DEMATEL steps.

Eq (4)

$$z_{ij}^{p} = mina_{lij}^{p} + x_{ij}^{p} * \Delta_{min}^{max};$$

Step 2d: Tot normalized CV z_{ij}^{p}	F1	F2	F3
F1	1,00	0,97	0,97
F2	0,45	1,00	0,70
F3	0,70	0,70	1,00
F4	0,21	0,00	0,00
F5	0,21	0,45	0,45
F6	0,97	0,97	0,45
F7	0,21	0,21	0,21
F8	0,00	0,21	0,21
F9	0,38	0,45	0,45
F10	0,70	0,73	0,27
F11	0,21	0,50	0,50
F12	0,21	0,03	0,03

Figure 58: Total normalized Crisp values of the Factor F1, F2, F3 of Canva Session [CV3]

Step 2d: DIM with Total normalized CV

$$Z^p = [z_{ij}^p]_{12*12}$$

Direct Influence Matrix DIM *with Crisp Values*			Digital Factors							SDGs Factors			LM & CE Factors	
			H/V Integration	Accessibility to_Information	Automation	Flexibility/ Variety	OEE	RTDCA	Virtualization	SDG8	SDG9	SDG12	LM	CE
			F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12
Digital Factors	H/V Integration	F1	1,000	0,967	0,967	0,698	0,500	0,689	0,698	0,689	0,433	0,689	0,500	0,250
	Accessibility to_Information	F2	0,445	1,000	0,698	0,445	0,500	0,500	0,698	0,250	0,433	0,500	0,689	0,250
	Automation	F3	0,698	0,698	1,000	0,212	0,689	0,500	0,445	0,500	0,433	0,250	0,500	0,250
	Flexibility/ Variety	F4	0,212	0,000	0,000	1,000	0,000	0,250	0,212	0,500	0,250	0,500	0,000	0,500
	OEE	F5	0,212	0,445	0,445	0,212	0,667	0,250	0,212	0,500	0,000	0,250	0,500	0,000
	RTDCA	F6	0,967	0,967	0,445	0,698	0,500	0,667	0,967	0,689	0,433	0,689	0,689	0,689
	Virtualization	F7	0,212	0,212	0,212	0,445	0,250	0,000	1,000	0,500	0,350	0,500	0,500	0,555
SDGs Factors	SDG8	F8	0,000	0,212	0,212	0,212	0,500	0,250	0,212	0,750	0,083	0,000	0,000	0,033
	SDG9	F9	0,376	0,445	0,445	0,000	0,250	0,250	0,000	0,033	0,624	0,033	0,000	0,033
	SDG12	F10	0,698	0,733	0,267	0,212	0,083	0,302	0,000	0,033	0,083	0,750	0,083	0,750
LM & CE Factors	LM	F11	0,212	0,500	0,500	0,000	0,595	0,302	0,212	0,555	0,595	0,750	0,800	0,595
	CE	F12	0,212	0,033	0,033	0,698	0,083	0,033	0,000	0,302	0,129	0,750	0,595	0,800

Figure 59: Direct Influence Matrix with Crisp Values of Canva Session [CV3]

<u>*Step 3*</u> (*aggregation of the different matrixes constituted of total normalized crisp values into the Group Direct-influence Matrix):* In the dedicated sheet called "DEMATEL", it is present the *Average Direct-influence Matrix,* Z*, shown in Figure 60, got through the mathematical average of all the DIM with Crisp Values, Zp.

Step 3: aggregation of all the DIM with CV

$$Z^* = [z_{ij}^*]_{12*12}; \; z_{ij}^* = \frac{1}{p}\sum_{p=1}^{p} z_{ij}^p$$

Group ***DIM***			Digital Factors							SDGs Factors			LM & CE Factors		
			H/V Integration	Accessibility to_Information	Automation	Flexibility/ Variety	OEE	RTDCA	Virtualization	SDG8	SDG9	SDG12	LM	CE	
			F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	Sums
Digital Factors	H/V Integration	F1	0,857	0,908	0,928	0,782	0,683	0,769	0,778	0,688	0,599	0,756	0,691	0,589	9,028
	Accessibility to_Information	F2	0,314	0,952	0,737	0,577	0,582	0,584	0,698	0,434	0,527	0,513	0,645	0,435	6,998
	Automation	F3	0,633	0,727	1,000	0,230	0,675	0,571	0,262	0,430	0,573	0,405	0,702	0,292	6,500
	Flexibility/ Variety	F4	0,121	0,107	0,045	0,976	0,050	0,180	0,091	0,558	0,376	0,592	0,195	0,594	3,885
	OEE	F5	0,224	0,198	0,279	0,166	0,714	0,252	0,200	0,403	0,349	0,391	0,702	0,186	4,064
	RTDCA	F6	0,779	0,869	0,704	0,724	0,593	0,786	0,890	0,664	0,599	0,756	0,808	0,749	8,921
	Virtualization	F7	0,259	0,302	0,197	0,471	0,282	0,185	1,000	0,502	0,451	0,581	0,567	0,575	5,372
SDGs Factors	SDG8	F8	0,033	0,030	0,106	0,250	0,245	0,098	0,183	0,720	0,060	0,084	0,030	0,038	1,877
	SDG9	F9	0,235	0,200	0,330	0,091	0,176	0,167	0,091	0,002	0,628	0,100	0,200	0,089	2,309
	SDG12	F10	0,314	0,255	0,186	0,168	0,006	0,152	0,030	0,053	0,091	0,792	0,360	0,532	2,939
LM & CE Factors	LM	F11	0,140	0,392	0,541	0,030	0,589	0,324	0,136	0,443	0,450	0,588	0,819	0,531	4,983
	CE	F12	0,076	0,063	0,123	0,818	0,036	0,048	0,121	0,264	0,371	0,793	0,684	0,748	4,145
		Sums	3,985	5,003	5,176	5,283	4,631	4,116	4,480	5,161	5,074	6,351	6,403	5,358	

Figure 60: Group Direct influence Matrix

Step 4 (*normalization of the group direct-influence matrix):* Z* is then normalized through the transformation (6) to become the *Normalized Direct Influence Matrix*, Zn = $[zn_{ij}]_{n*n}$, where $zn_{ij} = zn_{ij}/\alpha$. Normalization factor α is the maximum between all the row-wise and column-wise sums computed in Figure 61.

Step 4: normalization of the Group DIM
Zn = $[zn_{ij}]_{12*12}$

Scaling Factor alfa

Max Row-wise sums	9,03	ALFA
Max Col-wise sums	6,40	**9,028**

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12
F1	0,095	0,101	0,103	0,087	0,076	0,085	0,086	0,076	0,066	0,084	0,077	0,065
F2	0,035	0,105	0,082	0,064	0,064	0,065	0,077	0,048	0,058	0,057	0,071	0,048
F3	0,070	0,081	0,111	0,025	0,075	0,063	0,029	0,048	0,063	0,045	0,078	0,032
F4	0,013	0,012	0,005	0,108	0,006	0,020	0,010	0,062	0,042	0,066	0,022	0,066
F5	0,025	0,022	0,031	0,018	0,079	0,028	0,022	0,045	0,039	0,043	0,078	0,021
F6	0,086	0,096	0,078	0,080	0,066	0,087	0,099	0,074	0,066	0,084	0,089	0,083
F7	0,029	0,033	0,022	0,052	0,031	0,020	0,111	0,056	0,050	0,064	0,063	0,064
F8	0,004	0,003	0,012	0,028	0,027	0,011	0,020	0,080	0,007	0,009	0,003	0,004
F9	0,026	0,022	0,037	0,010	0,019	0,018	0,010	0,000	0,070	0,011	0,022	0,010
F10	0,035	0,028	0,021	0,019	0,001	0,017	0,003	0,006	0,010	0,088	0,040	0,059
F11	0,016	0,043	0,060	0,003	0,065	0,036	0,015	0,049	0,050	0,065	0,091	0,059
F12	0,008	0,007	0,014	0,091	0,004	0,005	0,013	0,029	0,041	0,088	0,076	0,083

Figure 61: Normalized Group Direct Influence Matrix

Step 5 (*creation of the Group Indirect-influence Matrix):* In matrix ΔZ = $[\Delta z_{ij}]_{n*n}$, deriving from Equation (8), shown in Figure 62, there are visible the indirect influences between factors.

Step 5: Group Indirect Influence Matrix IIM

$$Eq\ (8):\ \Delta Z = Zn\,(I - Zn)^{-1}$$

$$\Delta Z = Zn * (I - Zn)^{-1}$$

0,178	0,207	0,213	0,196	0,173	0,172	0,178	0,184	0,172	0,219	0,212	0,178
0,097	0,187	0,166	0,146	0,140	0,130	0,148	0,129	0,140	0,159	0,176	0,134
0,135	0,164	0,200	0,100	0,153	0,131	0,096	0,126	0,144	0,142	0,181	0,113
0,036	0,038	0,033	0,152	0,029	0,043	0,033	0,098	0,075	0,114	0,061	0,108
0,057	0,063	0,075	0,057	0,122	0,062	0,055	0,088	0,081	0,098	0,135	0,065
0,166	0,199	0,184	0,188	0,159	0,170	0,189	0,178	0,170	0,217	0,222	0,196
0,067	0,082	0,072	0,110	0,077	0,060	0,159	0,111	0,104	0,138	0,133	0,126
0,014	0,016	0,025	0,045	0,042	0,022	0,034	0,101	0,021	0,028	0,021	0,020
0,049	0,050	0,067	0,035	0,045	0,041	0,032	0,025	0,099	0,043	0,057	0,036
0,060	0,060	0,054	0,053	0,027	0,042	0,027	0,036	0,041	0,135	0,083	0,098
0,055	0,095	0,116	0,051	0,117	0,078	0,055	0,101	0,103	0,133	0,163	0,115
0,032	0,036	0,045	0,133	0,030	0,030	0,035	0,065	0,077	0,143	0,123	0,130

Figure 62: Group Indirect Influence Matrix

<u>Step 6</u> (*creation of the Total Direct and Indirect Influence Matrix):* The Total Influence matrix T (Figure 63) is finally got, by summing up the Normalized Direct Influence Matrix Zn and the matrix ΔZ, related to indirect influences.

Step 6: Total Direct and Indirect Influence Matrix DIIM

$$Eq\ (9):\ T = Zn + \Delta Z$$

Total Influence matrix DIIM			Digital Factors							SDGs Factors			LM & CE Factors			
			H/V Integration	Accessibility to_Information	Automation	Flexibility/ Variety	OEE	RTDCA	Virtualization	SDG8	SDG9	SDG12	LM	CE		
			F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	R	R
Digital Factors	H/V Integration	F1	0,273	0,308	0,316	0,283	0,249	0,257	0,264	0,260	0,239	0,302	0,288	0,244	3,283	r1
	Accessibility to_Information	F2	0,131	0,293	0,248	0,210	0,204	0,195	0,225	0,177	0,199	0,216	0,248	0,183	2,527	r2
	Automation	F3	0,205	0,245	0,311	0,126	0,228	0,194	0,125	0,174	0,208	0,187	0,259	0,145	2,406	r3
	Flexibility/ Variety	F4	0,049	0,050	0,037	0,260	0,034	0,063	0,043	0,160	0,116	0,180	0,083	0,174	1,250	r4
	OEE	F5	0,082	0,085	0,106	0,075	0,201	0,090	0,078	0,133	0,120	0,141	0,213	0,086	1,409	r5
	RTDCA	F6	0,252	0,295	0,262	0,268	0,225	0,257	0,287	0,252	0,236	0,301	0,312	0,279	3,225	r6
	Virtualization	F7	0,096	0,115	0,094	0,162	0,108	0,080	0,269	0,167	0,154	0,202	0,196	0,190	1,834	r7
SDGs Factors	SDG8	F8	0,018	0,019	0,037	0,073	0,069	0,033	0,054	0,181	0,028	0,037	0,025	0,024	0,597	r8
	SDG9	F9	0,075	0,073	0,104	0,045	0,065	0,060	0,042	0,025	0,169	0,054	0,079	0,046	0,835	r9
	SDG12	F10	0,095	0,089	0,074	0,072	0,027	0,059	0,031	0,041	0,051	0,223	0,123	0,157	1,042	r10
LM & CE Factors	LM	F11	0,071	0,139	0,176	0,055	0,182	0,114	0,070	0,150	0,153	0,198	0,254	0,174	1,734	r11
	CE	F12	0,041	0,043	0,059	0,224	0,034	0,035	0,049	0,094	0,119	0,231	0,199	0,213	1,340	r12
		C	1,388	1,752	1,824	1,852	1,627	1,438	1,537	1,815	1,791	2,272	2,277	1,912		
		C	c1	c2	c3	c4	c5	c6	c7	c8	c9	c10	c11	c12		

Figure 63: Total Influence Matrix

Step 7 (production of the Influential Relation Map (IRM)): In order to get The IRM, it is computed the summation of the values on the rows and of the columns of the T matrix, denoted respectively as r_i for each row i and c_j for the sum of values in column j. They are visible in Figure 64, followed by Prominence (s_i^+) and Relation (s_i^-) computation.

Step 7: Production of the Influential Relation Map IRM
(11)$Prominence = s_i^+ = r_i + c_j$; (12)$Relation = s_i^- = r_i - c_j$;

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12
r.i	3,283	2,527	2,406	1,250	1,409	3,225	1,834	0,597	0,835	1,042	1,734	1,340
c.j	1,388	1,752	1,824	1,852	1,627	1,438	1,537	1,815	1,791	2,272	2,277	1,912
$Prom = s_i^+ = r_i + c_j$	4,671	4,279	4,230	3,102	3,036	4,663	3,370	2,412	2,626	3,314	4,011	3,252
$Rel = s_i^- = r_i - c_j$	1,896	0,775	0,582	(0,602)	(0,217)	1,787	0,297	(1,218)	(0,956)	(1,229)	(0,543)	(0,572)

Figure 64: Row-wise and column-wise sums, followed by Prominence and Relation values

Prominence and Relation are then used to construct the IRM, shown in Figure 65. The latter is put on the y-axis and it depicts, as explained in Section 3.2, the causal or effective role of the i-th factor in the Twin system, while the Prominence, which is on the x-axis, indicates the strength of the influence links.

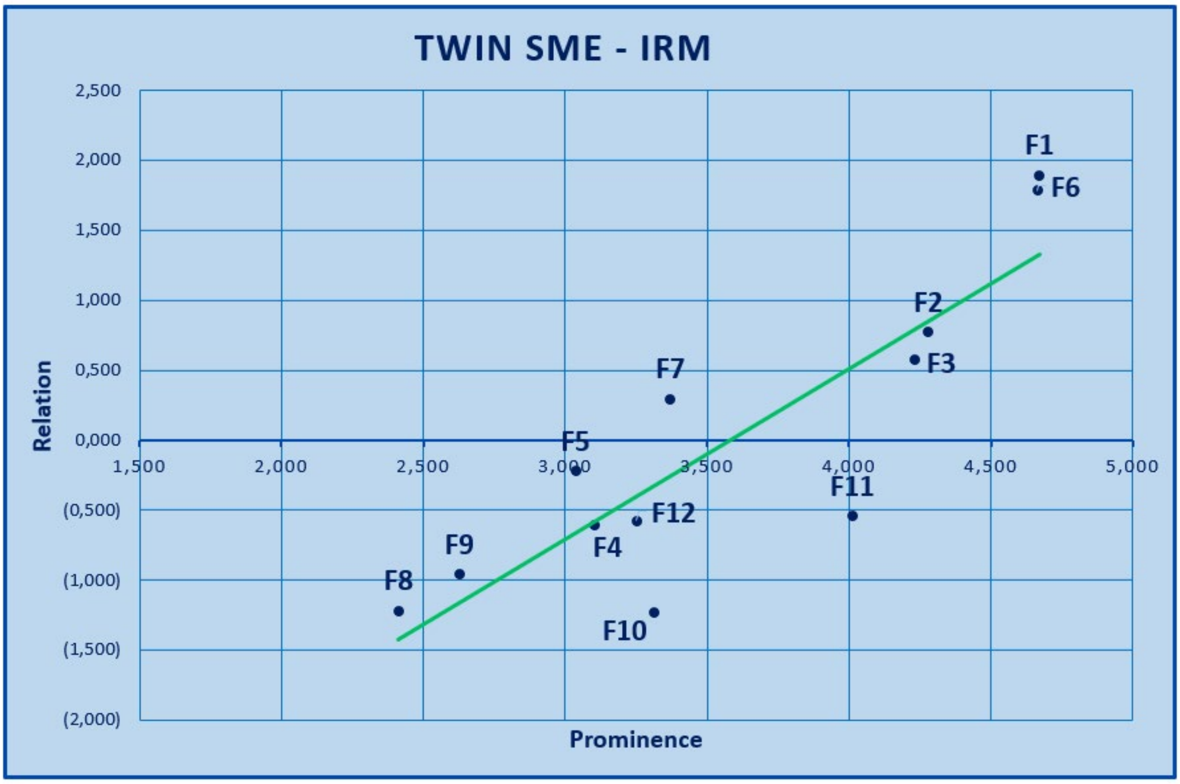


Figure 65: TwinSME Influential Relation Map

5.1.1. Preliminary results discussion

In order to analyse the obtained results, the Figure 66 has been realized. It is possible to see clearly which are the factors that resulted to be causes, by having a positive Relation and the ones that have been classified as effects. In the last row, there is also a ranking of the Relation levels of the different factors.

	Digital Factors							SDGs Factors			LM & CE Factors	
	H/V Integration	Data Access	Automation	Flexibility/ Variety	OEE	RTDCA	Virtualization	SDG8 - Human centricity	SDG9 - Resiliency	SDG12 - Sustainability	LM	CE
	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12
Relation	1,879	0,775	0,582	(0,603)	(0,218)	1,814	0,296	(1,219)	(0,957)	(1,231)	(0,544)	(0,574)
C/E	Cause	Cause	Cause	Effect	Effect	Cause	Cause	Effect	Effect	Effect	Effect	Effect
C/E	C	C	C	E	E	C	C	E	E	E	E	E
Rank	1	3	4	9	6	2	5	11	10	12	7	8

Figure 66: Cause and Effects

The framework provides important insights. Considering the interdependence among factors, much focus should be put on the cause group criteria, because by definition, by improving them, the effect factors are developed simultaneously. The positive Relation indeed expresses the factors that affect other criteria, while a negative relation features the dimensions which are affected by the others (Zileli, et al., 2022).
The cause group dimensions of TwinSME model are five Digital Factors, i.e. F1-Horizontal and Vertical Integration, F6-Real Time Data Collection and Analysis, F2-Data Access that stands for Access to Information, F3-Automation and F7-Virtualization. It is straightforward to see that between the cause factors there are two with a very high Prominence, that means that their level of influence on the other paradigms is very strong and they are F1-H/V Integration and F6-RTDCA. The remaining two digital factors F4-Flexibility and Variety and F5-OEE are in the effect group.
From Figure 66, it is straightforward to define an effect role for the three SDGs that present a very low level of Relation that suggests how much they can be influenced by the other dimensions in a Twin context. In addition, the prominence is significantly higher than zero, it means that the degree of influence that they feel is quite strong. Thus, organizations can attain sustainability goals by investing in Industry 4.0 paradigms (Yu et al., 2022).
In order to represent in a graphical way the cause-effect relationships among the twelve factors, a complete net diagram has been realized in Figure 68. It makes reference to the Figure 67, where it is reported a second time The Total Influence Matrix, but only the values above a defined threshold are shown. A threshold value has been determined in order to avoid the complexity of the criteria with a small effect level and it has been calculated by

averaging the values in the Total Influence Matrix, obtained after Step 6 and shown in Figure 63.

Threshold value: 0,150

Total Influence matrix DIIM			Digital Factors							SDGs Factors			LM & CE Factors	
			H/V Integration	Accessibility to_Information	Automation	Flexibility/ Variety	OEE	RTDCA	Virtualization	SDG8	SDG9	SDG12	LM	CE
			F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12
Digital Factors	H/V Integration	F1	-	0,308	0,316	0,283	0,249	0,257	0,264	0,26	0,239	0,302	0,289	0,244
	Accessibility to_Information	F2	-	-	0,248	0,21	0,204	0,195	0,225	0,177	0,199	0,216	0,248	0,183
	Automation	F3	0,206	0,245	-	-	0,228	0,195	-	0,174	0,208	0,187	0,259	-
	Flexibility/ Variety	F4	-	-	-	-	-	-	-	0,16	-	0,18	-	0,174
	OEE	F5	-	-	-	-	-	-	-	-	-	-	0,213	-
	RTDCA	F6	0,267	0,296	0,263	0,269	0,226	-	0,289	0,253	0,237	0,302	0,313	0,28
	Virtualization	F7	-	-	-	0,162	-	-	-	0,167	0,154	0,202	0,196	0,19
SDGs Factors	SDG8	F8	-	-	-	-	-	-	-	-	-	-	-	-
	SDG9	F9	-	-	-	-	-	-	-	-	-	-	-	-
	SDG12	F10	-	-	-	-	-	-	-	-	-	-	-	0,157
LM & CE Factors	LM	F11	-	-	0,176	-	0,182	-	-	0,15	0,153	0,199	-	0,174
	CE	F12	-	-	-	0,224	-	-	-	-	-	0,231	0,199	-

Figure 67: Total Influence Matrix with threshold value

Criteria below the threshold value, equal to 0,150 were determined as affected (effect) criteria, and criteria above the threshold value as affecting (cause) criteria, with reference to Zileli paper (et al., 2023). The formers don't appear in the matrix, while the latters are coloured with a different blue shade according to the magnitude of the influence. The graphic illustration of the influences detected among the twelve factors has been made in Figure 68, where the continuous lines indicate a strong influence of the cause factor on the effect one, the dashed lines correspond to a medium influence and the dotted ones to a minimal degree of influence.

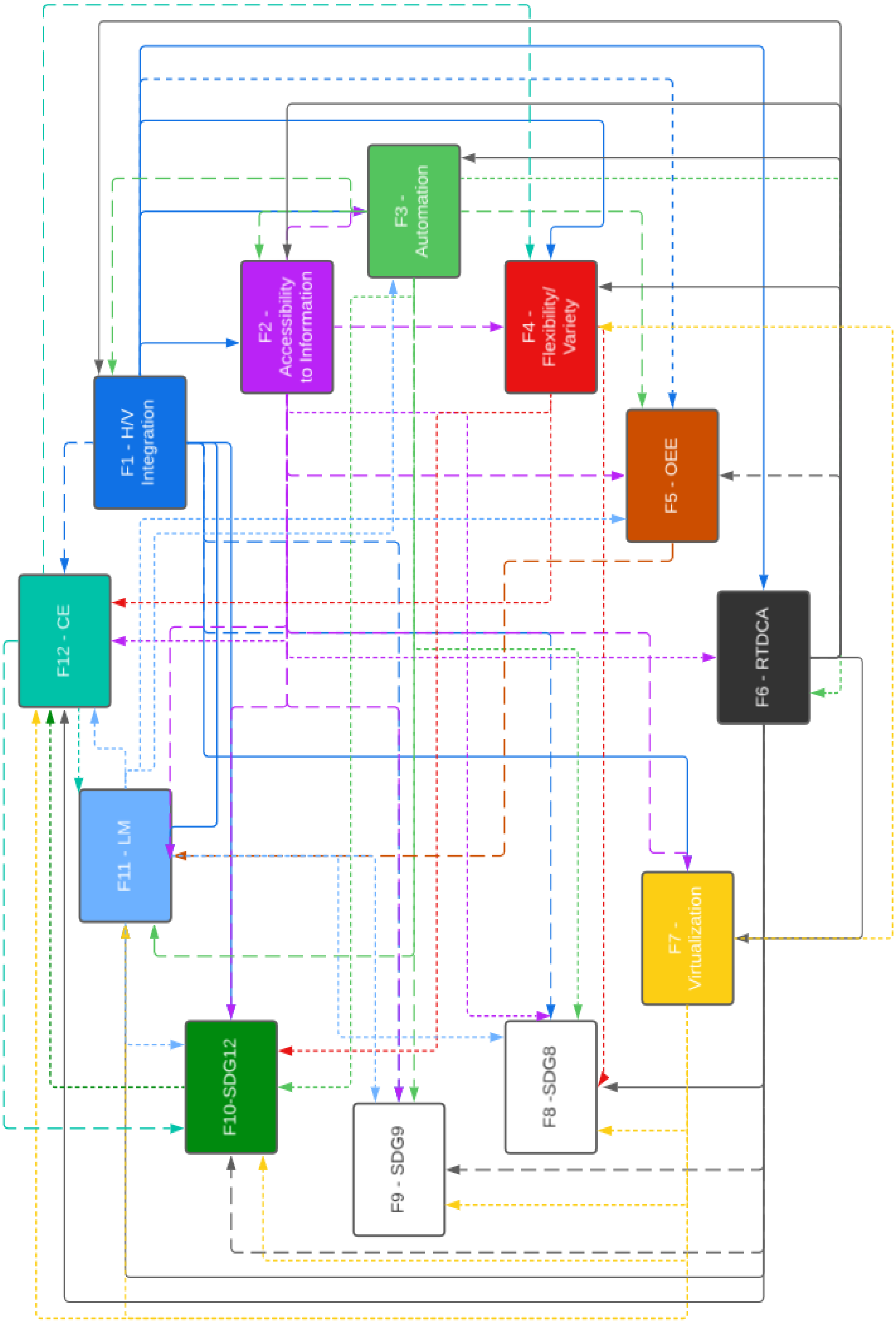


Figure 68: Illustration of the cause-effect relationships between the twelve factors

What is evident, it is the great number of significant cause-effect influences among the twelve factors in the achievement of a sustainable competitiveness. It is easy to be detected the strong degree of influence of F1 and F6 on the other paradigms, they indeed have a considerable number of continuous lines that exit from their boxes.
What is difficult to be interpreted from the TwinSME IRM of Figure 76 and from the illustration of Figure 80 is the role of F11-LM and F12-CE that don't have a positive Relation, so they don't appear as cause factors of this Twin system, but looking at their placement with respect to the green trend line of Figure 76, they are a way in the middle between the digital factors that resulted to be causes and the enabled SDGs targets.
In order to analyse in a deeper and clearer way the relationships in the system of Figure 68, it has repeated the Fuzzy DEMATEL procedure other two times, by focusing first only on the digital factors (Section 5.2) and then on the Lean and CE ones (Section 5.3). In this way, in the first case, it has been studied the relationships in a 4.0 scenario, between the digital criteria, from F1 to F7 included, that are the dimensions that resulted to be causes in the TwinSME model. In the second case instead, the attention is put on the influences between the effect group, that resulted to be composed of elements of the green transition.

5.2. Fuzzy DEMATEL Application on digital factors

This Section is dedicated to the analysis of the relationships among the digital factors that characterize an Industry 4.0 scenario, in which a 4.0 SME is collocated with the aim to increase its economic competitiveness [14]. This analysis is propaedeutic to the creation of the digital part of the TwinSME Model, where the digital enabling power of the KETs is put in light.
The dedicated sheet "Digital" of the "Fuzzy DEMATEL" Excel file starts with the Step 3 related to the aggregation of the Direct Influence Matrixes (DIM) with crisp values of all the respondents, but in this specific Group DIM only the first seven factors have been reported, as it is visible in Figure 69.

Step 3: aggregation of all the DIM with CV

$$Z^* = [z^*_{ij}]_{12*12};\ z^*_{ij} = \frac{1}{P}\sum_{p=1}^{P} z^p_{ij}$$

Group			Digital Factors							
DIM			H/V Integration	Data access	Automation	Flexibility/ Variety	OEE	RTDCA	Virtualization	
			F1	F2	F3	F4	F5	F6	F7	Sums
Digital Factors	H/V Integration	F1	0,857	0,908	0,928	0,782	0,683	0,769	0,778	5,705
	Data access	F2	0,314	0,952	0,737	0,577	0,582	0,584	0,698	4,444
	Automation	F3	0,633	0,727	1,000	0,230	0,675	0,571	0,262	4,098
	Flexibility/ Variety	F4	0,121	0,107	0,045	0,976	0,050	0,180	0,091	1,570
	OEE	F5	0,224	0,198	0,279	0,166	0,714	0,252	0,200	2,033
	RTDCA	F6	0,834	0,869	0,704	0,724	0,593	0,786	0,890	5,400
	Virtualization	F7	0,259	0,302	0,197	0,471	0,282	0,185	1,000	2,696
		Sums	3,242	4,063	3,890	3,926	3,579	3,327	3,919	

Figure 69: Group Direct influence Matrix of the Digital Factors

The step 4, 5, 6 and 7 have been performed on the same sheet to get the Digital Influential Relationship Map between the seven digital factors, that is shown in Figure 70.

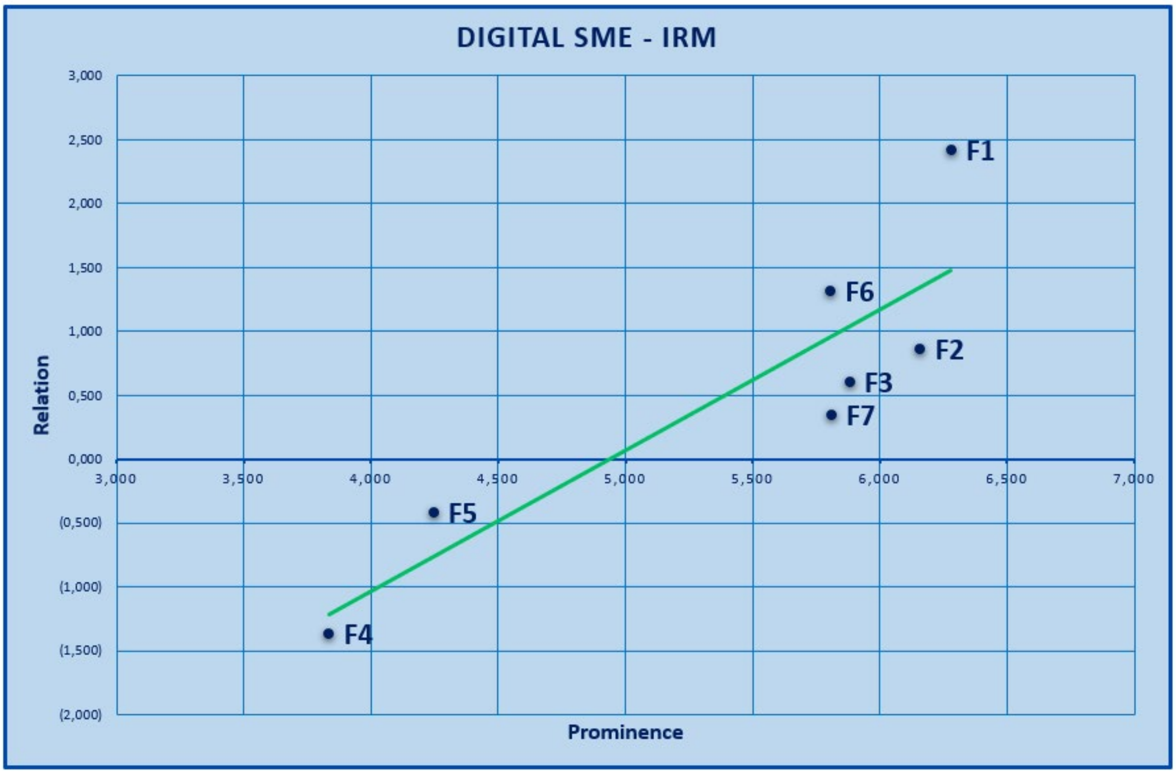


Figure 70: DigitalSME IRM between the Digital Factors

The so called <u>DigitalSME Influencial Relation Map</u> of Figure 70 depicts the deliverables that Industry 4.0 program gifts to an SME that starts the Digital Transformation Journey and adopts the Fourth Industrial Revolution philosophy [14]. Digitalization is considered as a reorganization by using new technologies that directly contribute to generate information to increase productivity and growth (Dabbous, et al., 2023).

The DigitalSME IRM has to be interpreted in the following way: the cause factors are the ones that has more impact on the 4.0 digital maturity level of an SME, it means that if an entrepreneur invests on one of them, the whole digital enterprise system will be positively affected with a certain magnitude. So it is important to focus on the causes, because an improvement of one or more of them may impact as consequence also the influenceable criteria (Prakash, et al., 2022). The Figure 71 shows clearly which are the influencing digital factors in a 4.0 system, and which are the influenced ones, in other words it enlightens the ranking of importance of the seven criteria based on the relation level.

	Digital Factors						
	H/V Integration	Data Access	Automation	Flexibility/ Variety	OEE	RTDCA	Virtualization
	F1	F2	F3	F4	F5	F6	F7
Relation	2,425	0,863	0,602	(1,368)	(0,419)	1,312	0,345
C/E	Cause	Cause	Cause	Effect	Effect	Cause	Cause
C/E	C	C	C	E	E	C	C
Rank	1	3	4	7	6	2	5

Figure 71: Cause and Effects between the digital factors

If an SME invests on the enhancement of the Digital paradigms which are in the cause group will be closer to Industry 4.0 philosophy (Mabkhot, et al., 2021). As resulted also from the general IRM, F1-H/V Integration, F6-RTDCA, F2-Data Access and F3-Automation are the causes in this I4.0 scenario, which has as a goal the achievement of a competitive advantage, an higher operational efficiency and an enlargement of market shares, in two words, an <u>economic competitiveness improvement</u> (Rehman, et al, 2023).

In Figure 72, the Digital section of the TwinSME Model is shown, that, as rest of the model, it is presented in the form of IDEF0. This graphic formalism has been adopted to wrap up and give a clear representation of the results got by the Fuzzy DEMATEL application. The Digital Transition block constitutes the Node A1 of the model, that will be completed by the Twin Transition block, Node A2, in next Section 5.3.

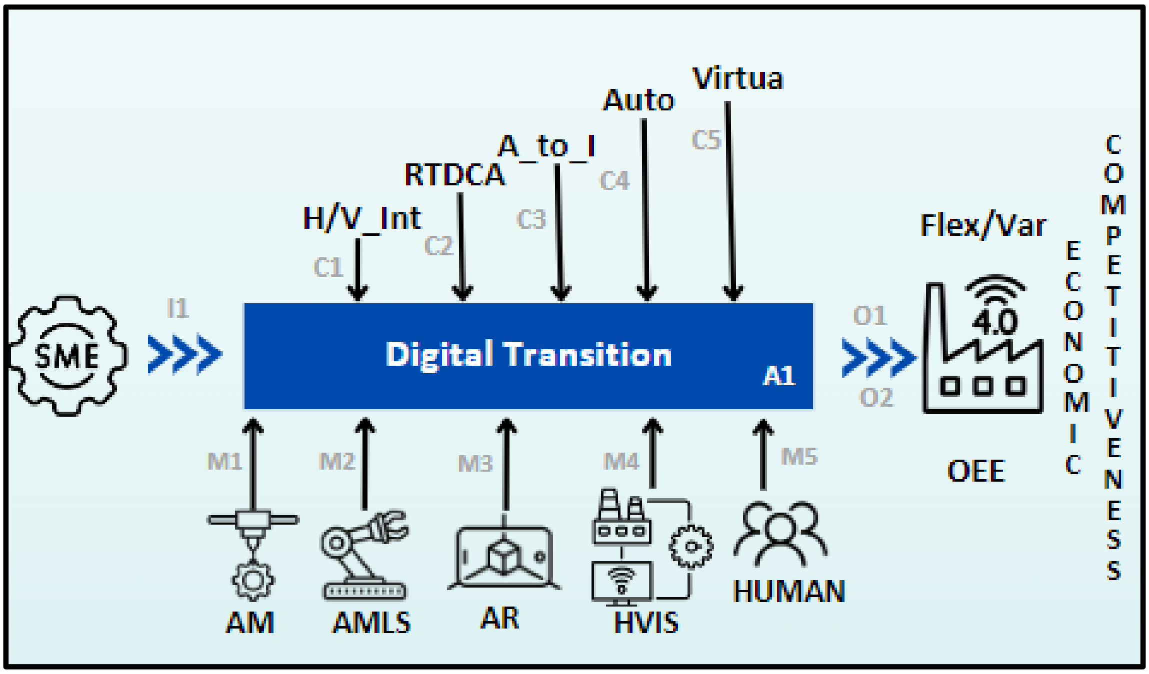


Figure 72: Digital Transition block of the TwinSME Model - Node A1

In this first Node, the input coincides with an SME that has passed through the Third Industrial Revolution and decides to start the Digital Transition, that is presented as a journey and enters the Fourth Industrial Revolution. Industry 4.0 indeed, is not 'something' that is possible to realize overnight, it is a process [2].

The *mechanisms* of this node are the four enabling technologies, Additive Manufacturing (AM), Advanced Manufacturing and Logistics Solutions (AMLS), Augmented Reality (AR) and Horizontal and Vertical Integration Software (HVIS), presented in Chapter 4, and the operators (HUMANS) that use them and who should adapt their skills to the adopted KETs. The *controls* are the five digital factors that resulted in the cause group according to the DEMATEL application. The KETs are indeed the resources an SME needs to succeed in the Digital Transformation journey, and the five digital paradigms are what is enabled by their adoption and they will guide the Digital Transition investments of the SME.

The output of this process is a 4.0 SME, that presents a more competitive profile, characterized by the enabled digital paradigms. The ideal 4.0 SME will be horizontally and vertically integrated (F1), by meaning that its business core will be sustained by an intelligent network of machines that collect real time data (F6). They will be freely exchanged from one working station to the other and from the suppliers plants to the production one, up to the outbound logistic warehouse. Thanks to data analysis, the decision making will be data-driven (F6) and the information will be easily accessible (F2) from any operator according to the different permissions, with as many devices as possible [12]. The 4.0 SME will present a partial transferring of autonomy (F3) to cyber-physical systems and machines. In addition, it will

report a good level of virtualization, through digital simulations of products and operation processes (F7), it will have the chance to investigate different options and scenarios before actually making investments (Machado et al., 2021).
Effects of investments in the previously nominated digital paradigms are an enhancement in the two effect digital factors, OEE (F5) and Flexibility (F4). It means that the output 4.0 SME will grant to the entrepreneur business continuity, an higher throughput and a greater quality (Ciliberto, et al., 2021). The increase of OEE, combined with a good level of production flexibility and variety of materials (F6) that could be worked thanks to new technologies, will increase the customization levels and the customers satisfaction (John, et al., 2021).
Node A1 could be decomposed (Figure 73) in four children nodes (A11, A12, A13, A14), one for each technological area (AM, AMLS, AR, HVIS) that has been analysed in Section 4.4, during the preliminary reasoning on the digital enabling power of the KETs in the Canva sessions. This decomposition is useful for the Backward Pass (explained in Subsection 3.1.1) of the Digital part of the model (Subsection 3.1.1.). By going through this IDEF0 representation an entrepreneur could have a rapid indication of which typology of KET is needed to enable a specific digital paradigm and increase the economic competitiveness of its SME.

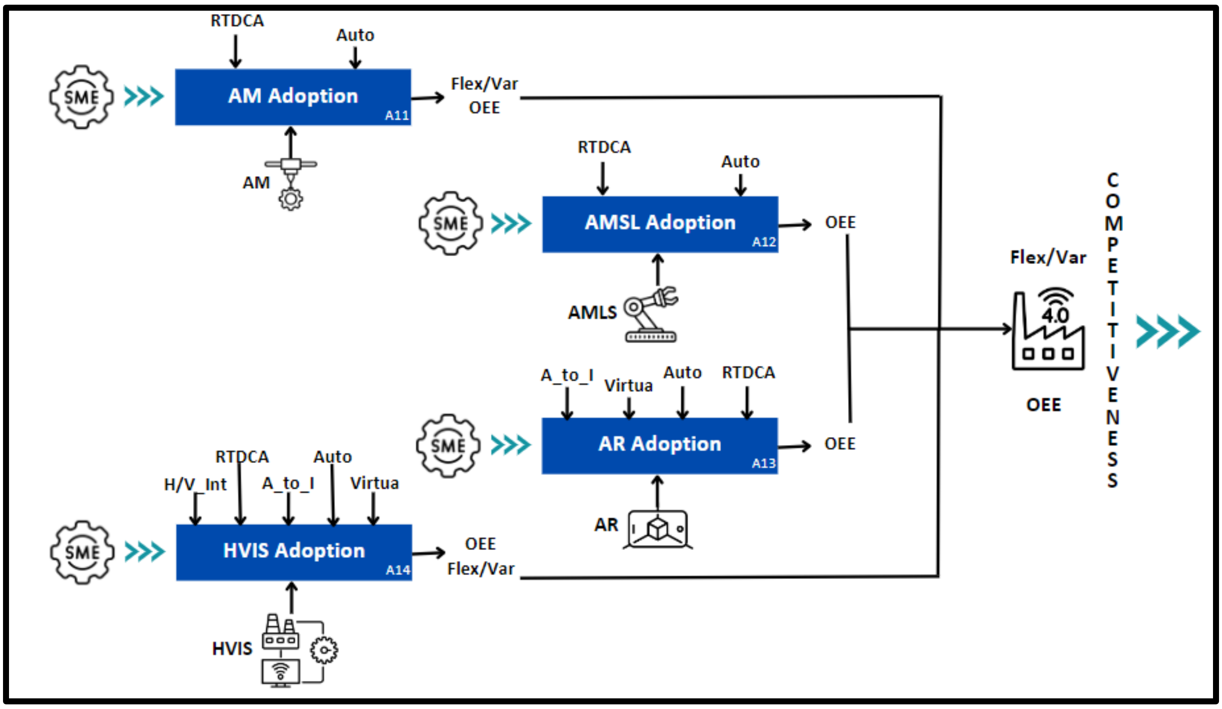


Figure 73: Explosion of the Digital block - Nodes A11, A12, A13, A14

Figure 85 shows graphically the connection between the Canva sessions results and the Digital part of the TwinSME model of Figure 84, shorter the arrow of the *controls*, higher the connection the specific digital paradigm has with the correspondent KET. Each children node indeed, shows as *mechanism* one specific key enabling technology, while the digital paradigms that have been considered enabled are presented as *controls* if they resulted to be causes after the Fuzzy DEMATEL application or as an *output* of the Adoption of that specific KET, if they resulted to be effects.

5.3. Fuzzy DEMATEL Application on SDGs, LM and CE factors

In order to try to figure out the role of LM and CE in this Twin scenario the DEMATEL process has been repeated other two times in the dedicated sheets of the Excel File, named "SDG, LM, CE" and "no LM-CE". The step 3 of both the cases are presented respectively in Figure 74 and 75. They show the factors considered in the two pages, in the first one only SDGs, LM and CE principles have been included in the analysis, in the second one instead, all the factors are present except for LM and CE. The first test has the aim to have a clue about the influences of LM and CE on SDGs targets without the presence of the digital factors in the system. The second analysis instead wants to detect the differences between the Relations among digital and sustainable factors with and without taking into consideration LM-CE couple.

Step 3: aggregation of all the DIM with CV

$$Z^* = [z_{ij}^*]_{12*12};\ z_{ij}^* = \frac{1}{p}\sum_{p=1}^{P} z_{ij}^p$$

Total group matrix			SDGs Factors			LM & CE Factors	
DIIM			SDG8	SDG9	SDG12	LM	CE
			F8	F9	F10	F11	F12
SDGs Factors	SDG8	F8	0,720	0,060	0,084	0,030	0,038
	SDG9	F9	0,002	0,628	0,100	0,200	0,089
	SDG12	F10	0,053	0,091	0,792	0,360	0,532
LM & CE Factors	LM	F11	0,443	0,450	0,588	0,819	0,531
	CE	F12	0,264	0,371	0,793	0,684	0,748

Figure 74: Group Direct influence Matrix of the sheet "SDG, LM, CE"

Step 3: aggregation of all the DIM with CV

$$Z^* = [z_{ij}^*]_{12*12};\ \ z_{ij}^* = \frac{1}{p}\sum_{p=1}^{p} z_{ij}^p$$

Group	DIM		Digital Factors							SDGs Factors		
			H/V Integration	Accessibility to_Information	Automation	Flexibility/ Variety	OEE	RTDCA	Virtualization	SDG8	SDG9	SDG12
			F1	F2	F3	F4	F5	F6	F7	F8	F9	F10
Digital Factors	H/V Integration	F1	0,833	0,898	0,922	0,751	0,658	0,759	0,813	0,681	0,584	0,744
	Accessibility to_Information	F2	0,331	0,944	0,765	0,597	0,563	0,565	0,698	0,412	0,500	0,482
	Automation	F3	0,600	0,710	1,000	0,214	0,626	0,549	0,251	0,407	0,553	0,378
	Flexibility/ Variety	F4	0,106	0,088	0,035	0,972	0,021	0,156	0,106	0,529	0,339	0,590
	OEE	F5	0,206	0,196	0,270	0,159	0,667	0,239	0,216	0,412	0,345	0,399
	RTDCA	F6	0,812	0,853	0,703	0,684	0,574	0,750	0,877	0,659	0,584	0,744
	Virtualization	F7	0,248	0,298	0,194	0,455	0,271	0,198	1,000	0,506	0,448	0,620
SDGs Factors	SDG8	F8	0,038	0,035	0,124	0,274	0,250	0,096	0,214	0,701	0,049	0,059
	SDG9	F9	0,239	0,216	0,368	0,106	0,188	0,177	0,106	0,003	0,621	0,117
	SDG12	F10	0,348	0,280	0,216	0,196	0,007	0,160	0,035	0,062	0,107	0,785

Figure 75: Group Direct influence Matrix of the sheet "no LM-CE"

In both the sheets, it is obtained at the end, the Influential Relation Map between the considered factors in the two cases. In Figure 76, it is visible the IRM between the factors from F8 and F12, while in Figure 77 the IRM between the factors between F1 and F10 included.

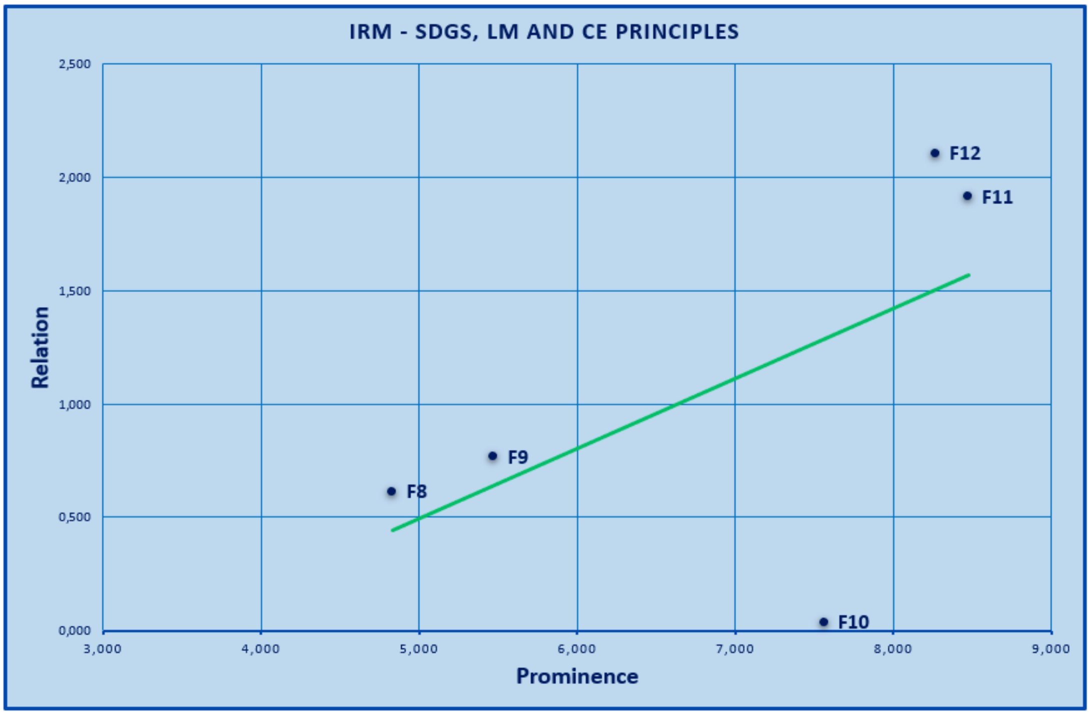


Figure 76: IRM of the sheet "SDG, LM, CE"

From the IRM of Figure 76, at first glance it is possible to notice how much higher is the Relation of LM and CE with respect to the ones of the three SDGs, that don't appear as effects because they have at least a low influence on F11 and F12.
From IRM in Figure 77 instead, it is possible to see that the Relation of F1 and F6 are lower than the ones in the original IRM of Figure 76, it means that in the case in which LM and CE are considered the cause role of these digital factors is stronger.

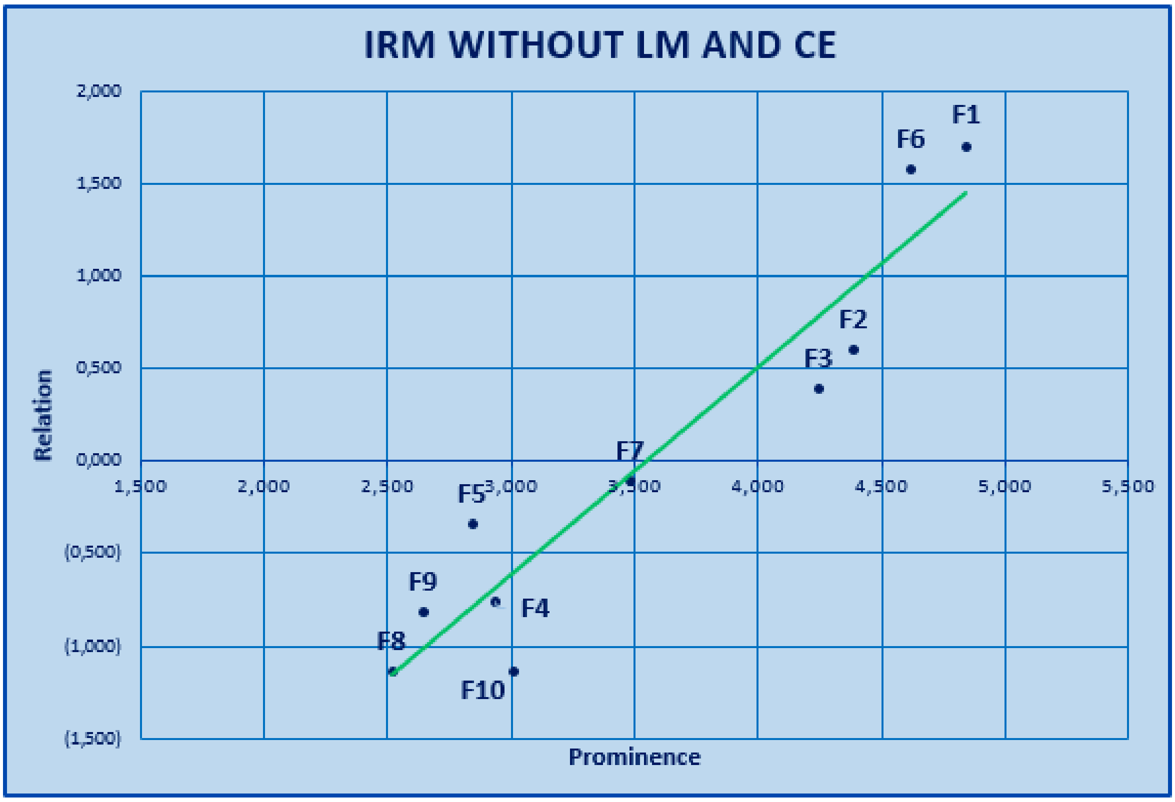


Figure 77: IRM of the sheet "no LM-CE"

As stated by Chen paper (et al., 2022), Ghaithan study (et al., 2021), Prakash team (et al, 2021) and Kayikci (et al., 2021) and Ciliberto analysis(et al., 2021), lean manufacturing and circular economy seem to be a significant bridging factor between digital and sustainable world and a prerequisite for digital solutions to reach a sustainable competitiveness, they promote it.
The findings of this Section indicate that Industry 4.0 technologies directly and positively affect the achievement of SDGs targets, but this relationship is strengthened with the presence of lean manufacturing and circular economies as mediating variables.
Digital investments create value and enhance economic competitiveness, but to be enablers of SDGs targets achievement, the generated economic value should support human centricity, enhance firm resiliency and contribute to sustainable footprint of the SME. The enabling power of KETs has to be guided and controlled by LM and CE approaches.

This statement is graphically represented in a dedicated IDEF0 representation, shown in Figure 78, which constitutes the node A2 of the TwinSME Model. In this case the digital paradigms are presented as *mechanisms* that enable the Twin Transition, the shorter the correspondent arrow, the higher the influence level on the specific SDG. As *controls* it is possible to see LM techniques, CE principles and Human creativity and needs. It is easily detectable the difference of the Human role in an Industry 5.0 SME with respect to a 4.0 one. The worker is not considered anymore as a resource (*mechanism*) that should be used for the activity accomplishment. In an Industry 4.0 context, operators should adapt their skills to the technologies present in the firm, while in a 5.0 scenario, human resources are seen as an investment. The SME should invest in the development of their skills to improve the competencies of the whole organization. An important prerequisite for Industry 5.0 is that technology serves people, rather than the other way around, then it means that the adopted technologies are adapted to the human needs (*controls*), instead of having workers that continuously adapt to ever-evolving technology [B4] (Sehrish, et al., 2022).
The output of the Twin Transition is a 5.0 SME that uses SDGs as guides for its business strategies. The elements that are considered as an output in this Node A2 are the ones that have resulted to be effects in the Twin IRM.

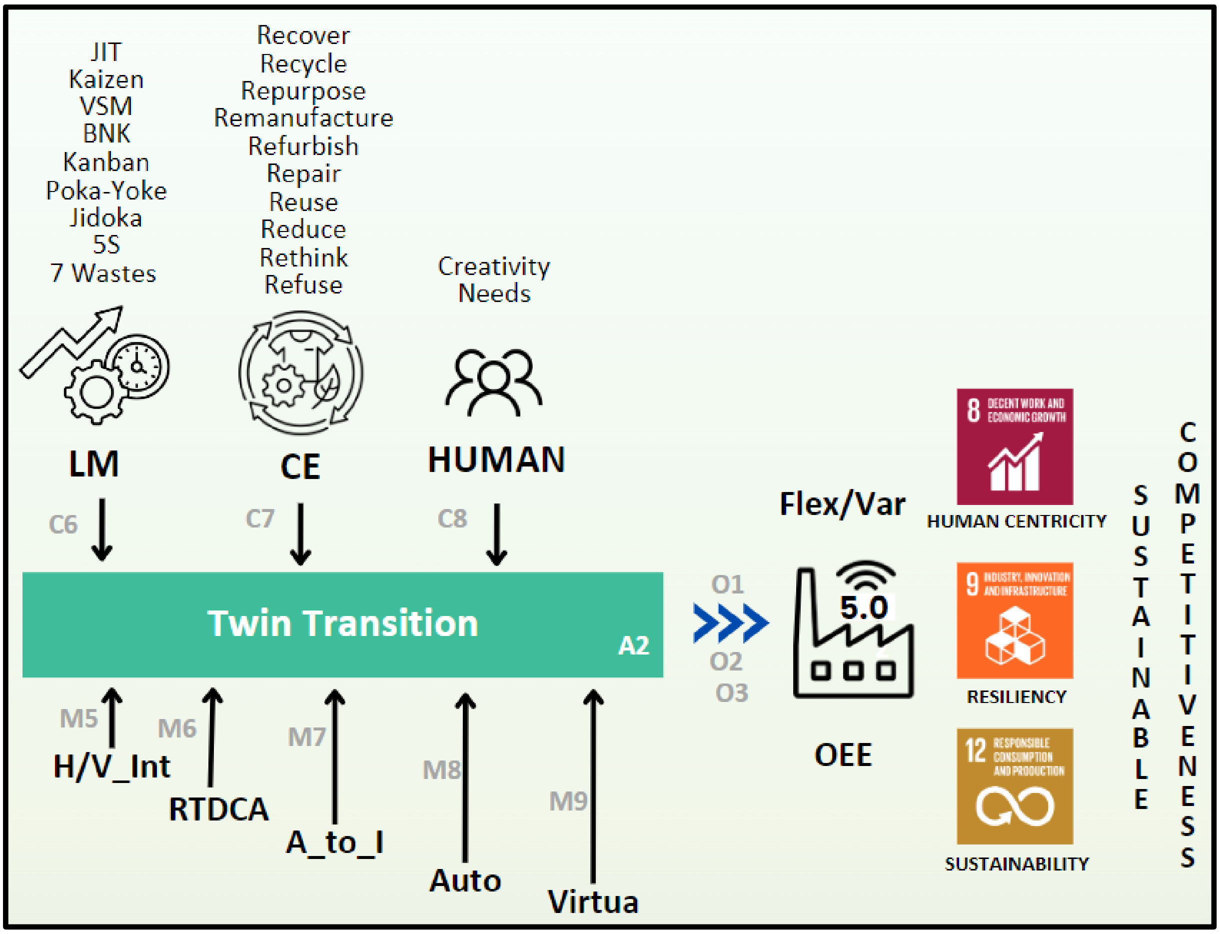


Figure 78: Twin Transition block of the TwinSME Model - Node A2

Also the node A2, as the A1, could be decomposed in children nodes, which are visible in Figure 79. This is useful for the Backward Pass of this Twin section of the model: through this IDEF0, an entrepreneur could have an idea of which LM and CE practices, sustained by digital investments, are needed to target one of the three selected SDGs.

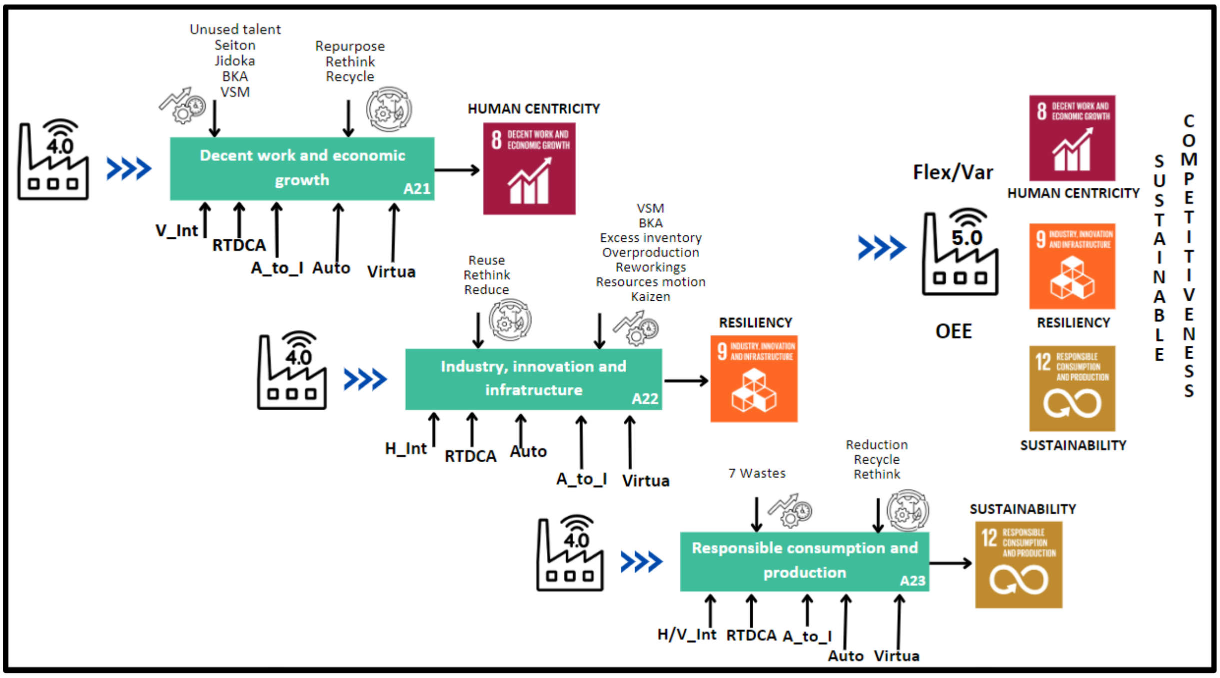


Figure 79: Breakdown of the Twin Transition block of the TwinSME Model - Node A2

In the following Subsections 5.3.1, 5.3.2 and 5.3.3, it is presented the Backward Pass of each children node, that is summarized in a dedicated table. Each table is discussed target by target, by stressing out which digital paradigms and KETs have an effect on the specific goal, and which LM and CE techniques can bridge them toward sustainable competitiveness. In other words, in these three Subsections for each target is presented the mix of digital investments, LM and CE principles that is needed to an entrepreneur to achieve it. It should be specified that the association of KETs to Digital Paradigms should be reconducted to Section 5.2.

5.3.1. Backward Pass - SDG8

An entrepreneur who chooses the SDG8 as strategic driver can perform the Backward Pass of the node A21 and get the following information:

Table 17: Mix of KETs, digital paradigms, LM and CE techniques to achieve SDG8 targets

SDG8 Targets - Human Centricity	LM / CE bridge	Digital Paradigms	Key Enabling Technologies
TARGET 8.2: higher **economic productivity** through diversification and innovation	VSM; BKA	RTDCA; ACC_TO_INFO	All KETs
TARGET 8.3: **decent job** and creativity	Repurpose; Rethink; Jidoka	FLEX; AUTO	AM; AMLS
TARGET 8.5: decent work for all **women, youngsters**, persons with **disabilities**	Unused Talent;	AUTO, VIRTUA	AMLS; AR
TARGET 8.8: labour **rights** and working **safety**	Seiton;	AUTO; V_INT; RTDCA	AMLS; HVIS

- Target 8.2 sustains the economic productivity through a focus on high-value added and labour intensive sectors, this is perfectly in line with the aim of reduction of any form of no value-added activities of Lean Manufacturing. Techniques like Value Stream Mapping (VSM) and Bottleneck Analysis (BKA) are the ones that the SME should consider to detect the activities that add more value and the operations that limit it [6]. The digital investments that can enhance the precision and velocity of these techniques are in the field of RTDCA (F6) and Access to Information (F2) (Ghaithan, et al., 2021), that resulted to be causes after Fuzzy DEMATEL application and that are represented as *mechanisms* in IDEF0.
- Target 8.3 promotes decent job creation, creativity and innovation and it can be enabled by two of the 9 CE Rs, that can drive a creative and alternative employment of old products and tools. In particular, *Repurpose* and *Rethink* can give an SME the chance to employ components of discarded products into different functions and suggest new ways to increase the efficiency of old tools [5]. The digital investments that have been considered mechanisms for this target are in Flexibility (F4) enhancement. They are what is needed to an entrepreneur to give to his/her SME the access to a multi shape production and to a higher variety of materials, in such a way to unblock side business and creative ideas [18]. Automation (F3) is important as well, but its enhancement should be controlled by *Jidoka* technique to be in line with Target 8.3, which means that production process could be automotized, but the presence of human operators should be of active type, like in Toyota production system, quality controls, decision-making, problem resolution should be on human creativity [6].

- Target 8.5 sustains productive employment of all people, including youngsters and persons with disabilities; the reduction of the 6th form of Lean Muda, *unused talent,* could drive its targeting. Each person has a talent that can positively influence the productivity of his/her firm [B2], investments in Automation (F3) of some processes and Virtualization (F7) of some tasks can enable any person to exploit his/her talent. The power of virtualization is also of learning type, training times of new employees, including the youngsters and the ones that come from other industries, could be shortened up by sustaining a higher productivity [19].
- Target 8.8 protects labour rights and promotes safety in the working environments. An entrepreneur that wants to target it, can make reference to the 2nd S of the Lean 5S Method, *Seiton*, that grants a safe and ordered working station. This S can be enabled by digital investments in Automation (F3), that can result in adoption of technologies that perform dangerous tasks and access unsafe places instead of humans [CV4] (Santhi, et al., 2023). Vertical Integration (F1) and RTDCA (F6) are important as well, because as discussed in Subsection 4.5.6, the number of incidents in productive plants decrease if there is a continuous monitoring of the operations, safer practices are adopted by workers. To grant a transversal control, the vertical integration of the hardware and software resources is fundamental [14].

5.3.2. Backward Pass - SDG9

An entrepreneur who decides to include the SDG9 in his/her industrial strategy as strategic driver should perform the Backward Pass of the node A22 by getting the following output:

Table 18: Mix of KETs, digital paradigms, LM and CE techniques to achieve SDG9 targets

SDG9 Targets - Resiliency	**LM / CE bridge**	**Digital Paradigms**	**Key Enabling Technologies**
TARGET 9.2: **sustainable** industrialization	Resources Motion; Reworkings	V_INT; AUTO	HVIS; AMLS
TARGET 9.3: integration of **SMEs** into **value chains**	VSM; BKA	ACC_TO_INFO; RTDCA; H_INT	HVIS; AMLS
TARGET 9.4: industries retrofitting, **resource-use efficiency**, environmentally sound technologies	Excess Inventory; Overproduction; Reuse; Rethink, Reduce	RTDCA; V_INT	All KETs
TARGET 9.5: scientific **research**	Kaizen	RTDCA; FLEX	HVIS

- Target 9.2 promotes sustainable industrialization that includes also the optimization of *resources motion*, with consequent reduction of employed energy for the fleet and reduction of *reworkings, t*hat leads to *e*nergy and water employment reduction (Joao, et al., 2023). An entrepreneur should notice the fact that the digital investments made for the achievement of this target shouldn't be collocated in an "end-of-life" economic system, but in a circular economic model, that could be a first step toward sustainable industrialization (Ciliberto, et al., 2021). Digital Paradigms that work as *mechanisms* are the the Vertical Integration, RTDCA and Automation, enabled by KETs that collect data about emissions, production, resource usage.
- Target 9.3 sustains the integration of SMEs into supply chains (SC). For an entrepreneur that targets it, Lean practices for flow analysis, like VSM and BKA are very important to remain in line with the high requested production rates and the desired quality level by the SC [6]. This target is the one that most of the others could be enabled by Horizontal Integration (F1), that resulted to be indeed the factor with the highest Relation in the system. In addition, techniques like JIT, VSM or Bottleneck analysis may become more precise thanks to the possibility to receive information from any step of the supply chain and to be able to access data (F2), by enabling LM principles of continuous improvement and waste reduction (Ciliberto, et al., 2021; Chen, et al., 2023). About this target, it should be stressed out the connection with an important element of Industry 5.0, the Resiliency. The supply chains in which the SMEs should be integrated must have an adaptable production capacity and enough flexibility to support disruptions.
- Target 9.4 promotes retrofitting of industries, an increase resource-use efficiency and a greater adoption of clean technologies. The pertinent LM practices are the decrease of *excess inventory* and *over-production* that constitute an inefficient processing of materials and energy sources employment (Reyes, et al., 2021). About the second life of the old machines, *Reusage* and *Rethinking* of production machines and tools can be valid approaches for Target 9.4 achievement. Another important R is *Reduce*, that indicates a reduction of the used material and of the CO2 emissions. This is in line with the concept of resource efficiency, which is about doing "better with less", which translates in optimising the relationship between product output and resource input [B4].

  As main enabler there is the RTDCA (F6), which is justified by the fact that the innovation and resiliency fostering of industries has to pass through data driven decisions (Estevao, et al., 2023). Collection and Analysis of data of logistic and productive flows is fundamental for the material movements and fleet allocating optimization. This is a way toward efficiently and environmentally sound industrial processes [15]. Another enabler is F7-Virtualization: investments in digitalization of products and simulation of processes can lead to better understanding of business systems, by making industries more sustainable and usage of resources more efficient [19].

- Target 9.5 encourages scientific research and innovation and it is in parallel with the aim of continuous improvement of the *Kaizen* practice [6]. At this regard the RTDCA (F5) results to be of crucial importance. First of all, the Fuzzy DEMATEL technique evidenced its cause role in the system and on the other hand, literature and ESIR paper by UN [B3] sustain that the collection and analysis of data is of crucial importance to monitor the actual industrial situation, create new strategies and measure progresses. Another digital enabler is the Flexibility (F4), the chance to get new geometries with a variety of materials, whose potential before I4.0 was undiscovered, like polycarbonates and photopolymers, may transform old manufacturing paradigms [18].

5.3.3. Backward Pass - SDG12

An entrepreneur who selects the SDG12 as driver for a sustainable competitiveness may look at node A23:

Table 19: Mix of KETs, digital paradigms, LM and CE techniques to achieve SDG12 targets

SDG12 Targets - Sustainability	LM / CE bridge	Digital Paradigms	Key Enabling Technologies
TARGET 12.2: **efficient use** of natural resources	Reduction;	V_INT; AUTO; ACC_TO_INFO	HVIS; AMLS
TARGET 12.4: **wastes** reduction throughout **life cycle**	Reworkings; Resources motion	V_INT; AUTO; ACC_TO_INFO	HVIS; AMLS
TARGET 12.5: waste reduction through prevention, **reduction, recycling and reuse**	Reduction; Recycling; Reuse; Lean Muda	RTDCA; V_INT; FLEX	HVIS; AM
TARGET 12.6: integration of **sustainable information** into the reporting life cycle	VSM; Kanban; BKA	RTDCA; V_INT	HVIS

- Target 12.2 sustains an efficient use of natural resources and it can be supported by the 7th R, *Reduction* of natural resources and materials employment and CO2 emissions. It is enabled by digital investments in Automation (F3), that can unblock reduction of waste, downtimes and efficient use of resources (Ortega, et al., 2021). RTDCA (F6) and Integration (F1) are fundamental, because without a continuous collection of data that should be analysed to extrapolate value cannot be tracked neither the use of resources, nor its efficiency (Yasanur, et al., 2022; Sehrish, et al., 2023). According to Fuzzy DEMATEL application and SLR, the data analysis is the most powerful tool for sustainable improvement (Ghaitan, et al., 2021; Mabkhot , et al., 2021): reduction of the consumption of resources (material, water, tools) and energy. Efficient use of resources is mainly attributed by real-time interaction and enhanced information visibility (F2) about machine status, productivity, material flows, inventory and waste (Chen, et al., 2023).

- Target 12.4 encourages the reduction of air, water and soil release throughout the product life-cycle, that as previously stated could be favoured by practices of reduction of *reworkings* and optimization of *resources motions.* Also in this case, the digital investments that an entrepreneur should go through to achieve this target are in terms of Integration (F1), Data access (F2) and Automation (F3).
- Target 12.5 promotes waste reduction through the 3R, *reduction*, *recycling* and *reuse*; an entrepreneur who wants to work to reach it can put in practice as much Lean practices of waste reduction he/she can afford, because by definition all of them are useful to reduce the waste [6]. It is clear the connection of this target with the CE framework, the previously listed 3R are indeed a subset of the 9R theory of CE. The mechanism that can enable them are the digital paradigms that enable a circular-economic model, hence, RTDCA (F6) and Horizontal and Vertical Integration (F1) (Sehrish, et al., 2022) .
- Target 12.6 sustains integration of sustainable information. An SME that has already gone through investments in Vertical and Horizontal Integration (F1) and RTDCA (F6) is able to collect data in real time through different sources and extrapolate value from them. In order to achieve this target, that promotes sustainable information, the digital enabling power of these investments should be filtered first of all by LM practices, like VSM, Kanban or BKA that let the SME detect the information derived from value added activities with waste minimization, to avoid the digitalization of wastes. The other *control* is the CE framework, the collection of information should point at a circular economic model, where old products are re-used, consumption of natural resources is reduced, as the amount of waste [14].

5.4. TwinSME Model

In this Section the results got through Section 5.2 and 5.3 are put together, the Digital and Twin Transition blocks are presented in a single IDEF0, shown in Figure 80.

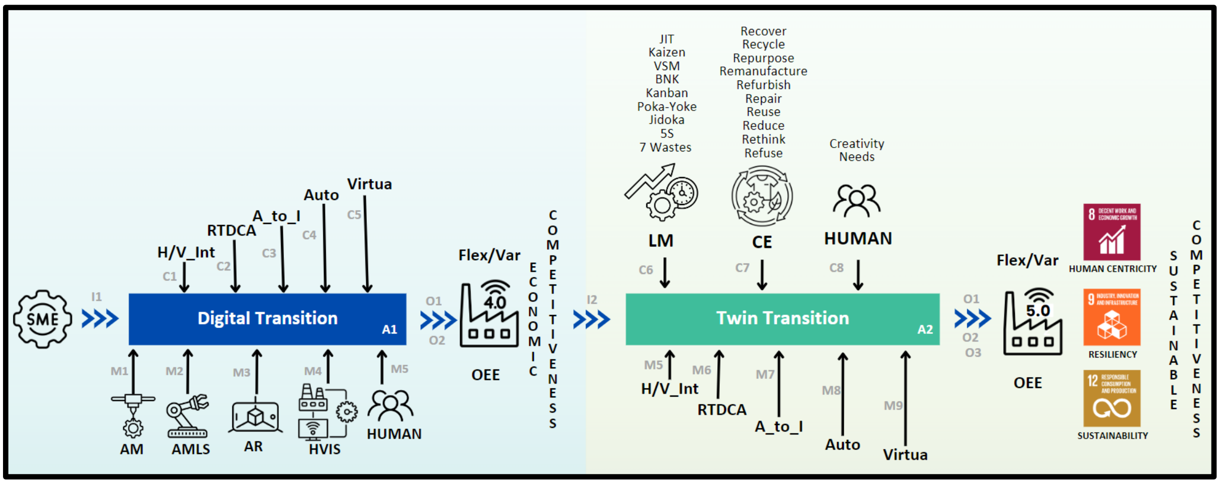


Figure 80: TwinSME Model – Nodes A1 and A2

This complete model enlightens the differences between the Digital and the Twin Transition and it represents in a clear way the journey of an SME to reach sustainable competitiveness, "the ability to generate and maintain wealth without diminishing the future capability of sustaining or increasing current wealth levels". All the elements of 5.0 discussed in this work thesis are present: the KETs and their digital enabling power, LM, CE practices and human creativity and the three SDGs linked to the three core elements of 5.0, Human Centricity, Resilience and Sustainability.

To wrap up, it is present on the left the Digital section dedicated to the digital paradigms that make an SME a 4.0 structure through a Digital Transformation journey, by encouraging digitally-enabled extractive and consumptive economic activities, which results on one side in higher performance, but on the other they could distance from sustainable achievements and SDG targets. This statement has been supported by the paper on I5.0 by ESIR, expert group on the Economic and Societal impact of Research and Innovation of the European Commission [B3].

On the right hand side instead, there is an Industry 5.0 system, where to capture the whole potential the nature of the transformation doesn't have to be only digital. The node A2 symbolises the results shown in the TwinSME IRM, digital factors are seen as *mechanisms* and they are governed by two sets of *controls*, lean and circular economy principles, requisites for the digitalization to be enabler of the sustainability.

LM and CE paradigms are considered a sort of a bridge. On one side there are the digital paradigms enabled by Industry 4.0 technologies that have a direct effect on lean manufacturing (Ghaithan, et al., 2021; Chen et al., 2023) and that are fundamental for the development of a circular economic model [B3]. On the other side, there are Sustainable Development Goals that the SME could target to reach sustainable development and competitiveness (Dabbous, et al., 2023).
The most coincided version of the TwinSME Model is shown in Figure 81, where it is visible the node A0 of the IDEF0 representation.

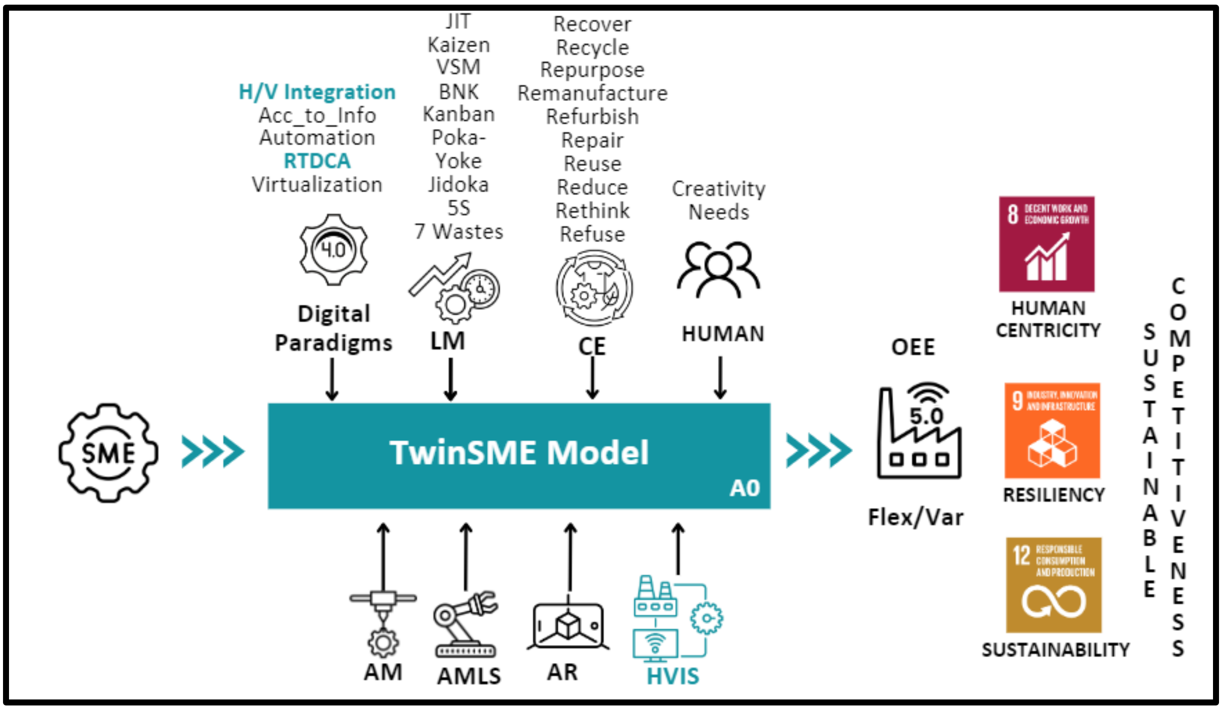


Figure 81: Twin SME Model - AO

It should be stressed out that in this TwinSME Model, Digital Integration (F1) and Data collection and analysis (F6), enabled mainly by Horizontal and Vertical Integration Systems, resulted to be the factors that mostly affect sustainable competitiveness. They are indeed the digital factors with the highest Relation level in the Fuzzy DEMATEL IRM (Figure 71) and according to the Backward Pass of the model (Figure 73) and the Canva sessions results, the KET that enables them the most is the HVIS area. Similar arguments were put forth also by Dabbous paper (et al., 2023) and United Nations blog about Global issues, where the collection and analysis of data is presented as enabler of a more agile, efficient and evidence-based decision-making and it is stated that it can measure progress on the Sustainable Development Goals (SDGs) in a way that is both inclusive and fair. UN indeed, sustains the key role of data analysis for economic development and enhancement of humanitarian action within a global community [B3]. The Secretary-General's Independent Expert Advisory Group of UN had made specific recommendations about the need of a Data Revolution for Sustainable Development, fostering and promoting innovation to fill data gaps to support the achievement of the 2030 Agenda [23].

Figure 93 represents in a schematic way the relationships between the elements of I5.0 that play a role in the Twin Transition of an SME. It conveys the final message: digital investments can function as an accelerator of SDGs targets achievement only if the digitalization doesn't work only to enhance economic competitiveness based only on value creation, as in I4.0 context, but also to reduce waste, promote efficient use of resources and Recover, Recycle, Repurpose, Remanufacture, Refurbish, Repair, Reuse, Reduce, Rethink and Refuse materials and products, by adapting to human needs.

CHAPTER 6

6. Conclusion

In this conclusive chapter, it will be presented the main findings, the academic and practical implications and the limitations of the work, together with the potential future research that can take place starting from this thesis results.

6.1. Main Findings

This thesis focused on investigating the cause-effect relationships between the factors of Industry 5.0 that contribute to the Twin Transition of an SME, with the aim to reach a sustainable competitiveness. The selected factors are twelve, first of all, there have been considered seven paradigms of 4.0 that resulted from SLR and DRA analysis (Horizontal and Vertical Integration, Access to Information, Automation, Flexibility, OEE, Real Time Data Collection and Analysis and Virtualization). Then there were included two criteria dedicated respectively to Lean Manufacturing and Circular Economy frameworks and three factors representing specific targets of three SDGs of the Economical dimension, according to the division of the Stockholm Resilience Centre. They are number 8, “Decent Work and Economic Growth”, connected to Human Centricity concept of 5.0, number 9 “Industry, Innovation and Infrastructure”, that supports Resiliency of industries and number 12, namely “Responsible Production and Consumption”, in favour of third I5.0 core element, Sustainability. These twelve dimensions filled the Fuzzy DEMATEL matrix that has been used during the Canva applicative sessions with fourteen technology providers of the Piedmont region. The author discussed with them about the digital enabling power of their technologies, asking the following question: “Which paradigms of industry 4.0 are enabled by your KET?”. The answer was quite straightforward for all the vendors, because each one of them knows very well the digital profile of his/her product. In the second part of the sessions, the participants have been introduced to Industry 5.0 elements and they were asked to evaluate the degree of influence between the factors present in the Fuzzy DEMATEL matrix, by making reference to their personal hands-on experience. After the application of the Fuzzy DEMATEL procedure to the fourteen matrixes, the obtained Influential Relationship Map (IRM) revealed important results: five over seven digital factors resulted to be causes in a Twin Transition scenario for the sustainable competitiveness achievement. In particular, Horizontal and Vertical

Integration and Real Time Data Collection and Analysis resulted to be the factors with the highest Relation in the system. The three SDGs factors instead, resulted to be effects, affected with an high level of influence by specific digital investments. LM and CE paradigms have been found to be a sort of a bridge. On one side there are the digital paradigms that resulted to have a direct effect on a lean and circular economic model. On the other side, there are Sustainable Development Goals that the SME could target to reach sustainable competitiveness.
The effects of each factor on the system, resulting from the Fuzzy DEMATEL application, are schematized in an IDEF0 representation, called TwinSME Model, that shows in a graphic way the relationships between the analysed factors.
From this study, it can be concluded that the enabling power of the 4.0 KETs could be Twin, Digital&Green, if its value creating power is conveyed through LM and CE techniques and enhanced by human creativity. This is a remarkable finding, since it shows how much digital investments with economic competitiveness aim can contribute to specific SDG targets achievement, with reference to the three core elements of 5.0, Human Centricity, Resiliency and Sustainability. It resulted to be possible by conveying the KETs' digital enabling power into a circular economic model, that reduces wastes and maximizes resource efficiency and letting the technology adapt to human needs to reach sustainable competitiveness.

6.2. Academic and managerial contributions

This thesis fills the four research gaps individuated after the SLR and brings new outcomes on the state of art, with a holistic approach that combines the current literature, empirical evidence, theoretical background and research at EU and UN level.
First of all, no evidence of the Twin Transition interest and readiness of SMEs have been found in the literature and it was registered a very low rate of involvement of industrial players in the academic research on this topic. This work is the first one in which technology providers have been involved in a study that includes all the following elements of the Industry 5.0 state of art: key enabling technologies of 4.0, LM techniques, CE approaches, human creativity and twelve targets of three specific SDG, number 8, 9 and 12, named "SME SDGs", with reference to the three core elements of 5.0. The input data of the Fuzzy DEMATEL methodology come from a mix of academic papers and hands-on experience of suppliers of the territory, that are personally in contact with the SMEs reality and see in a practical way the chances of employment of their own KETs in a circular economic model through the application of lean approaches.
Secondly, this thesis confirms some of the evidence of the literature about the active enabling role of Industry 4.0 technologies in the nowadays sustainable challenges. It should be stressed

out that very few quantitative models were found about the cause-effect relationships in a Industry 5.0 context.

Then, the thesis provides evidence of the permeation of LM and CE practices in the Sustainable Development Goals panorama, by analyzing their contributions and correlations target by target for each selected SDG.

By 2030, every individual, enterprise, country must contribute to the sustainability goals achievement to ensure a sustainable environment for future generations. This study empowers managers of small and medium structures to contribute to Agenda 2030 achievement. In this regard, this work provides SMEs entrepreneurs and technology providers with a strategic model, called TwinSME, that can assist them to understand which KETs, LM and CE techniques could be adopted for SDGs achievement through their businesses. For each target the model shows which is the combination of enabling technologies, LM techniques and CE approaches that contribute the most to reach it.

The TwinSME model offers an enlarged vision to entrepreneurs on the power of their digital investments that is not only in terms of economic drivers, because they are part of a greater scenario which is the Industry 5.0 one. This study demonstrates that entrepreneurs that think to make a digital investment should collocate it in a bigger picture, which is human-centric, circular and waste minimizer with sustainable development as the final aim.

The main contribution of this work is the demonstration that also Small and Medium Enterprises could use specific SDGs as drivers for their strategies aiming for sustainable competitiveness.

6.3. Thesis limitation and future research

This thesis features some limitations that may be overcome in next research.

The main limit is the number of technology providers who joined the Canva applicative sessions: 14 vendors with at least a Piedmont seat. It should be considered that this kind of collaborations never reach a high rate of adhesions, because of the time and the technical knowledge that are requested and the extreme novelty of the discussed topics. In any case, the limited number of participants has been managed with the choice of the Fuzzy version of the DEMATEL technique. On one side indeed, the population of the interviewed experts for this process is commonly between eight and sixteen. On the other hand, this version considers information that come from human and personal experiences, but making use of Fuzzy variables, it takes into consideration the blurriness of data, due to different perceptions. It was chosen to go through the sessions with Microsoft Teams meetings to avoid misunderstandings on the topics, by promoting personal discussions on them.

The second limitation is the consideration of only four typologies of key enabling technologies, that resulted to be the most adopted in the SMEs of the territory, but in any case they don't cover the whole spectrum of technologies of 4.0. It would be interesting to fill the Fuzzy DEMATEL matrix with the contribution also of technology providers of IoT sensors, Cloud Computing solutions and Simulation ones. It could be intriguing to analyse the role of Cybersecurity in the enhancement of Resiliency of the industries.

Based on these observations, future research can take into consideration aspects of Industry 5.0 that haven't been considered in this thesis for lack of reliable references on such a new framework. It could be interesting to extend the TwinSME model to other SDGs, by studying the relationships with the technologies of 4.0 and LM and CE principles.

In addition, this work made reference only to academic papers, United Nations and European Commission research publications up to March 2023. The TwinSME model could be enlarged with the results of the studies of the rest of the year. In the next years, when the adoption rate in the SMEs of the territory will be higher, among the enabling technologies may be intriguing to include Artificial Intelligence and Blockchain.

The investigation could be broadened by involving in the development of the model, not only technology providers, but also SMEs managers and operators to collect their perceptions of influence of technologies 4.0 on Sustainable Development Goals, by giving higher importance to human role in the Twin Transition process.

As stated Antonio Guterres indeed, the Secretary-General of the United Nations:

"Unless we act now, the 2030
Agenda will become an epitaph for
a world that might have been."

It may be added that also Small and Medium Enterprises could and must give their contribution to these global goals.

References

Abdullah Fawaz M., Abdulrahman M. Al-Ahmar, Saqib Anwar, "A Hybrid Fuzzy Multi-Criteria Decision-Making Model for Evaluating the Influence of Industry 4.0 Technologies on Manufacturing Strategies", Machines 2023, 11, 310. , https://doi.org/10.3390/machines11020310

Ahmad Najid , Liu Youjin, Sasa Zikovi, Zhanna Belyaeva , "The effects of technological innovation on sustainable development and environmental degradation: Evidence from China", Technology in Society 72 (2023) 102184, https://10.3390/su15086333

Akyuz, E., Celik, E., "A Fuzzy DEMATEL Method to Evaluate Critical Operational Hazards During Gas Freeing Process in Crude Oil Tankers", Journal of Loss Prevention in the Process Industries, 2015, 38 243-253, https://doi.org/10.1016/j.jlp.2015.10.006

Alcácer V., V. Cruz-Machado, "Scanning the Industry 4.0: A Literature Review on Technologies for Manufacturing Systems", Engineering Science and Technology, an International Journal Volume 22, Issue 3, June 2019, Pages 899-919 https://doi.org/10.1016/j.jestch.2019.01.006

Bianchini Stefano , Giacomo Damioli, Claudia Ghisetti , "The environmental effects of the "twin" green and digital transition in European regions", Environmental and Resource Economics (2023) 84:877–918 https://doi.org/10.1007/s10640-022-00741-7

Chatzistamoulou Nikos , "Is digital transformation the Deus ex Machina towards sustainability transition of the European SMEs?", Ecological Economics 206 (2023) 107739, https://doi.org/10.1016/j.ecolecon.2023.107739

Chauhan S, Singh R, Gehlot A, Akram SV, Twala B, Priyadarshi N , "Digitalization of Supply Chain Management with Industry 4.0 Enabling Technologies: A Sustainable Perspective" (2023), ProcessesOpen AccessVolume 11, Issue 1January 2023 Article number 96, https:// 10.3390/pr11010096

Chen X., Kurdve M., Johansson B., Despeisse M., 2022. Enabling the twin transitions: Digital technologies support environmental sustainability through lean principles https://www-scopus-com.ezproxy.biblio.polito.it.

Ciliberto, C., Szopik-Depczyńska, K., Tarczyńska-Luniewska, M., Ruggieri, A., Ioppolo, G., 2021. Enabling the circular economy transition: a sustainable lean manufacturing recipe for industry 4.0. Bus. Strateg. Environ. https://doi.org/10.1002/bse.2801.

Dabbous Amal , Karine Aoun Barakat, Sascha Kraus, "The impact of digitalization on entrepreneurial activity and sustainable competitiveness: A panel data analysis", Technology in Society 73 (2023) 102224, https://doi.org/10.1016/j.techsoc.2023.102224

De Miranda S, Cordoba RA, Aguayo Gonzalez F, Avila Gutierrez MJ, "Neuro-competence approach for sustainable engineering", Sustainability (Switzerland)Open AccessVolume 13, Issue 82 April 202, https://10.3390/su13084389

Dinis-Carvalho José , Rui M. Sousa , Inês Moniz, Helena Macedo and Rui M. Lima “Improving the Performance of a SME in the Cutlery Sector Using Lean Thinking and Digital Transformation”, 2023, Sustainability 2023, 15, 8302. https://doi.org/10.3390/su15108302

Estevao Joao, Jose Dias Lopes, Daniela Penela, SDG9 and the competitiveness: Employing mixed methods to understand how countries can use science to compete, Technological Forecasting & Social Change 187 (2023) 122178, https://doi.org/10.1016/j.techfore.2022.122178

Ghobakhloo, M. (2020). Industry 4.0, digitization, and opportunities for sustainability. Journal of Cleaner Production, 252, 119869. https://doi.org/10.1016/j.jclepro.2019.119869

Hassani H, Huang X, MacFeely S , “Enabling Digital Twins to Support the UN SDGs”, Big Data and Cognitive ComputingOpen AccessVolume 6 (2022), https://10.3390/bdcc6040115

John, L., Sampayo, M., Peças, P., 2021. Lean & green on industry 4.0 context – contribution to Understand L&G Drivers and design principles. Int. J. Math. Eng.Manag. Sci. https://doi.org/10.33889/IJMEMS.2021.6.5.073.

Kayikci Y, Kazancoglu Y, Gozacan-Chase N, Lafci C , “Analyzing the drivers of smart sustainable circular supply chain for sustainable development goals through stakeholder theory”, 2021, wileyonlinelibrary.com/journal/bse, https://10.1002/bse.3087

Kirchherr, J., Reike, D., & Hekkert, M. (2017). Conceptualizing the circular economy: An analysis of 114 definitions. Resources, Conservation and Recycling, 127, 221–232. https://doi.org/10.1016/j.resconrec.2017.09.005

Kürpick Christian ; Arno Kühn; Luca Olszewski; Roman Dumitrescu , “Framework for Dual Transformation: A Systematic Literature Review on the Interplays between Digitalization and Sustainability”, 2023 IEEE Conference on Technologies for Sustainability (SusTech) , https://10.1109/SusTech57309.2023.10129630

Kwartnik-Pruc A, Grzegorz Ginda and Anna Trembecka, “Using the DEMATEL Method to Identify Impediments to the Process of Determining Compensation for Expropriated Properties”, Land 2022, 11, 693. https://doi.org/10.3390/land11050693 --> DEMATEL

Findik Derya, Abdullah Tirgil, Fatih Cemil ¨Ozbu˘gday, ”Industry 4.0 as an enabler of circular economy practices: Evidence from European SMEs”, Journal of Cleaner Production 410 (2023) 137281, https://10.1016/j.jclepro.2023.137281

Ghaithan, A., Khan, M., Mohammed, A., Hadidi, L., “Impact of industry 4.0 and lean manufacturing on the sustainability performance of plastic and petrochemical organizations in Saudi Arabia”, Sustainability (Switzerland), 2021, https://doi.org/10.3390/su132011252.

Isensee, C., Teuteberg, F., Griese, K.-M., & Topi, C. (2020). The relationship between organizational culture, sustainability, and digitalization in SMEs: A systematic review. Journal of Cleaner Production, 275, 1–19. https://doi.org/10.1016/j.jclepro.2020.122944

Lagorio Alexandra, Giovanni Zenezini , Giulio Mangano & Roberto Pinto, A systematic literature review of innovative technologies adopted in logistics management, International Journal of Logistics Research and Applications (2020), https://doi.org/10.1080/13675567.2020.1850661

Lauria M, Azzalin M, "Digital Twin Approach for Maintenance Management", 2023, Urban Book SeriesOpen AccessVolume Part F813, Pages 237, https://10.1007/978-3-031-29515-7_22

Lekan Amusan, Clinton Aigbavboa, Ogunbayo Babatunde, Fagbenle Olabosipo & Adediran Christiana, "Disruptive technological innovations in construction field and fourth industrial revolution intervention in the achievement of the sustainable development goal 9", INTERNATIONAL JOURNAL OF CONSTRUCTION MANAGEMENT 2022, VOL. 22, NO. 14, 2647–2658 https://doi.org/10.1080/15623599.2020.1819522

Mabkhot MM, Ferreira P, Maffei A, Podrzaj P, Madziel M, Antonelli Dario, Lanzetta M, Barata J, Boffa E, Finzgar M, Pasko L, Minetola P, Chelli R, Nikghadam S, Wang V, Priarone P, Lupi F, Litwin O, Stadnicka D, Lohse N, "Mapping industry 4.0 enabling technologies into united nations sustainability development goals", 2021, Sustainability (Switzerland)Open AccessVolume 13, https://10.3390/su13052560

Machado, C.G., Winroth, M.P., & Ribeiro Da Silva, E.H.D. (2020). Sustainable manufacturing in Industry 4.0: an emerging research agenda. International Journal of Production Research, 58(5), 1462-1484. https://doi.org/10.1080/00207543.2019.1652777.

Matt Dominik T., Giulio Pedrini, Angelo Bonfanti, Guido Orzes (2023). Industrial digitalization. A systematic literature review and research agenda. European Management Journal, 41(1), pp. 47-78. https://doi.org/10.1016/j.emj.2022.01.001

Moktadir, M. A., Ahmadi, H. B., Sultana, R., Zohra, F.-T., Liou, J. J. H., & Rezaei, J. (2020). Circular economy practices in the leather industry: A practical step towards sustainable development. Journal of Cleaner Production, 251, 119737. https://doi.org/10.1016/j.jclepro.2019.119737

Morelli, J., 2011. Environmental sustainability: a definition for environmental professionals. J. Environ. Sustain. 1, 1–10. https://doi.org/10.14448/jes.01.0002.

Muench, S., Stoermer, E., Jensen, K., Asikainen, T., Salvi, M., Scapolo, F., 2022. Towards a Green and Digital Future. Publications Office of the European Union, Luxemburg https://doi.org/10.2760/977331.

Muhammad Nazir Muhammad, Nadire Cavus, Fuzzy DEMATEL method for identifying LMS evaluation criteria, ScienceDirect, Procedia Computer Science 120 (2017) 742–749, https://www.sciencedirect.com/science/article/pii/S1877050917325164

Ortega-Gras JJ, Bueno-Delgado MV, Canavat-Cuzado G, Garrido-Lova J , "Twin transition through the implementation of industry 4.0 technologies: Desk-research analysis and practical use cases in europe" (2021), Sustainability (Switzerland); https://10.3390/su132413601

Pan Chung-Lien, Han-Teng Liao and Yuan Zhang, "Knowledge mapping of resilience and human rights in supply chains: A roadmapping taxonomy for twin green and digital transition design", Frontiers in Environmental Science, 2023, https://10.3389/fenvs.2023.1152345

Prakash Gyan and Ambedkar Kumar, “Digitalization of manufacturing for implanting value, configuring circularity and achieving sustainability”, Journal of Advances in Management Research Vol. 20 No. 1, 2023 pp. 116-139, https://10.1108/JAMR-01-2022-0010

Rehman Shafique Ur, Daniele Giordino, Qingyu Zhang, Gazi Mahabubul Alam, “Twin transitions & industry 4.0: Unpacking the relationship between digital and green factors to determine green competitive advantage”, Technology in Society 73 (2023) 102227; https://10.1016/j.techsoc.2023.102227

Reyes, J., Mula, J., Díaz-Madroñero, M., 2021. Development of a conceptual model for lean supply chain planning in industry 4.0:multidimensional analysis for operations management. Prod. Plan. Control https://doi.org/10.1080/09537287.2021.1993373.

Rüßmann, M., M. Lorenz, P. Gerbert, M.Waldner, J. Justus, P. Engel, and M. Harnisch. 2015. *Industry 4.0*. The Boston Consulting Group. Sallez, Y., T. Berger, D. Deneux, and D. Trentesaux. 2010. “The Lifecycle of Active and Intelligent Products: The Augmentation Concept.” *International Journal of Computer Integrated Manufacturing* 23 (10): 905–924. https://10.1080/0951192X.2010.490275

Salis A, Marguglio A, De Luca G, Razzetti S, Quadrini W, Gusmeroli S – “An Edge-Cloud based Reference Architecture to support cognitive solutions in Process Industry”, 4th International Conference on Industry 4.0 and Smart Manufacturing; https://10.1016/j.procs.2022.12.198

Santhi Abirami Raja, Muthuswamy Padmakumar , 2023. Industry 5.0 or industry 4.0S? Introduction to industry 4.0 and a peek into the prospective industry 5.0 technologies. International Journal on Interactive Design and Manufacturing 17, pp 947-979. https://10.1007/s12008-023-01217-8

Saucedo-Martínez, Pérez-Lara, J.A., Marmolejo-Saucedo, Salais-Fierro, P. Vasant, Industry 4.0 framework for management and operations: A review., J. Ambient Intell. Humaniz. Comput. 2018, 9, 789–801, https://10.1007/s12652-017-0533-1

Sehrish Atif, “Analysing the alignment between circular economy and industry 4.0 nexus with industry 5.0 era: An integrative systematic literature review”, Sustainable Development. 2023;1–21., https://10.1002/sd.2542

Seker Sukran, Edmundas Kazimieras Zavadskas , “Application of Fuzzy DEMATEL Method for Analyzing Occupational Risks on Construction Sites”, Journals Sustainability Volume 9 Issue 11, 2017, https://10.3390/su9112083

Si Sheng-Li,Xiao-Yue You, Hu-Chen Liu and Ping Zhang, 2018, DEMATEL Technique: A Systematic Review of the State-of-the-Art Literature on Methodologies and Applications, *Mathematical Problems in Engineering, Volume 2018, Article ID 3696457*, https://doi.org/10.1155/2018/3696457

Shirin M. Rai, Benjamin D. Brown, Kanchana N. Ruwanpura, SDG 8: Decent work and economic growth – A gendered analysis, World Development 113 (2019) 368–380, 2018, http://creativecommons.org/licenses/by/4.0/

Tavares Maria C ; Graça Azevedo, “Contribution of Industry 4.0 Technologies to Social Responsibility and Sustainability”, 17th Iberian Conference on Information Systems and Technologies (CISTI), 2022, https://10.23919/CISTI54924.2022.9820334

Tranfield, D., D. Denyer, and P. Smart. 2003. “Towards a Methodology for Developing Evidence-Informed Management Knowledge by Means of Systematic Review.” British Journal of Management 14 (3): 207–222, https://doi.org/10.1111/1467-8551.00375

Tripathi, V., Chattopadhyaya, S., Mukhopadhyay, A.K., Sharma, S., Singh, J., Pimenov, D.Y., Giasin, K., 2021. An innovative agile model of smart lean–green approach for sustainability enhancement in industry 4.0. J. Open Innov. Technol. Mark. Complex. 7. https://doi.org/10.3390/joitmc7040215.

Viles Elisabeth, Florencia Kalemkerian, Jose Arturo Garza-Reyes, Jiju Antony, Javier Santos, “Theorizing the Principles of Sustainable Production in the context of Circular Economy and Industry 4.0”, 2022, Sustainable Production and Consumption 33 (2022) 1043–1058, http://creativecommons.org/licenses/by-nc-nd/4.0/

Wang Zehua, Fachao Liang, Sheng-Hau Lin, “Can socially sustainable development be achieved through homestead withdrawal? A hybrid multipleattributes decision analysis”, Humanities and Social Sciences Communications, Open Access, Volume 10, 2023, https://doi.org/10.1057/s41599-023-02035-9

Yao X, Ma N, Zhang J, Wang K, Yang E, Faccio M , “Enhancing wisdom manufacturing as industrial metaverse for industry and society 5.0”, 2022, Journal of Intelligent Manufacturing, https://10.1007/s10845-022-02027-7

Yu, Z., Khan, S.A.R. and Umar, M., “Circular economy practices and industry 4.0 technologies: a strategic move of automobile industry”, Business Strategy and the Environment”, Vol. 31 No. 3, pp. 796-809, 2022, https://doi.org/10.1002/bse.2918

Zileli Yaprak Akçay, “Development of a Risk Management Model by the Fuzzy DEMATEL Method in the Evaluation of Authorized Certification Bodies”, IntechOpen, Risk Management, Sustainability and Leadership, Feb 2023, http://dx.doi.org/10.5772/intechopen.110018

Cited websites List

[1] Trailhead, (2023), “Meet the Three Industrial Revolutions”, available at: https://trailhead.salesforce.com/it/content/learn/modules/learn-about-the-fourth-industrial-revolution/meet-the-three-industrial-revolutions

[2] “Towards a green & digital future”, Joint Research Centre, Strategic Foresight Report of European Commission 2022, Stefan Muench, Eckhard Stoermer, Kathrine Jensen, Tommi Asikainen, Maurizio Salvi, Fabiana Scapolo, available at: https://joint-research-centre.ec.europa.eu/jrc-news/twin-green-digital-transition-how-sustainable-digital-technologies-could-enable-carbon-neutral-eu-2022-06-29_en

[3] “Il SDG Action Manager”, Marco Piccolo, Confindustria Piemonte (2022), available at: https://www.google.com/search?q=il+SDG+action+manager+plan+confindustria

[4] What is ESG?, Dean Emerick, https://www.esgthereport.com/what-is-esg/

[5] “The EU Green Deal – a roadmap to sustainable economies”, Switch2Green, available at: https://www.switchtogreen.eu/the-eu-green-deal-promoting-a-green-notable-circular-economy/

[6] Enrico Giovannini, Circular Economy Forum 2020, Tondo article of 2021, https://www.tondo.tech/blog/2021/01/22/sustainable-development-goals-and-ce/

[7] “Exploring Lean – Top 25 Lean Tools & Techniques”, Lean Production, last access: 5/9/23, available at: https://www.leanproduction.com/top-25-lean-tools/

[8] Damiano Dotti, Headvisor, Business Process Reengineering, https://www.headvisor.it/5s

[9] Favarin Ambra, Cabigiosu Anna, “Lean e green: l’impresa ecocompatibile”, available at: https://iris.unive.it/bitstream/10278/34762/1/lean%20and%20green.pdf

[10] “The 9R Framework”, Research Gate, Source: Potting et al. (2017, p.5), available at: https://www.researchgate.net/figure/The-9R-Framework-Source-Adapted-from-Potting-et-al-2017-p5_fig1_320074659

[11] Danone - Our contribution to the UN's Sustainable Development Goals, available at: https://www.danone.com/impact/un-sustainable-developement-goals.html

[12] “INDUSTRIA 4.0” ITALY’S NATIONAL PLAN FOR INDUSTRY, Italian Trade Agency and Ministry of Economic Development, 2016, https://www.mimit.gov.it/images/stories/documenti/INDUSTRIA-40-NATIONAL%20PLAN_EN-def.pdf

[13] Radim Belohlavek, “What is a fuzzy concept lattice”, Rough sets, fuzzy sets, data mining and granular computing, 2011, pp 19-20 , http://belohlavek.inf.upol.cz/publications/BeVy_Wifcl.pdf

[14] “Industry 4.0 and the fourth industrial revolution explained”, i-scoop, available at: https://www.i-scoop.eu/industry-4-0/

[15] The 17 Goals, United Nations, https://sdgs.un.org/goals

[16] The SDGs wedding cake – Stockholm Resilience Centre, available at: https://bit.ly/2JLe29S

[17] Global Compact Network Italia, Business and SDG, last access on 4/9/23, available at: https://www.globalcompactnetwork.org/files/global_compact/sdgs/business-sdgs/scheda-di-approfondimento-sdg-08.pdf

[18] Overmach website, last access on 16/10/23, available at: https://www.overmach.it

[19] 5 reasons why you should choose Augmented Reality solutions, Kiber white paper, available at: https://kiber.tech/

[20] Digitalsoft website, last access on 22/10/23, available at: https://www.digitalsoft.com/

[21] rsAutomazione website, last access 24/10/2023, available at: https://www.rsautomazione.com/

[22] Tesisquare website, last access 25/10/2023, available at: https://tesisquare.com/it/

[23] PlaNet website, last access 01/11/2023, available at: https://www.planetweb.it/en/services.html

[24] "Big Data for Sustainable Development", United Nations website, last access 1/11/2023, available at: https://www.un.org/en/global-issues/big-data-for-sustainable-development

Bibliography

[B1] "An Invitation to Further Thought within The Framework of DEMATEL", A Gabus, E Fontela, S. Gabus, (1972)

[B2] "The Sustainable Development Goals Report 2023" by United Nations, available at: https://unstats.un.org/sdgs/report/2023/

[B3] "Industry 5.0: A Transformative Vision for Europe, Governing Systemic Transformations towards a Sustainable Industry" ESIR -Policy Brief 3 - Research and Innovation UE, 2022, https://10.2777/17322

[B4] "Industry 5.0: Towards a sustainable, human-centric and resilient European industry" Research and Innovation UE, 2021, Maija Breque Lars De Nul Athanasios Petridis, https://10.2777/308407

List of Acronyms

A_to_I	Access to Information
AM	Additive Manufacturing
AMLS	Advanced Manufacturing and Logistics Solutions
AR	Augmented Reality
Auto	Automation
BNK	Bottleneck Analysis
CE	Circular Economy
CV	Crisp Values
DIM	Direct Influence Matrix
DRA	Digital Readiness Assessment
ERP	Enterprise Resource Planning
Flex	Flexibility
H/V_Int	Horizontal and Vertical Integration
HVIS	Horizontal and Vertical integration Software
I4.0, I5.0	Industry 4.0, 5.0
IIM	Indirect Influence Matrix
IRM	Influential Relation Map
KETs	Key Enabling Technologies
LM	Lean Mabufacturing
MCDM	Multi Criteria Decision Making
OEE	Overall Equipment Effectiveness
RTDCA	Real Time Data Collection and Analysis
SMEs	Small and Medium Enterprises

SDGs	Sustainable Development Goals
SLR	Systematic Literature Review
Virtua	Virtualization
VSM	Value Stream Mapping

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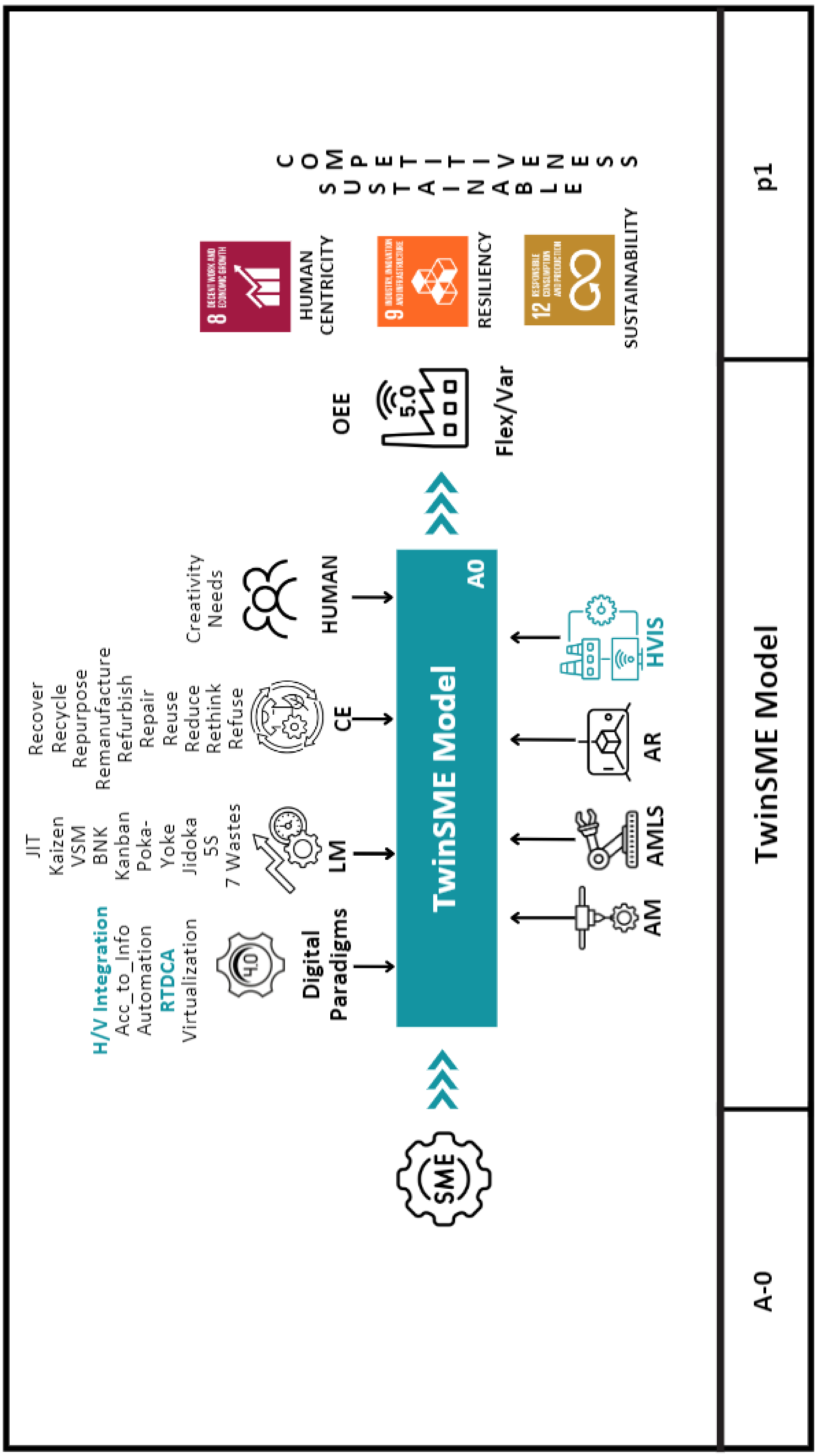
Growing up means also define your own personality, attitude and goals and obviously not all of them will be in line with the ones your family expected from you, but look at this result: we did good!

Appendix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Digital Paradigms
H/V Integration
Acc_to_Info
Automation
RTDCA
Virtualization
4.0
LM
JIT
Kaizen
VSM
BNK
Kanban
Poka-Yoke
Jidoka
5S
7 Wastes
CE
Recover
Recycle
Repurpose
Remanufacture
Refurbish
Repair
Reuse
Reduce
Rethink
Refuse
HUMAN
Creativity
Needs
TwinSME Model
A0
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AMLS
AR
HVIS
OEE
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Flex/Var
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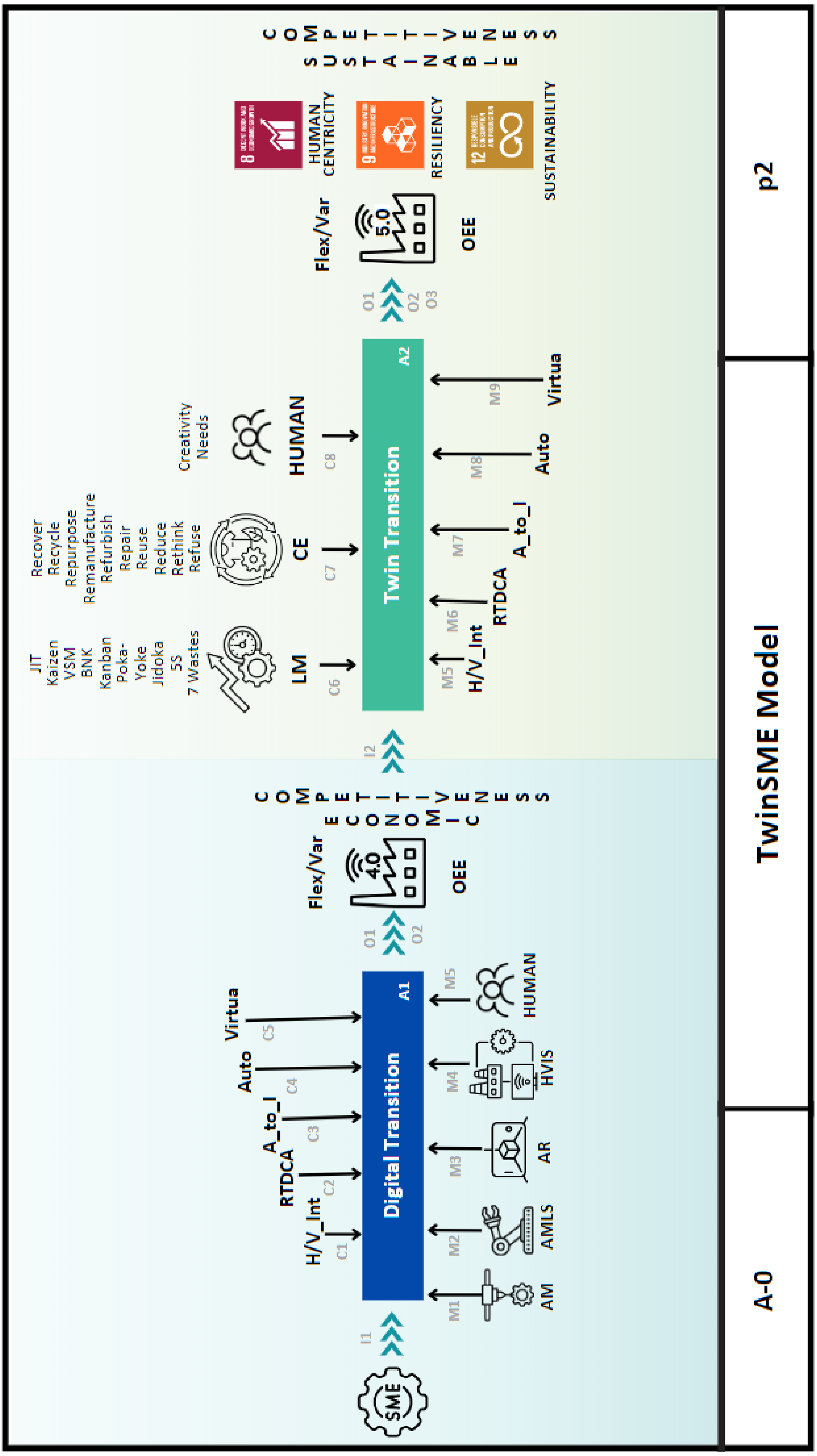
RESILIENCY
SUSTAINABILITY
SUSTAINABLE COMPETITIVENESS
A-0
TwinSME Model
p1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p2
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H/V_Int
RTDCA
A_to_I
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Virtua
C1
C2
C3
C4
C5
M1
M2
M3
M4
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COMPETITIVENESS
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Creativity
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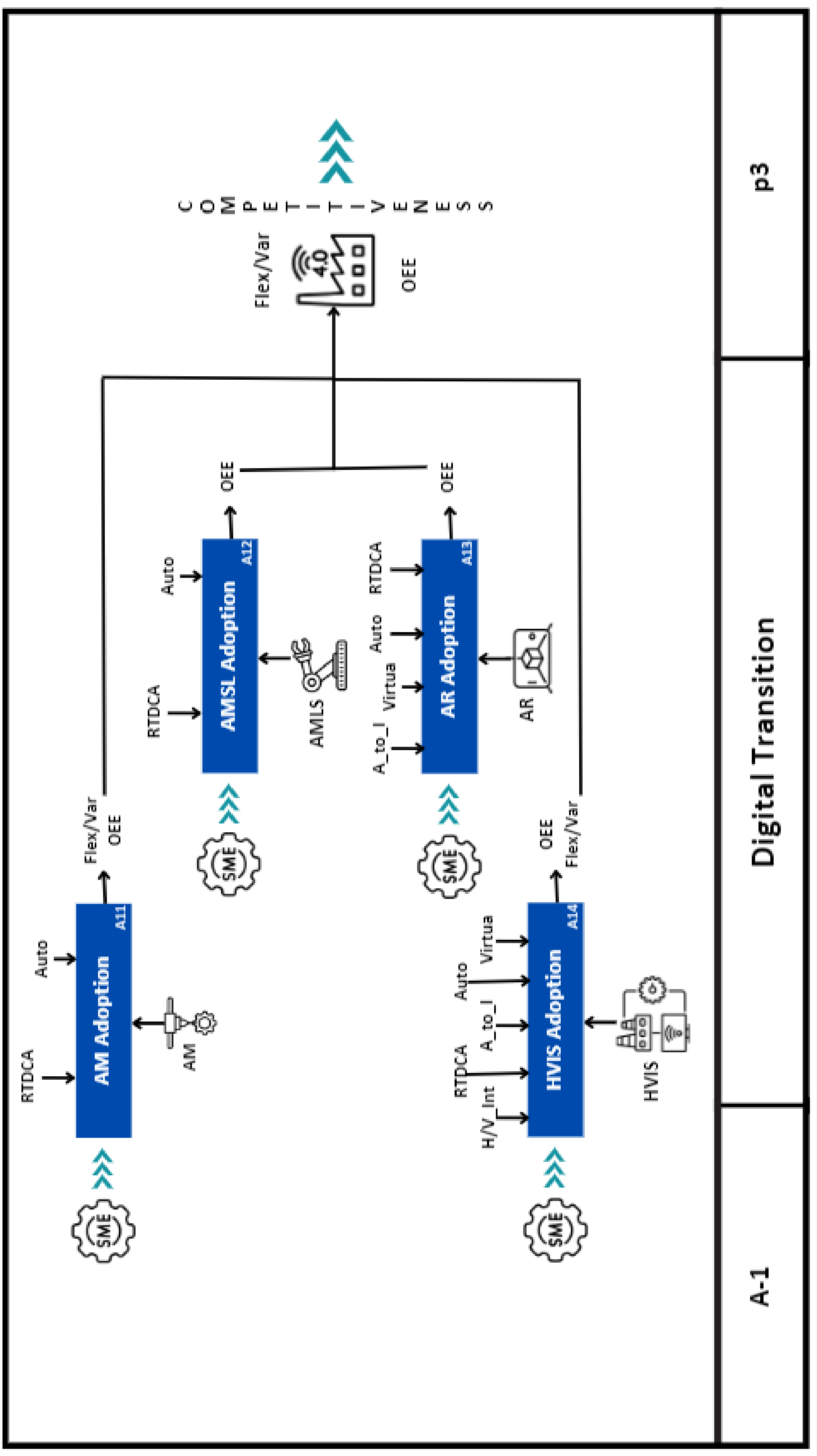
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A13
A_to_I
Virtua
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RTDCA
AR
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HVIS Adoption
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H/V_Int
RTDCA
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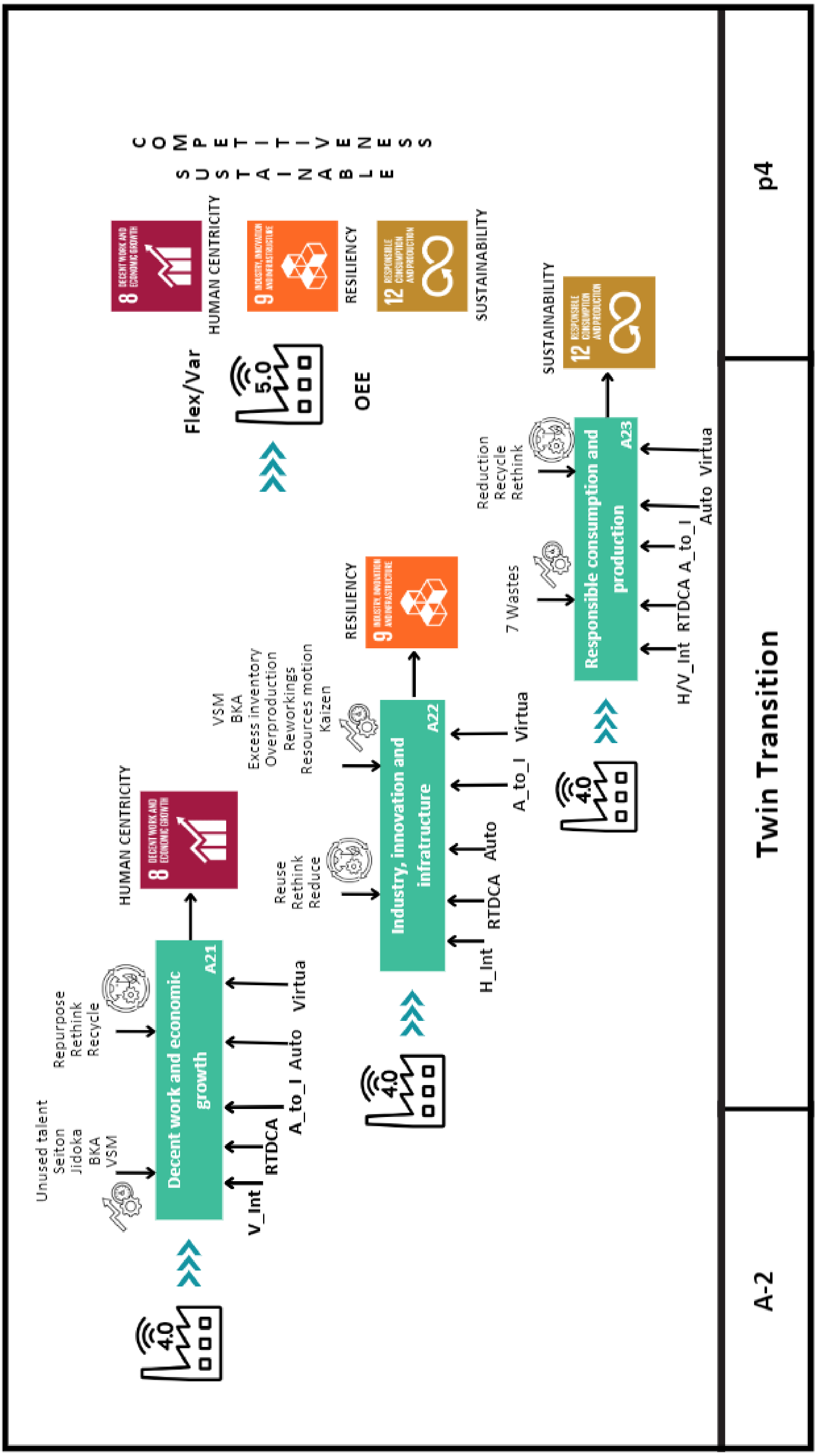
4.0
OEE
COMPETITIVENESS
A-1
Digital Transition
p3



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RTDCA
A_to_I
Auto
Virtua
HUMAN CENTRICITY
Industry, innovation and infratructure
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Rethink
Reduce
VSM
BKA
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Overproductions
Reworkings
Resources motion
Kaizen
H_Int
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Auto
A_to_I
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A23
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SUSTAINABILITY
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SUSTAINABILITY
COMPETITIVENESS
SUSTAINABLE