Digital transformation towards Industry 4.0 in Spain: An analysis of the progress of Smart Factory implementation

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Abstract*: This study investigates Industry 4.0 implementation in Spain, focusing on strategies integrating IoT, AI, Big Data, and robotics. Analyses illustrate the digital maturity of Spanish industries, highlighting regional variability and the need for tailored support policies to enhance national competitiveness.* ***Objective****: This study explores the complexity and practical implementation of Industry 4.0 in Spain, elucidating national strategies and programs. It provides quantitative and qualitative data on Spain's advancements in Industry 4.0 technologies, with a regional case study demonstrating the concept's application.* ***Method****: A systematic search using databases such as DIALNET, SCOPUS, and Web of Science (WoS) focused on recent studies with keywords like "Industry 4.0," "smart factory," and "digital transformation." Relevant articles were identified through inclusion and exclusion criteria. Quantitative analysis used sources including the National Institute of Statistics (INE) of Spain, the Organization for Economic Co-operation and Development (OECD), World Bank Open Data, and EUROSTAT. The Spanish public platform "HADA" analysed industries' digital maturity, assessing their incorporation of digital technologies in operations and strategy.* ***Results****: Spain's digital maturity map reveals regional disparities. Northern regions like País Vasco and Navarra exhibit "Dynamic" and "Leader" levels due to advanced Industry 4.0 integration and robust infrastructure. Castilla-La Mancha, Extremadura, and Andalucía show "Competent" levels, indicating significant digitalization efforts but room for optimization. Higher R&D investment correlates with higher digital maturity. Implementation issues include varying levels of data automation, integration with suppliers and customers, and sector-specific challenges. Regions with lower maturity need tailored support policies to address these challenges, increase R&D investment, improve infrastructure, and foster collaboration. Castilla-La Mancha has potential to advance with adequate support, demonstrating the importance of customized strategies for effective digital transformation.* ***Originality****: This study is original, providing an overview of the state of Spain in implementing the complex concept of Industry 4.0.*

Keywords*: Industry 4.0, smart factories, digital transformation, technological enablers*
JEL classification*: O33*

1. Introduction

Industry 4.0, often termed the fourth industrial revolution (Gubert, 2019), is defined by a complex array of interconnected and intelligent technologies that transform the manufacturing landscape. This revolution extends beyond simple automation, embedding deep system interconnectivity and real-time data exchange across platforms and entities. Central to Industry 4.0 are cyber-physical systems which integrate

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computation, networking, and physical processes (Universidad Politécnica Madrid, Miríadax, 2018; Kalsoom et al., 2020). Embedded with sensors and actuators, these systems interact with the physical world and users, enabling decentralized, real-time responsive actions. The Internet of Things (IoT) expands connectivity beyond conventional devices to industrial assets, facilitating seamless communication between machines, systems, and objects. This technology enables the collection and exchange of vast amounts of data, enhancing operational efficiency and predictive maintenance capabilities. Artificial Intelligence (AI) and machine learning algorithms leverage this big data to uncover patterns, predict outcomes, and make autonomous decisions, which are crucial for optimizing processes and driving innovations in product development and manufacturing techniques (Arroyave, 2019; Cotteleer & Sniderman, 2017; Solanki, 2023).

Big Data Analytics involves the processing and analysing of the large volumes of data generated by industrial operations (Gupta & George, 2016), which can improve decision-making processes, reduce operational costs, and enhance product quality (Adrian, 2011). Cloud computing and edge computing provide the necessary infrastructure for data processing and storage, with cloud computing offering scalable and flexible data storage solutions and edge computing processing data closer to the source of data generation to reduce latency and improve response times in real-time operations. Advanced robotics and automation, equipped with sensors and linked to networked systems (Higuera, 2005), perform complex manufacturing tasks with high precision and flexibility. These robots can learn and adapt to new processes quickly, increasing production rates and reliability. Additive manufacturing, or 3D printing, builds products layer by layer from digital files, allowing for complex designs and on-demand production, which supports customization and reduces waste.

Digital twins are virtual replicas of physical devices or systems used for simulation, analysis, and optimization (Parrott & Warshaw., 2017). They aid in the maintenance and troubleshooting of actual systems and predict performance under various scenarios (Feeney et al., 2015). Collectively, the strategic integration of these technologies within Industry 4.0 not only enhances operational efficiency but also drives substantial improvements in resource management, production speed, and product customization, significantly impacting the global industrial economy. The adoption of these advanced technologies allows industries to remain competitive in an increasingly digital world where agility, sustainability, and innovation are paramount.

This fourth industrial revolution promotes the creation of 'Smart Factories' which optimize production processes through increased efficiency, flexibility, and data-driven decision-making, facilitating a competitive edge in the global economy (Joyanes, 2017). Given the profound impact of Industry 4.0 on national competitiveness and economic sustainability, countries around the world are increasingly interested in adopting these technologies. The transition to smart manufacturing systems is seen as essential for maintaining industrial viability amid global shifts in supply chains and consumer demands for greater customization and rapid delivery (Pérez et al., 2015). To effectively understand and implement Industry 4.0, it is crucial to study how various countries and their specific regions integrate these technologies within their industrial sectors. Such analyses can reveal valuable insights into the diverse strategies and contextual adaptations necessary to harness the full potential of Industry 4.0. Each nation's approach provides unique lessons on leveraging technological advancements to enhance industrial productivity and economic growth.

Illustrating this, the case of Spain, particularly the examination of its regions and productive units, serves as an instructive example for other countries. This study explores Spain's strategic deployment of Industry 4.0 technologies across different sectors and regions, highlighting how specific regional strategies and industrial policies can effectively support the adoption and integration of advanced manufacturing technologies. By examining Spain's efforts to modernize its industrial capabilities and enhance economic resilience, this research not only sheds light on the complexities of technological integration at a national level but also underscores the importance of contextual and regional nuances in realizing the vision of Industry 4.0. Through such detailed case studies, other nations can gain insights into developing tailored Industry 4.0 strategies that align with their unique industrial landscapes and economic contexts, facilitating a smoother transition to advanced manufacturing and bolstering global competitiveness.

2. Literature review

Understanding how economists have historically treated technology is an optimal starting point for this thesis. This review explores how the technological variable has been understood and modelled for its impact on growth.

Industry 4.0 represents a technological evolution in industrial production (Zhong et al., 2017), focusing on the digitalization of processes and the integration of advanced technologies such as artificial intelligence (AI), robotics, augmented reality (AR), the Internet of Things (IoT), cybersecurity, and additive manufacturing (Alcácer & Cruz-Machado, 2019; Cisco Systems, Inc., 2019). Originating in Germany in 2011, Industry 4.0 was part of a governmental strategy to enhance the competitiveness of German manufacturing amid rapid global digital transformation (Bundesministerium für Bildung und Forschung, 2017). This strategy aimed to improve efficiency, optimize resource use, and enhance societal quality of life (DFKI, 2011). Although initially German, Industry 4.0 has been adopted worldwide and recognized as a key factor for economic growth and national competitiveness (ACATECH, 2013).

To understand Industry 4.0, it is necessary to trace its roots back to Industry 3.0, the era of automation characterized by the introduction of electronics and IT in industrial production. Spanning from the 1970s to the 2000s, Industry 3.0 laid the groundwork for Industry 4.0 by developing numerical control systems, industrial robotics, and enterprise resource planning (ERP) systems, which increased production automation. The transition from Industry 3.0 to Industry 4.0 results from rapid advancements in digital technologies and the growing need for efficiency and flexibility in industrial production. Industry 4.0 integrates digital technologies across all production aspects, enhancing interconnectivity and collaboration throughout the supply chain, thereby improving efficiency and responsiveness (Alcácer & Cruz-Machado, 2019).

Technology has consistently influenced human history, transforming lifestyles, work, and social interactions. Initially focused on survival tools, technology evolved significantly with the advent of writing, the printing press, and the Industrial Revolution. Each technological milestone - from steam engines to electricity and electronics - profoundly impacted economic production and societal structure. In the current era, technologies like AI, robotics, and nanotechnology continue to drive significant changes. These advancements, while beneficial, also pose challenges such as job displacement and data security concerns.

Prominent economic theorists have long incorporated the concept of technology into their models, generally perceiving a positive relationship between knowledge and growth. Notably, Robert M. Solow's 1956 growth model emphasized technology as a key factor in long-term economic growth, though it treated technological progress as an exogenous variable (Solow, 1956). Solow's model, which diverged from Harrod's earlier model, suggested that capital, labour, and technology collectively drive economic growth, with technology enhancing the efficiency and productivity of both capital and labour. Paul Romer's 1986 model, on the other hand, treated technological progress as an endogenous factor, driven by innovation and research and development (R&D). Romer argued that technology, as accumulated knowledge, could be directly influenced by investment in R&D and government policies promoting innovation (Romer, 1991).

The Industrial Revolution, with its successive phases, has fundamentally altered the production of goods. The first Industrial Revolution, marked using steam engines and mechanized production, began in 18th century Britain and spread globally (Cameron & Neal, 2010). This era introduced significant changes in production efficiency and societal organization, including urbanization and the formation of new social classes. The second Industrial Revolution, spanning the late 19th and early 20th centuries, brought electrification, mass production, and significant technological innovations like the internal combustion engine and telecommunications (Mokyr, 1990). This period also saw advancements in organizational management, such as Taylorism and the development of bureaucratic structures, which further enhanced productivity.

The third Industrial Revolution, also known as the Digital Revolution, began in the late 20th century with the advent of electronics, computers, and information technology (Rifkin, 2011). This era enabled unprecedented connectivity and access to information, transforming various industries and societal

interactions. Innovations such as the internet, personal computers, and mobile devices have revolutionized communication, work, and production processes.

Industry 4.0 relies on several key technological enablers. One of the primary technologies is the Internet of Things (IoT), which involves the networked connection of physical devices embedded with sensors and software, facilitating real-time data exchange and process automation. This connectivity enables enhanced operational efficiency and data-driven decision-making in industrial settings (Gokhale et al., 2018). Another crucial component is Artificial Intelligence (AI), which encompasses machine learning and other technologies that allow machines to perform tasks requiring human intelligence. AI applications in Industry 4.0 range from predictive maintenance and quality control to autonomous robots and intelligent logistics (Dopico et al., 2016; Guo, 2021). Big Data also plays a significant role, referring to the massive volume of structured and unstructured data generated by various sources. Industry 4.0 leverages Big Data analytics to gain insights, optimize operations, and drive innovation (Ghasemaghaei, 2021). Advanced robotics are essential as well, enabling automation, precision, and flexibility in manufacturing processes (Sirkin et al., 2015a; Sirkin et al., 2015b). Collaborative robots, or cobots, work alongside humans to enhance productivity and safety (Roland Berger Strategy Consultants, 2014). Finally, additive manufacturing, commonly known as 3D printing, allows for the creation of complex and customized products through layer-by-layer material deposition. This technology supports rapid prototyping, reduces waste, and enables on-demand production (Fundación COTEC, 2011).

Spain's digital transformation, particularly in the context of Industry 4.0, has involved various initiatives at both national and regional levels. The national initiative "Industria Conectada 4.0," launched in 2015, aims to enhance the digitalization of Spanish industry, supported by major corporations like Indra and Telefónica. At the regional level, autonomous communities like Castilla-La Mancha have also undertaken efforts to modernize their economies through digital transformation (Gobierno de Castilla-La Mancha, 2022). Despite these initiatives, challenges remain in achieving significant economic growth through digitalization, highlighting the need for continued investment in R&D and innovation (García-Moreno, 2023).

Castilla-La Mancha's specific efforts towards Industry 4.0 include several strategic initiatives aimed at boosting economic growth through technological advancements. For instance, the region has implemented programs to modernize its economy, focusing on creating new and improved opportunities, enhancing quality, innovation, and technological development to expand trade horizons (Gobierno de Castilla-La Mancha, 2022). These efforts are part of a broader strategy to align with the national "Industria Conectada 4.0" framework, which emphasizes the importance of industry and all its sectors for the growth of the Spanish economy (Gobierno de Castilla-La Mancha, 2022).

Despite these efforts, the region faces significant challenges in terms of innovation and development. For instance, Castilla-La Mancha's expenditure on R&D has historically been lower compared to other regions in Spain. Data from INEbase indicates that the region's spending on R&D has not seen substantial increases since the initiation of Industry 4.0, and it remains one of the regions with the lowest R&D expenditure in Spain (INEbase, 2020). This low investment in R&D is a critical barrier to the effective implementation of Industry 4.0 in the region.

The correlation between economic growth and R&D expenditure in Castilla-La Mancha is weak, suggesting that the current levels of investment in innovation and development are insufficient to drive significant economic growth. This situation underscores the need for a re-evaluation of the strategies and policies in place to support the digital transformation and the adoption of Industry 4.0 technologies (García-Moreno & López-Ruiz, 2023).

The historical and technological context of Industry 4.0 underscores its potential to transform industrial production and economic systems globally. Technological enablers like IoT, AI, Big Data, and robotics play a critical role in this transformation. While Spain and its regions, including Castilla-La Mancha, have made strides in digital transformation, the effectiveness of these efforts in driving economic growth remains an area for further exploration. Continued investment in technology and innovation, coupled with tailored regional strategies, will be essential for realizing the full potential of Industry 4.0.

3. Methodology and data

This study employs a comprehensive methodology to analyse the digital transformation and implementation of Industry 4.0, with a specific focus on the industrial sector of Castilla-La Mancha. A systematic approach was adopted, integrating both qualitative and quantitative methods to ensure a robust and detailed analysis.

A systematic search was conducted using electronic databases such as DIALNET, SCOPUS, and Web of Science (WoS). The search focused on studies published within the last decade to capture the most recent advancements and insights. Keywords such as "Industry 4.0," "smart factory," "digital transformation," were utilized to guide the selection process. Inclusion and exclusion criteria were meticulously applied to filter the search results, ensuring the identification of articles that specifically addressed the themes of digital transformation and Industry 4.0 within the context of Spain.

For the quantitative analysis, data were sourced from several reputable organizations, including the National Institute of Statistics (INE) of Spain, the Organization for Economic Co-operation and Development (OECD), World Bank Open Data, and EUROSTAT (the statistical office of the European Union). These sources provided a robust dataset to extract indicators relevant to the progress of digital transformation and the implementation of smart factories in Spain.

To assess the digital maturity levels of industries, the Spanish public platform “HADA” (“Herramienta Avanzada de Diagnóstico Digital”) was utilized. The HADA platform serves as a diagnostic tool that evaluates the incorporation and adaptation of digital technologies in operations and strategy. This tool measures digital maturity across various dimensions, including market and business strategy, processes, organization and people, infrastructure, and products and services. In this study, the analysis focuses on industries classified under the CNAE 25 category, which corresponds to the manufacturing of metal products, except machinery and equipment. The following subgroups from the CNAE 25 category are evaluated:

- 2511: Fabrication of metal structures and their components.
- 2512: Fabrication of metal carpentry.
- 2521: Fabrication of radiators and boilers for central heating.
- 2529: Fabrication of other tanks, large containers, and metal storage units.
- 2530: Fabrication of steam generators, excluding central heating boilers.
- 2540: Fabrication of arms and ammunition.
- 2550: Forging, stamping, and metalworking; powder metallurgy.
- 2561: Metal treatment and coating.
- 2562: Mechanical engineering for third parties.
- 2571: Fabrication of cutlery and flatware.
- 2572: Fabrication of locks and hinges.
- 2573: Fabrication of tools.
- 2591: Fabrication of steel and iron drums.
- 2592: Fabrication of light metal packaging.
- 2593: Fabrication of wire products, chains, and springs.
- 2594: Fabrication of screws and fasteners.
- 2599: Fabrication of other metallic products not elsewhere classified.

This classification allows for a detailed analysis of the digital maturity within each industry, based on their specific activities under “CNAE 25 group”.

In the HADA digital maturity model, maturity levels are described on a scale reflecting the depth of integration and effectiveness of digital technologies within business operations and strategies. The levels are as follows: Level 0 - Static: The company does not meet the requirements of Industry 4.0. Level 1 - Aware: Participation in Industry 4.0 through pilot initiatives. Level 2 - Competent: Industry 4.0 initiatives are incorporated into the company’s strategy. Level 3 - Dynamic: An Industry 4.0 transformation strategy is defined, with investments and 4.0 solutions integrated across multiple areas. Each level indicates a

progressive degree of digital technology integration and adaptation to Industry 4.0 dynamics, ranging from minimal or no commitment to digitalization to full integration into operations and strategic planning.

A critical synthesis of the literature was performed to outline the current state of the art in Industry 4.0 and digital transformation. Quantitative data were analysed to extract indicators providing insights into the progress of digital transformation in Spain, particularly focusing on smart factory implementation. This synthesis provided a theoretical framework, while the data analysis offered empirical evidence of progress and challenges in the implementation of Industry 4.0 technologies.

By combining diverse data sources and utilizing the HADA platform for digital maturity assessment, this methodological approach enables a thorough assessment of the digital maturity and transformation within the industrial sector of Castilla-La Mancha. This study provides valuable insights into the current state and future potential of Industry 4.0 in the region, ensuring a comprehensive understanding of the digital transformation landscape.

4. Research results and comments

The connection between the German and Spanish initiatives in Industry 4.0 is evident at multiple levels. In 2015, Wolfgang Wahlster, scientific advisor to German Chancellor Angela Merkel, visited the País Vasco with the primary goal of promoting Industry 4.0 in the region. This support translated into establishing a target to elevate the industrial sector to 25% of the GDP (Ruiz, 2015). During his visit, Wahlster emphasized the crucial role of the human factor, asserting that machinery and robotics should complement, not replace, human labor. He concluded that for technology and workers to cooperate effectively, workers must possess sufficient qualifications and training (Ruiz, 2015).

At the national level, Spain launched the "Industria Conectada 4.0" initiative in 2015 with the backing of Spanish multinationals and tech companies like Indra and Telefónica. That same year, the platform published the report "La transformación digital de la industria española," which highlighted the industry's importance to the overall Spanish economy. The report explains that the "Industria Conectada 4.0" initiative was created to address this significance (Del Val Román, 2016). The "Industria Conectada 4.0" report, prepared by the Spanish Ministry of Industry, Energy, and Tourism in 2015, outlines the economic and societal impact of this new industrial revolution and provides recommendations and measures for its implementation.

The report follows the precedent set by its German counterpart, detailing the characteristics and challenges of the Spanish industry and the growth opportunities presented by Industry 4.0. It draws on initiatives from countries like Germany, the United States, and France, as it underscores the need for comprehensive strategies that leverage the lessons learned from these leading nations.

The German initiative, notably the High-Tech Strategy (Bundesministerium für Bildung und Forschung, 2015) launched in 2006 (Kagermann et al., 2013) and the Plattform Industrie 4.0 established in 2013, aims to increase productivity by €90,000 to €150,000 million, enhance revenue by €30,000 million, and boost employment by 6% (Rüßmann et al., 2015; Bundesministerium für Wirtschaft und Energie, 2019). The United States' Advanced Manufacturing Plan initiated in 2010 focuses on evolving the manufacturing industry through digital transformation and the creation of a network of institutes (IMIs) (PCAST, 2011; Rüßmann et al., 2015).

France's "La Nouvelle France Industrielle," launched in 2013, includes specific plans and the development of priority technologies such as cloud computing and cybersecurity to enhance innovation and competitiveness (Rüßmann et al., 2015). The European Union's framework, "Europa 2020," aims to achieve 20% of the European GDP through manufacturing, reflecting a comprehensive approach to industrial policy in the globalization era (Rüßmann et al., 2015).

Romania has also made significant strides in implementing Industry 4.0. The Romanian government launched the "National Strategy on the Digital Agenda for Romania 2020," which aligns with the European Union's digital agenda. This strategy aims to increase Romania's digital economy and improve its global competitiveness. Key focus areas include developing digital skills, enhancing digital

infrastructure, and promoting research and innovation in digital technologies. Romania's "Industry 4.0 Strategy" emphasizes the adoption of advanced manufacturing technologies, fostering public-private partnerships, and integrating digital technologies across various industrial sectors. The strategy outlines measures to support SMEs in their digital transformation journey and highlights the importance of continuous investment in R&D and workforce training to achieve sustainable growth and competitiveness in the global market (Romanian Government, 2015).

These international efforts provide valuable insights and frameworks for Spain's approach to Industry 4.0. The "Industria Conectada 4.0" initiative and its subsequent report "La transformación digital de la industria española" outline a comprehensive strategy for integrating advanced technologies such as IoT, AI, Big Data, and robotics into Spanish industries. This initiative aims to enhance the digital maturity of Spanish industries, addressing regional disparities in technology adoption and emphasizing the need for tailored support policies. By learning from the successes and strategies of Germany, the United States, France, and Romania, Spain can foster a robust and competitive industrial sector, driving economic growth and innovation in the era of digital transformation.

The integration of Industry 4.0 in Spain, officially initiated in 2015 with the "Industria Conectada 4.0" initiative (Ministerio de Industria, Energía y Turismo, 2015), has highlighted significant regional disparities in R&D investment. These disparities are evident in the data from 2020 and 2022, reflecting both the progress and ongoing challenges in adopting advanced technologies across different autonomous communities.

In 2020, regions such as Madrid and Cataluña exhibited exceptionally high levels of R&D spending, each surpassing €1 billion. This substantial investment underscores the strong commitment of these regions to digital transformation and innovation. Their well-developed infrastructure, presence of large corporations, and established innovation ecosystems have facilitated sustained high investment levels, positioning them as leaders in the national Industry 4.0 landscape.

In stark contrast, regions like Extremadura and La Rioja showed significantly lower investment levels, under €200 million. This indicates a slower pace in adopting advanced technologies and highlights existing inequalities in digital infrastructure and innovation capacity. These regions face challenges in accessing resources and support necessary for substantial digital transformation, which can hinder their ability to compete on a national and international scale.

By 2022, the trend of regional disparity in R&D spending persists. While Madrid and Cataluña continue to lead with robust investments, other regions such as Andalucía and País Vasco have shown notable increases in R&D spending. Andalucía, for example, has moved from the lower mid-tier bracket to a higher level of investment, demonstrating a positive trend towards adopting Industry 4.0 technologies and improving its digital infrastructure and innovation capacity.

However, regions like Castilla-La Mancha and Extremadura have shown minimal changes in their R&D spending, remaining in the lower investment brackets (García-Moreno, 2022). This stagnation suggests that these regions still struggle with the same challenges identified in 2020, including limited access to resources, insufficient support policies, and weaker innovation ecosystems. The persistent low investment levels in these areas highlight the need for specific and targeted support policies to address their unique challenges.

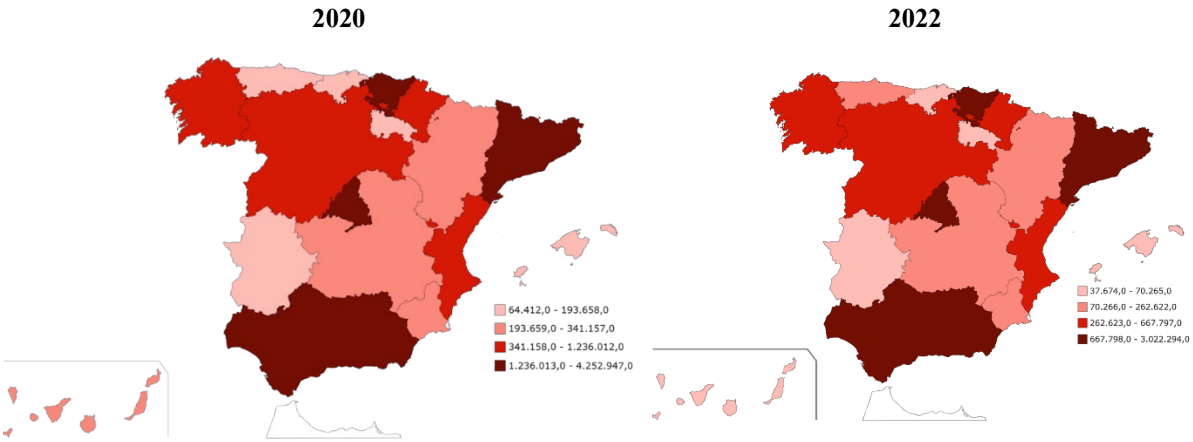
The consistently high investment in regions such as Madrid and Cataluña can be attributed to effective support policies, greater R&D funding, and strong public-private collaborations. These factors are critical for sustaining and enhancing digital maturity and ensuring that these regions remain at the forefront of technological advancement. On the other hand, regions with minimal growth in R&D investment underscore the necessity for specific strategies to foster local innovation.

Enhancing digital infrastructure, fostering local innovation ecosystems, and providing incentives for both public and private sector investment in R&D are essential measures needed to uplift these lagging areas (Parque Científico y Tecnológico de Castilla-La Mancha, 2022). The evolution from 2020 to 2022 emphasizes the importance of targeted regional policies to ensure a balanced national approach to Industry 4.0. While leading regions continue to advance, concerted efforts are necessary to uplift lagging regions,

ensuring that the benefits of digital transformation are equitably distributed across Spain. This balanced approach is crucial for maximizing the potential of Industry 4.0 to drive economic growth, competitiveness, and innovation on a national scale.

While Spain has made significant strides in implementing Industry 4.0 since 2015, the varied levels of R&D investment across regions reflect ongoing disparities that need to be addressed. The data from 2020 and 2022 provide a clear picture of where progress has been made and where further efforts are required, emphasizing the need for continued and focused investment in digital transformation initiatives to achieve nationwide economic advancement. Continued attention to these disparities will ensure a more balanced and equitable distribution of the benefits of Industry 4.0, driving comprehensive economic growth and competitiveness across all regions of Spain.

Figure 1. Comparative map of R&D activities (thousands of euros): 2020 vs. 2022



Source: INEbase (2020). Detailed results 2020: Business sector. Expenditure and personnel in internal R&D by autonomous communities where internal R&D activities were carried out and type of indicator. National Institute of Statistics. And INEbase. (2022). Detailed results 2022: Business sector. Expenditure and personnel in internal R&D by autonomous communities where internal R&D activities were carried out and type of indicator. National Institute of Statistics.

The national R&D investment disparities observed in the previous data are further reflected in the digital maturity levels presented by the HADA tool. This study utilizes a representative industry to provide an in-depth analysis, which will be elaborated on later. The HADA map illustrates varying levels of digital maturity across Spain, with regions like the Basque Country and Catalonia achieving "Dynamic" or "Leader" status, while regions such as Andalusia and Extremadura are classified as "Competent."

This correlation between R&D investment and digital maturity levels highlights the direct impact of sustained investment and supportive policies on technological advancement. Regions with higher investment in R&D, such as Madrid and Catalonia, show greater digital maturity, reinforcing the importance of targeted investment and policy support. This conclusion is crucial for devising strategies to enhance digital transformation uniformly across the nation, ensuring balanced economic growth and competitiveness.

To effectively work on the adoption of Industry 4.0 and understand its dimensions, possibilities, and development, it is essential to conduct studies tailored to each region, considering their specific characteristics. This approach ensures that the unique needs and potential of each area are addressed, facilitating a more efficient and targeted implementation of digital transformation strategies. For this purpose, the study uses the case of Castilla-La Mancha as a representative example. By focusing on this region, we can gain insights into the local challenges and opportunities, providing a detailed framework

that can be adapted and applied to other regions to enhance their Industry 4.0 adoption and overall digital maturity (García-Moreno & López-Ruiz, 2024).

Figure 2. Technology maturity map, 2023

Source: database HADA.

Initially, the situation of Castilla-La Mancha is presented, with the latest available figures from 2022. It is indicated that the average expenditure of companies in the region on innovation is €463.76 thousand. Additionally, the proportion of both companies and expenditure in Castilla-La Mancha compared to the national total is considered. This percentage is only 3.69% in terms of the number of companies with expenditure and 1.98% in terms of innovation expenditure compared to the national total (calculated from INE data > Survey on innovation in companies).

Table 1. Companies and innovation expenditure, 2022

Region	**Companies with Expenditure**	**Innovation Expenditure (€ thousand**
Spain (total)	24,065	20,836,041
Castilla-La Mancha	888	411,815

Source: INEbase > Research and Development > Science and Technology > Survey on Innovation in Companies

Average expenditure per company = (Total innovation expenditure)/(num. of companies) = €463.76 thousand. *(1)*

These figures suggest a low level of investment for Castilla-La Mancha, providing an initial insight into the current situation of the region. For this study, a representative profile of the region has been created. Within the industrial sector, the activity National Classification of Economic Activities code (CNAE), number 25: "Manufacture of fabricated metal products, except machinery and equipment" (hereinafter group 25 or group CNAE 25), has been selected for a detailed analysis. The reasons for choosing this group are based on the following points observed in the table (Annex 1):

- Volume of Revenues: This activity has the highest number of companies with operating revenues exceeding €50,000 and shows a strong presence in the lower ranges. This indicates a robust sector with a wide range of companies of different sizes, suggesting a good level of diversification and economic stability.
- Number of Companies: There is a significant number of companies within this category (1,793 companies), indicating a broad and potentially influential sector in the economy.
- Revenue Distribution: Companies in this activity are distributed across all ranges of operating revenues, from less than €1,000 to more than €100,000, showing the presence of both SMEs and large companies. This reflects a varied market structure and provides a comprehensive representation of the sector's financial health.

Supporting the above, the concentration of revenues is estimated to determine the income concentration index (ICI) (Annex 2). By focusing on this representative industry in Castilla-La Mancha, the study aims to provide a detailed and accurate analysis that can be extrapolated to other regions, ensuring that the specific characteristics and needs of each area are addressed effectively for the adoption and development of Industry 4.0.

$$ICI = \frac{\sum_{i=1}^{n}(EiV_i)}{T} = 1{,}683.77 \qquad (2)$$

Where:
ICI: is the Income Concentration Index for a specific category.
Ei: is the number of companies in the i-th income bracket.
Vi: is the estimated average value for the i-th income bracket.
T: is the total number of companies in the category.
n is the total number of income brackets.

Although the ICI is not the highest, this activity stands out due to its substantial revenue volume, indicating a significant contribution to the region's GDP. The manufacture of fabricated metal products is essential for a wide range of sectors and, therefore, is a crucial indicator of overall industrial health. With 1,793 registered companies, this activity represents one of the largest bases of the manufacturing industry in the region. A high number of companies suggests a robust internal market and a significant source of employment, which are critical factors for economic stability and social well-being in Castilla-La Mancha.

The established infrastructure and solid supply chain in Castilla-La Mancha for this activity enable continuous growth and investment opportunities, justifying its selection as representative despite a non-maximal ICI. This sector is key for construction, automotive, and other industrial sectors, making its strength vital for the regional economy. Its economic health directly impacts the broader value chain of the region. Therefore, the decision to focus on the "Manufacture of fabricated metal products, except machinery and equipment" is based on a comprehensive view that considers economic impact, employment, strategic relevance, and growth potential, which justifies its selection as a representative activity in Castilla-La Mancha beyond the absolute values of the ICI.

Additionally, for the profile, companies with fewer than 10 employees (micro-SMEs) have been selected, given that the average number of employees in group 25 in Castilla-La Mancha is 10 (based on data from 2013 to 2022). This focus on micro-SMEs aligns with the typical company size in the region, providing a more accurate representation of the local industrial landscape.

Table 2. Employees. CNAE 25 group. Castilla-La Mancha (2012-2022)

Year	Average	Median	Std_Dev	Num_Emp
2012	8	4	17	865
2013	8	3	17	830
2014	8	3	17	825
2015	9	4	18	824
2016	9	4	19	829
2017	10	4	21	839
2018	11	4	25	834
2019	11	4	27	842
2020	11	4	28	846
2021	11	4	28	818
2022	12	5	29	731
Total averages	10	4	22	826

Note: Data corresponds to industries classified under Group 25 of the CNAE, as described in the methodology.
Source: Own elaboration based on SABI data.

The interpretation of the values from the table reveals a business structure dominated by small entities. The consistent median of 4, even with an average employee count of 10, indicates that at least half of the companies in the sector maintain a reduced staff size. This is further reinforced by an average standard deviation of 22, suggesting considerable variability in the size of the remaining companies, which does not significantly affect the prevalent condition of micro-enterprises. The average total number of companies remains at 826, which, along with other indicators, supports the presence of a solid base of small enterprises forming the core of the sector. Consequently, selecting companies with fewer than 10 employees as representative for analysis is an appropriate and justified choice, encapsulating the predominant reality of the business fabric.

Finally, to complete the study profile, the category of micro-SMEs (with less than €2 million in annual turnover) was applied, not only in terms of the number of employees but also regarding sales volume (turnover). The associated data are provided in Annex 3. An analysis of sales figures for companies in group 25 in Castilla-La Mancha (from 2012 to 2022) shows an increasing trend in average sales over time, which could suggest general growth in company size or greater entry of larger companies into the market. However, the median sales figures are significantly lower than the average, especially in recent years. This indicates an asymmetrical distribution of data where many companies have lower sales figures and a few have much higher sales figures, raising the average.

The standard deviation is broad and has also been increasing, suggesting that the dispersion in company sizes (based on sales) is growing. This indicates considerable variability in turnover among companies within the sector. The relatively constant number of companies, with some year-to-year fluctuations, further impacts this variability. To solidify the decision for the profile, an estimation of the Confidence Interval for the Mean, with a 95% confidence interval, was also conducted. This comprehensive approach ensures that the analysis accurately reflects the realities of the industrial sector in Castilla-La Mancha, providing a robust foundation for understanding the region's adoption of Industry 4.0.

$$CI = \bar{x} \pm z * \left(\frac{s}{\sqrt{n}}\right) \quad (3)$$

Where:
$\bar{x}$: represents the average sales figure.
z: corresponds to the z-value for a 95% confidence level, which is approximately 1.96.
s: is the standard deviation of the sample sales figures.
n: is the number of companies in the sample.
Application:
CI2012 = 0.820 ± 1.96 * (2.852/30.38) = 0.820 ± 183.994; [0.636, 1.004]
CI2013 = 0.800 ± 1.96 * (2.818/30.03) = 0.800 ± 183.905; [0.616, 0.984]
CI2014 = 1.064 ± 1.96 * (3.560/29.75) = 1.064 ± 234.549; [0.829, 1.299]
CI2015 = 0.895 ± 1.96 * (2.991/29.90) = 0.895 ± 196.067; [0.699, 1.091]
CI2016 = 1.055 ± 1.96 * (3.458/29.73) = 1.055 ± 227.958; [0.827, 1.283]
CI2017 = 1.165 ± 1.96 * (3.899/30.12) = 1.165 ± 253.750; [0.911, 1.419]
CI2018 = 1.332 ± 1.96 * (4.431/30.13) = 1.332 ± 288.214; [1.044, 1.620]
CI2019 = 1.420 ± 1.96 * (5.182/30.18) = 1.420 ± 336.507; [1.083, 1.757]
CI2020 = 1.292 ± 1.96 * (4.522/30.10) = 1.292 ± 294.457; [0.998, 1.586]
CI2021 = 1.569 ± 1.96 * (5.548/29.60) = 1.569 ± 367.401; [1.202, 1.936]
CI2022 = 1.849 ± 1.96 * (6.943/28.07) = 1.849 ± 484.775; [1.364, 2.334]

Each of these intervals indicates the estimated range within which we can expect the true mean sales figure for that particular year to fall. As observed, in all years, the upper limit of the confidence interval remains below €2,334 thousand, reinforcing the decision to focus the analysis on companies with turnover less than €2 million. This suggests that the average sales figure in the population of companies is below this threshold, making it representative of the profile of companies in the region for the studied period.

With this in mind, we proceed with the HADA platform (Herramienta de Autodiagnóstico Digital Avanzada), an initiative by the Spanish Ministry of Industry, Trade, and Tourism within the framework of Industria Conectada 4.0. Its objective is to provide industrial companies with a self-diagnosis of their digitalization and technological maturity. The tool evaluates various dimensions of the company, such as Market and Business Strategy, Processes, Organization and People, Infrastructure, and Products and Services, to determine their level of maturity in digital transformation.

Through HADA, companies can identify areas for improvement and receive personalized recommendations to advance their digitization process. The level of digital maturity is categorized into different grades: Static, Aware, Competent, Dynamic, and Leader, with "Static" being the lowest level and "Leader" the highest.

Initial reports from the platform indicate that, for Castilla-La Mancha, companies in group 25 are at the "Competent" level. This indicates that companies in the community are making significant investments and efforts in digitalization and have integrated these technologies into various areas of their activities. While they are not yet at the highest levels of digital maturity, they are already reaping tangible benefits from digitization initiatives and are on the path to greater integration and optimization. Specifically, this "Competent" level indicates that in Castilla-La Mancha, companies in the manufacturing sector related to the manufacture of fabricated metal products, except machinery and equipment, are:

- Implementing digital initiatives in their business strategy.
- Making Industry 4.0 investments in various areas.
- Collecting some data automatically, although exploitation is limited.
- Beginning to integrate information with suppliers and customers.

The platform data is presented in Table 3, which includes the calculation of the overall maturity percentages based on the data from the indicated CNAE subcategories.

Table 3. Data of the subcategories of CNAE 25 group, for the 5 evaluation dimensions

CNAE_25	Market and business strategy	Processes	Organization and people	Infrastructure	Products and services
2511	26%	40%	41%	43%	30%
2512	26%	37%	43%	31%	31%
2521	0%	0%	0%	0%	0%
2529	0%	0%	0%	0%	0%
2530	0%	0%	0%	0%	0%
2540	0%	0%	0%	0%	0%
2550	26%	68%	55%	49%	48%
2561	7%	13%	18%	4%	26%
2562	43%	57%	65%	47%	47%
2571	0%	0%	0%	0%	0%
2572	0%	0%	0%	0%	0%
2573	11%	37%	37%	0%	46%
2591	0%	0%	0%	0%	0%
2592	0%	0%	0%	0%	0%
2593	0%	0%	0%	0%	0%
2594	0%	0%	0%	0%	0%
2599	28%	27%	47%	30%	17%
General	10%	16%	18%	12%	14%

Note: Data corresponds to industries classified under Group 25 of the CNAE, as described in the methodology.
Source: Own elaboration based on HADA data.

These averages serve as a baseline for measuring the performance of each individual CNAE subcategory in comparison to the overall group average. The general average percentages of each item are used to conduct a trend analysis:

The average sales figures act as a reference point, providing a baseline against which the performance of each CNAE subcategory can be compared. This comparative analysis helps identify how each subcategory performs relative to the overall group. By using these general average percentages, a trend analysis can be conducted, highlighting patterns and tendencies across different subcategories. This approach allows for a more nuanced understanding of the sector's performance, enabling targeted strategies for improvement and investment in Industry 4.0 initiatives. This method ensures that any deviations from the average can be identified and addressed, thereby promoting a more balanced and comprehensive approach to enhancing digital maturity and innovation within the sector. As we proceed with the HADA platform, these baseline averages and trend analyses will provide critical insights into the digital transformation progress of companies in Castilla-La Mancha, particularly within the manufacturing sector related to fabricated metal products, excluding machinery and equipment.

Table 4. Trend analysis of the CNAE 25 subcategories (CNAE 25 Group)

CNAE_25	Market and business strategy	Processes	Organization and people	Infrastructure	Products and services
2511	16.18%	23.59%	23.00%	31.00%	15.59%
2512	16.18%	20.59%	25.00%	19.00%	16.59%
2521	-9.82%	-16.41%	-18.00%	-12.00%	-14.41%
2529	-9.82%	-16.41%	-18.00%	-12.00%	-14.41%
2530	-9.82%	-16.41%	-18.00%	-12.00%	-14.41%
2540	-9.82%	-16.41%	-18.00%	-12.00%	-14.41%
2550	16.18%	51.59%	37.00%	37.00%	33.59%
2561	-2.82%	-3.41%	0.00%	-8.00%	11.59%
2562	33.18%	40.59%	47.00%	35.00%	32.59%
2571	-9.82%	-16.41%	-18.00%	-12.00%	-14.41%
2572	-9.82%	-16.41%	-18.00%	-12.00%	-14.41%
2573	1.18%	20.59%	19.00%	-12.00%	31.59%
2591	-9.82%	-16.41%	-18.00%	-12.00%	-14.41%
2592	-9.82%	-16.41%	-18.00%	-12.00%	-14.41%
2593	-9.82%	-16.41%	-18.00%	-12.00%	-14.41%
2594	-9.82%	-16.41%	-18.00%	-12.00%	-14.41%
2599	18.18%	10.59%	29.00%	18.00%	2.59%

Note: Data corresponds to industries classified under Group 25 of the CNAE, as described in the methodology.
Source: Own elaboration based on HADA data.

The digital maturity percentages provided by subcategory, compared to general averages, allow for a multifaceted analysis that identifies industry-specific trends, potential areas for development, and technology investment strategies. A positive value indicates that the subcategory exceeds the general average, while a negative value indicates that it falls below the average. The calculated general averages represent a composite indicator of digital maturity, serving as a benchmark for comparative performance among subcategories. The results reveal varied digital maturity across CNAE subcategories, with some significantly exceeding the general averages, while others remain below. This heterogeneity highlights significant differences in the adoption of digital technologies and practices within the sector.

The 'Processes' dimension shows a high level of maturity in several subcategories, indicating early and effective adoption of automation and process management technologies. Subcategory 2550, for example, is 52% above the average, suggesting concentrated investment in operational efficiency and value chain optimization. In the 'Organization and People' dimension, there is a general trend toward lower maturity compared to 'Processes,' possibly reflecting a focus on technology over human and organizational capital. The 'Infrastructure' dimension shows notable variability among subcategories, with some, like 2562, demonstrating outstanding development in integrating digital solutions at the infrastructure level. This indicates companies that are leveraging digital transformation to enhance their operations and production

capacity. Regarding 'Products and Services,' the percentages in certain cases (such as CNAE 2550 with 34% above average) reflect progress towards innovation and the development of offerings that align with current market expectations, suggesting potential for growth and adaptability.

The disparity in digital maturity among CNAE subcategories indicates opportunities for targeted development and investment in lagging segments. Differences in digital maturity can serve as a diagnostic tool for personalized support policies aimed at accelerating digital adoption in specific subsectors and promoting balanced economic growth within the industry. Additionally, areas with higher digital maturity can be considered success stories, warranting further study to extract lessons that can be generalized to other subcategories. These leading subcategories can also act as role models, providing a reference framework for other companies in the sector to compare and improve their practices.

By conducting an analysis of variability and studying the dispersion in maturity percentages among different CNAE categories, we observe that: Each of these insights contributes to a comprehensive understanding of the current state of digital transformation in the industry, guiding strategic decisions and policymaking to foster a more technologically advanced and economically competitive sector.

Table 5. Analysis of variability and dispersion of percentages for each CNAE 25 group

CNAE_25	Range For Each CNAE	Average For Each CNAE	Relative Variability
2511	0.17	0.36	0.47
2512	0.17	0.34	0.51
2521	0.00	0.00	N/A
2529	0.00	0.00	N/A
2530	0.00	0.00	N/A
2540	0.00	0.00	N/A
2550	0.42	0.49	0.85
2561	0.22	0.14	1.62
2562	0.22	0.52	0.42
2571	0.00	0.00	N/A
2572	0.00	0.00	N/A
2573	0.46	0.26	1.76
2591	0.00	0.00	N/A
2592	0.00	0.00	N/A
2593	0.00	0.00	N/A
2594	0.00	0.00	N/A
2599	0.20	0.30	0.67

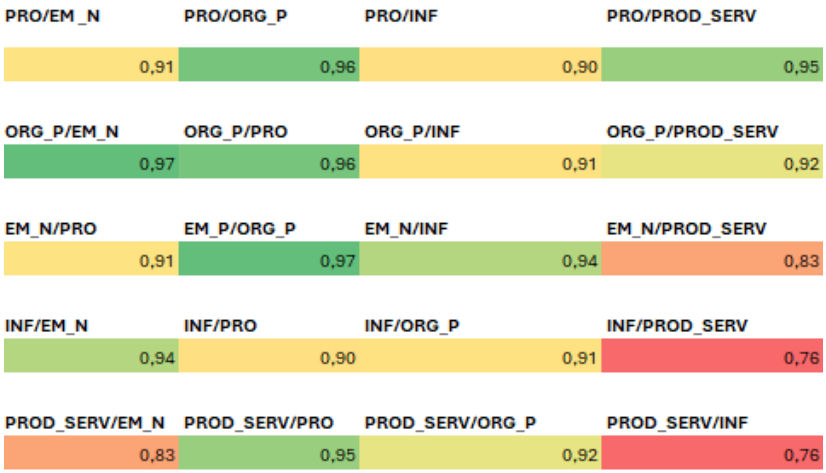
Note: Data corresponds to industries classified under Group 25 of the CNAE, as described in the methodology.
Source: Own elaboration.

The evaluation of relative variability in maturity among CNAE subcategories reveals notable differences in the degree of adoption of digital practices and technologies. The results obtained allow for an in-depth interpretation of the digital positioning of each subcategory, providing valuable insights for strategic decision-making. CNAE subcategories such as 2550 and 2562, which present high relative variability, stand out for heterogeneous digital maturity across various dimensions. This could be interpreted as a specialization in certain digital areas, where the strategic focus is likely more selective and targeted. On the other hand, CNAE subcategories with low relative variability, such as 2561 and 2599, suggest a more balanced and homogeneous approach to digital maturity. These subcategories may be adopting a comprehensive approach to digital transformation, applying digital practices more uniformly across all analysed dimensions. CNAE subcategories with "N/A" relative variability reflect an absence of maturity in all dimensions, indicating a critical need for investment and development in digital practices to enhance their market competitiveness.

Following this, it is useful to study how the maturity levels of different dimensions correlate with each other. In the study of digital maturity of companies, the correlation between various dimensions reveals

the interconnection between key components of corporate strategy and operational infrastructure. Evaluating these correlations is particularly relevant in the era of Industry 4.0, where the harmonious integration of processes and digital technology is fundamental for competitive advantage and innovation. To visually illustrate the strength and direction of correlations between the maturity levels of different business dimensions, a heatmap is used. This comprehensive analysis aids in identifying areas of strength and opportunities for improvement, thereby facilitating targeted strategies for enhancing digital maturity and fostering innovation within the sector.

Figure 3. Heatmap of correlations



Source: Own elaboration.

In the context of evaluating the digital maturity level of companies, the linear correlation between different maturity dimensions reveals important insights into the underlying dynamics of digital transformation. Through data analysis, we have determined that there is a significant relationship between the strategic and operational dimensions of companies, as reflected in high correlations within the evaluation matrix.

The interpretation of the heatmap in Figure 3, the following abbreviations have been used to represent the different dimensions of digital maturity:

- EM_N (Market and Business Strategy): Refers to the alignment of market strategy and business objectives with digital transformation initiatives.
- PRO (Processes): Represents the degree of automation and optimization of internal processes within the organization.
- ORG_P (Organization and People): Assesses the organizational capacity and skills of human capital in adopting and integrating digital technologies.
- INF (Infrastructure): Reflects the availability and adequacy of technological infrastructure, including hardware and software solutions.
- PROD_SERV (Products and Services): Evaluates the digitalization of product and service offerings to meet market demands.

The correlations between company processes and their focus on organization and people (0.97), as well as their market and business strategy (0.91), indicate a strong interconnection. This suggests that improvements in organizational structure and strategic clarity are not only parallel but also possibly interdependent. Similarly, the company's infrastructure shows a significant association with its strategy and market (0.94), implying that investments in digital infrastructure may be closely aligned with corporate strategic objectives.

However, it is important to highlight the moderate correlations observed between the evolution of products and services and other factors such as infrastructure (0.76) and market and business strategy (0.83).

While these still indicate a positive relationship, it is less pronounced, which could suggest the presence of unexamined variables exerting significant influence. This finding points to the need for a more nuanced view of product development, possibly requiring a differentiated strategy that addresses both internal and external influences. These correlation patterns underscore the systemic nature of digital transformation, where maturity in one dimension tends to reinforce and be reinforced by maturity in another.

In summary, the results suggest that companies seeking excellence in the digital era should adopt an integrated approach, where continuous process improvement, strategic investment, and technological infrastructure advancement progress together in a coordinated manner. This holistic strategy will ensure that all aspects of the company evolve harmoniously, fostering sustainable growth and competitive advantage in the digital age.

The integration of Industry 4.0 in Spain, initiated through the "Industria Conectada 4.0" initiative in 2015, has highlighted significant regional disparities in R&D investment. These disparities present both challenges and opportunities for digital transformation across the nation. A thorough understanding of these disparities is crucial as they directly influence national and regional productivity and competitiveness on an international scale.

Nationally, regions such as Madrid and Cataluña are leading in R&D investment, with each exceeding €1 billion. These regions have well-established infrastructures, robust innovation ecosystems, and significant public-private collaborations. Their advanced integration of Industry 4.0 technologies, including IoT, AI, Big Data, and robotics, positions them at the forefront of digital transformation. The benefits of this technological advancement include enhanced operational efficiencies, increased productivity, and greater innovation capabilities, all of which contribute to their competitive edge on a global scale.

On the other hand, regions like Extremadura and La Rioja, with significantly lower R&D investments (below €200 million), are lagging in digital maturity. This gap highlights existing inequalities in digital infrastructure and innovation capacity. These regions face substantial challenges in accessing the resources and support necessary for comprehensive digital transformation, which hampers their ability to compete both nationally and internationally. The necessity for targeted policies and investment strategies to foster digital adoption and infrastructure development in these areas is evident.

The disparities in digital maturity levels have profound implications for productivity and competitiveness. Regions with higher digital maturity levels, such as País Vasco and Navarra, demonstrate advanced integration of Industry 4.0 technologies. This integration results in improved operational efficiencies, product innovation, and the ability to adapt quickly to market changes. Such regions are better positioned to compete on an international scale, leveraging their technological advancements to enhance productivity and market responsiveness.

Conversely, regions with lower digital maturity, such as Castilla-La Mancha and Andalucía, show considerable room for improvement. The "Competent" level of digital maturity observed in these regions suggests that, while there are significant efforts towards digitalization, further optimization is required. Companies in these regions are beginning to implement digital initiatives and integrate information with suppliers and customers, but the full potential of these technologies is yet to be realized. The focus on industries such as "Manufacture of fabricated metal products, except machinery and equipment" in Castilla-La Mancha provides a representative case study for understanding the local challenges and opportunities in digital transformation.

From an international perspective, Spain's overall progress in Industry 4.0 presents a mixed picture. High-maturity regions bolster the country's reputation and capabilities in global markets, while lagging regions can detract from the overall competitiveness. This uneven progress highlights the need for a balanced and inclusive approach to digital transformation.

To enhance international competitiveness, Spain must address regional disparities in digital maturity. Investing in digital infrastructure, fostering innovation ecosystems, and providing tailored support policies for lagging regions are essential. Enhancing digital maturity across all regions will lead to more uniform productivity gains, thereby strengthening Spain's position in the global market. Addressing the

regional disparities in digital maturity within Spain necessitates a multifaceted approach, rooted in strategic recommendations that can drive uniform advancement across all regions. To build robust digital infrastructure and innovation ecosystems, it is imperative to increase R&D funding in lagging regions. This can be achieved through public-private partnerships and incentives aimed at encouraging private sector investment. Such targeted investment will help bridge the gap between high-maturity and low-maturity regions, fostering a more balanced digital economy. Developing tailored support policies is essential to address the unique challenges faced by different regions. These policies should focus on enhancing digital skills, improving access to technology, and supporting small and medium-sized enterprises (SMEs) in their digital transformation efforts. By creating region-specific initiatives, it is possible to provide the necessary resources and training that can empower local businesses to embrace Industry 4.0 technologies effectively.

Encouraging collaboration between regions with varying levels of digital maturity can facilitate knowledge transfer and shared initiatives. This approach allows less advanced regions to benefit from the experiences and best practices of more advanced areas. Collaborative efforts can include joint projects, regional innovation hubs, and inter-regional partnerships that promote collective growth and development. Implementing a comprehensive national digital strategy is crucial to aligning regional efforts with overarching national goals. Such a strategy should promote a cohesive approach to Industry 4.0 adoption, ensuring that all regions contribute to and benefit from the digital economy. This national framework would provide a structured pathway for digital transformation, facilitating coordinated efforts and resource allocation across the country.

Establishing mechanisms for continuous monitoring and evaluation of digital maturity and transformation progress is vital. These mechanisms will enable timely adjustments to policies and strategies, ensuring they remain effective and responsive to the evolving needs of each region. Regular assessments and feedback loops can help identify areas of improvement, measure the impact of initiatives, and refine approaches to achieve optimal outcomes. By addressing these strategic recommendations, Spain can enhance its national productivity and strengthen its competitiveness on the international stage. A holistic strategy that includes targeted investment, tailored support policies, fostering collaboration, implementing a comprehensive digital strategy, and continuous monitoring will ensure that all regions can leverage the benefits of Industry 4.0. This approach will contribute to a robust and resilient national economy capable of thriving in the global digital landscape, fostering sustainable economic growth, innovation, and technological advancement.

The integration of Industry 4.0 in Spain has highlighted significant regional disparities in digital maturity and R&D investment, revealing the need for a comprehensive and multifaceted policy approach. These disparities must be addressed through targeted regional, national, and international policies to enhance productivity and competitiveness. At the regional level, it is crucial to increase R&D funding in lagging areas, such as Extremadura and La Rioja, to build robust digital infrastructure and innovation ecosystems. Public-private partnerships and incentives for private sector investment can play a vital role in this process. Tailored support policies that focus on enhancing digital skills, improving access to technology, and supporting SMEs in their digital transformation efforts are essential for addressing specific local challenges.

Nationally, Spain must implement a cohesive digital strategy that aligns regional efforts with national goals, ensuring that all regions contribute to and benefit from the digital economy. The "Industria Conectada 4.0" initiative, launched in 2015, exemplifies such an effort by promoting the integration of advanced technologies in industrial processes. Expanding this strategy to include continuous monitoring and evaluation mechanisms, along with public-private partnerships and financial incentives, will help achieve more uniform digital maturity across the country. This national strategy will facilitate coordinated efforts and resource allocation, ultimately boosting national productivity.

Internationally, Spain's approach to Industry 4.0 can serve as a model for other countries facing similar regional disparities in digital maturity. Collaborative efforts within the European Union, such as participation in the "Digital Agenda for Europe" and "Horizon 2020," can facilitate the exchange of best practices and joint initiatives to enhance digital transformation. Engaging in international collaborations

will provide Spain with additional resources, access to cutting-edge technologies, and opportunities to contribute to setting global standards for Industry 4.0. The primary objective of these policies should be to enhance productivity across all sectors. Regions like Madrid and Cataluña, with substantial R&D investment, demonstrate a clear correlation between digital transformation and increased productivity. The adoption of Industry 4.0 technologies, including IoT, AI, Big Data, and robotics, has been shown to improve operational efficiencies, foster innovation, and enhance competitive advantage. Therefore, regional and national policies must prioritize the integration of these technologies to drive productivity growth.

Addressing regional disparities through targeted investment and tailored policies will accelerate digital maturity and productivity (Grau Ríos, 2010). A cohesive national strategy, complemented by international collaboration, will position Spain as a leader in Industry 4.0, enhancing its competitiveness and innovation capacity. Continuous monitoring and evaluation will ensure that policies remain effective and responsive to evolving needs, driving sustained economic growth and technological advancement. This holistic strategy will ensure that all regions can leverage the benefits of Industry 4.0, contributing to a robust and resilient national economy capable of thriving in the global digital landscape. The projected impact of implementing these strategic recommendations is substantial. If lagging regions receive targeted R&D funding and support, similar to high-performing regions, significant improvements in their digital maturity can be expected. Castilla-La Mancha, currently at a "Competent" digital maturity level, could advance to "Dynamic" or even "Leader" status within five years with consistent investment and strategic support. Nationally, a cohesive digital strategy could lead to increase in productivity over the next decade, driven by enhanced digital integration and operational efficiencies. International collaborations will facilitate the exchange of best practices positioning Spain as a leader in Industry 4.0 within Europe and attracting international investments.

5. Conclusion

The implementation of Industry 4.0 in Spain reveals a complex landscape characterized by significant regional disparities in digital maturity and R&D investment. These disparities highlight the urgent need for a multifaceted policy approach that addresses regional specificities while aligning with national and international goals to enhance productivity and competitiveness. This study has explored these dimensions in detail, providing critical insights and recommendations for future actions.

Analysis indicates that regions such as Madrid and Cataluña have made substantial progress in adopting Industry 4.0 technologies, largely due to higher levels of R&D investment and better-developed digital infrastructures. In contrast, regions like Extremadura and La Rioja lag behind, reflecting significant gaps in digital maturity. This disparity not only affects regional competitiveness but also has broader implications for national economic cohesion and growth. For example, the digital maturity of Castilla-La Mancha, classified as "Competent," indicates that while there are ongoing efforts and investments in digital technologies, these efforts are not yet sufficient to achieve the highest levels of digital integration and productivity.

Data from regions that have advanced in digital maturity, such as País Vasco and Navarra, demonstrate the positive impact of targeted investment and strategic support. These regions exhibit a "Dynamic" or "Leader" level of digital maturity, showcasing advanced integration of Industry 4.0 technologies and robust digital infrastructure. This serves as a model for other regions, suggesting that with appropriate investments and policies, lagging regions can similarly enhance their digital maturity and productivity.

The Spanish government's "Industria Conectada 4.0" initiative, launched in 2015, aims to promote the integration of advanced technologies into industrial processes. While this initiative has laid the groundwork for digital transformation, its impact has been uneven across regions. To address these disparities, a cohesive national strategy is essential. Increasing R&D funding in lagging regions is crucial. Public-private partnerships and incentives for private sector investment can help build robust digital infrastructure and innovation ecosystems. By channelling resources into regions with lower digital maturity,

the overall national productivity can be enhanced. Developing region-specific policies that address unique local challenges is essential. These policies should focus on enhancing digital skills, improving access to technology, and supporting small and medium-sized enterprises (SMEs) in their digital transformation efforts. Tailored initiatives can provide the necessary resources and training, empowering local businesses to embrace Industry 4.0 technologies effectively. Encouraging collaboration between high-maturity and low-maturity regions can facilitate knowledge transfer and shared initiatives. Joint projects, regional innovation hubs, and inter-regional partnerships can promote collective growth and development, helping less advanced regions catch up. Implementing a national digital strategy that aligns regional efforts with national goals is crucial. This strategy should promote a cohesive approach to Industry 4.0 adoption, ensuring that all regions contribute to and benefit from the digital economy. Continuous monitoring and evaluation mechanisms should be included to assess progress and make necessary adjustments.

Spain's approach to Industry 4.0 can serve as a model for other countries facing similar regional disparities in digital maturity. Collaborative efforts within the European Union, such as participation in the "Digital Agenda for Europe" and "Horizon 2020," can facilitate the exchange of best practices and joint initiatives to enhance digital transformation. International collaboration provides Spain with additional resources, access to cutting-edge technologies, and opportunities to contribute to setting global standards for Industry 4.0. The primary objective of these policies should be to enhance productivity across all sectors. Empirical evidence indicates that the adoption of Industry 4.0 technologies, including IoT, AI, Big Data, and robotics, leads to significant improvements in operational efficiencies, cost savings, and productivity gains. Regions like Madrid and Cataluña, with substantial R&D investments, demonstrate a clear correlation between digital transformation and increased productivity. Therefore, prioritizing the integration of these technologies at both regional and national levels is essential for driving productivity growth. Addressing regional disparities through targeted investment and tailored policies will accelerate digital maturity and productivity. A cohesive national strategy, complemented by international collaboration, will position Spain as a leader in Industry 4.0, enhancing its competitiveness and innovation capacity. Continuous monitoring and evaluation will ensure that policies remain effective and responsive to evolving needs, driving sustained economic growth and technological advancement.

Future research should focus on developing detailed case studies of regions that have successfully implemented Industry 4.0 technologies to extract best practices and lessons learned. Additionally, longitudinal studies that track the progress of regions over time can provide valuable insights into the long-term impacts of digital transformation initiatives. Understanding the factors that contribute to successful digital integration can help policymakers refine strategies and optimize resource allocation. Moreover, investigating the role of human capital in the digital transformation process is critical. As highlighted by Wolfgang Wahlster during his visit to País Vasco, the collaboration between technology and human workers is vital. Ensuring that the workforce possesses the necessary skills and qualifications is essential for maximizing the benefits of Industry 4.0 technologies (Festo Group, 2017). The implementation of Industry 4.0 in Spain presents both significant opportunities and challenges. Addressing regional disparities, aligning national efforts with strategic goals, and engaging in international collaborations will enhance productivity, foster innovation, and strengthen competitiveness on the global stage. This comprehensive approach will drive sustainable economic growth, positioning Spain as a leader in the digital age and setting a benchmark for other nations aiming to harness the full potential of Industry 4.0.

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Annex 1. Operating revenues (thousand EUR)

Activity (NACE Rev. 2)	Less than 1,000	1,000 to 5,000	5,000 to 10,000	10,000 to 50,000	50,000 to 100,000	More than 100,000	Total
Food industry	836	269	67	74	19	15	1,280
Beverage manufacturing	251	110	32	38	6	2	439
Textile industry	142	22	4	5	0	0	173
Garment manufacturing	508	50	3	2	0	0	563
Leather and footwear industry	291	68	6	8	0	1	374
Wood and cork industry, except furniture; basketry and wickerwork	505	109	17	18	2	0	651
Paper industry	56	14	6	6	1	0	83
Graphic arts and reproduction of recorded media	316	29	1	5	0	0	351
Chemical industry	116	44	11	17	2	1	191
Pharmaceutical products manufacturing	9	2	1	5	0	0	17
Rubber and plastics products manufacturing	105	57	10	11	1	2	186
Other non-metallic mineral products manufacturing	385	135	34	25	1	1	581
Metallurgy; manufacturing of iron, steel and ferro-alloy products	99	33	4	10	3	3	152
Manufacturing of metal products, except machinery and equipment	1,460	263	38	28	3	1	1,793
Manufacturing of computer, electronic and optical products	52	9	4	2	0	0	67

Activity (NACE Rev. 2)	Less than 1,000	1,000 to 5,000	5,000 to 10,000	10,000 to 50,000	50,000 to 100,000	More than 100,000	Total
Electrical equipment manufacturing	66	13	5	4	1	2	91
Manufacturing of machinery and equipment n.e.c.	192	65	10	5	1	1	274
Manufacturing of motor vehicles, trailers and semi-trailers	61	18	7	10	0	2	98
Manufacturing of other transport equipment	10	5	1	7	1	1	25
Furniture manufacturing	696	102	21	10	1	0	830
Other manufacturing industries	110	21	1	3	0	0	135
Repair and installation of machinery and equipment	325	52	4	2	0	1	384
Total	6,591	1,490	287	295	42	33	8,738

Source: SABI >NACE; Castilla-La Mancha Region >Operating Revenues (thousand euros)

Annex 2. Income Concentration Index global industry activity

Business number																					
	Operating income (thousand EUR)																				
Activity (NACE Rev. 2)	Less than 1,000	ESTIMATE	EMP*ESTIMATE	At 1,000	ESTIMATE	EMP*ESTIMATE	at 10,000	ESTIMATE	EMP* ESTIMATE	at a 30,000	ESTIMATE	EMP* ESTIMATE	at a 100,000	ESTIMATE	EMP* ESTIMATE	More than 100,000	ESTIMATE	EMP* ESTIMATE	All	SUM	ICI
Food industry	836	500	418000	269	3000	807000	67	7500	502500	74	30000	2220000	19	75000	1425000	13	150000	2250000	1.280	7622500	5955,08
Beverage manufacturing	251	500	125500	110	3000	330000	32	7500	240000	38	30000	1140000	6	75000	450000	2	150000	300000	439	2585500	5889,52
Textile industry	142	500	71000	22	3000	66000	4	7500	30000	5	30000	150000	0	75000	0	0	150000	0	173	317000	1832,37
Clothing making	308	500	234000	50	3000	150000	3	7500	22500	2	30000	60000	0	75000	0	0	150000	0	563	486500	864,12
Leather and footwear industry	291	500	145500	68	3000	204000	6	7500	45000	8	30000	240000	0	75000	0	1	150000	150000	374	784500	2097,59
Wood and cork industry, except furniture; basket weav esparto	505	500	252500	109	3000	327000	17	7500	127500	18	30000	540000	2	75000	150000	0	150000	0	651	1397000	2145,93
paper industry	56	500	28000	14	3000	42000	6	7500	45000	6	30000	180000	1	75000	75000	0	150000	0	83	370000	4457,83
Graphic arts and reproduction of recorded media	316	500	158000	29	3000	87000	1	7500	7500	5	30000	150000	0	75000	0	0	150000	0	351	402500	1146,72
Chemical industry	116	500	58000	44	3000	132000	11	7500	82500	17	30000	510000	2	75000	150000	1	150000	150000	191	1082500	5667,54
Manufacturing of pharmaceutical products	9	500	4500	2	3000	6000	1	7500	7500	5	30000	150000	0	75000	0	0	150000	0	17	168000	9882,35
Manufacturing of rubber and plastic products	105	500	52500	57	3000	171000	10	7500	75000	11	30000	330000	1	75000	75000	2	150000	300000	186	1003500	5395,16
Manufacture of other non-metallic mineral products	385	500	192500	135	3000	405000	34	7500	255000	25	30000	750000	1	75000	75000	1	150000	150000	581	1827500	3145,44
Metallurgy; manufacturing of iron, steel and fer products	99	500	49500	33	3000	99000	4	7500	30000	10	30000	300000	3	75000	225000	3	150000	450000	152	1153500	7588,82
Manufacture of metal products, except machiner equipment	1.460	500	730000	263	3000	789000	38	7500	285000	28	30000	840000	3	75000	225000	1	150000	150000	1.793	3019000	1683,77
Manufacture of computer, electronic and optical produ	52	500	26000	9	3000	27000	4	7500	30000	2	30000	60000	0	75000	0	0	150000	0	67	143000	2134,33
Manufacture of electrical material and equipmen	66	500	33000	13	3000	39000	5	7500	37500	4	30000	120000	1	75000	75000	2	150000	300000	91	604500	6642,86
Manufacture of machinery and equipment nec	192	500	96000	65	3000	195000	10	7500	75000	5	30000	150000	1	75000	75000	1	150000	150000	274	741000	2704,38
Manufacture of motor vehicles, trailers and semi-traile	61	500	30500	18	3000	54000	7	7500	52500	10	30000	300000	0	75000	0	2	150000	300000	98	737000	7520,41
Manufacture of other transport equipment	10	500	5000	5	3000	15000	1	7500	7500	7	30000	210000	1	75000	75000	1	150000	150000	25	462500	18500,00
Furniture manufacturing	696	500	348000	102	3000	306000	21	7500	157500	10	30000	300000	1	75000	75000	0	150000	0	830	1186500	1429,52
Other manufacturing industries	110	500	55000	21	3000	63000	1	7500	7500	3	30000	90000	0	75000	0	0	150000	0	135	215500	1596,30
Repair and installation of machinery and equipm	325	500	162500	52	3000	156000	4	7500	30000	2	30000	60000	0	75000	0	1	150000	150000	384	558500	1454,43
All	6.591			1.490			287			295			42			33			8.738		

Source: Own elaboration based on SABI data

Estimate:
Less than 1,000 EUR: 500
From 1,000 to 5,000 EUR: 3,000

From 5,000 to 10,000 EUR: 7,500
From 10,000 to 50,000 EUR: 30,000
From 50,000 to 100,000 EUR: 75,000
More than 100,000 EUR: 150,000

Source: Own elaboration based on SABI data

Annex 3. Net sales revenue (thousand EUR)

Year	Average	Median	Standard Deviation	Number of companies
2012	82	19	285	92
2013	80	17	281	90
2014	89	19	299	89
2015	106	23	366	88
2016	105	24	345	88
2017	116	29	389	90
2018	133	32	443	90
2019	142	33	518	91
2020	129	29	452	90
2021	156	36	554	87
2022	184	41	694	78

Source: SABI > Group and subgroups 25 CNAE > C-LM