

## Article

# Industry 4.0 Accelerating Sustainable Manufacturing in the COVID-19 Era: Assessing the Readiness and Responsiveness of Italian Regions

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**Abstract:** An unpredictable shock hit the Italian economy in February 2020 when the spread of the COVID-19 virus began in Italy and other countries worldwide. In this context, Industry 4.0 (I4.0) technologies can be a fundamental tool for economic recovery by favouring the shift towards sustainable manufacturing. Therefore, it is necessary to measure the readiness of countries for I4.0 in order to guide policies in defining incentives to promote I4.0 and unlock its potential in the pandemic era. In this context, the paper aims to understand the readiness and responsiveness of the Italian Regions with respect to I4.0 concepts prior to the pandemic and identify best practices that are supporting companies in I4.0 adoption, with a focus on those incentivizing sustainable practices. An assessment framework before the pandemic is provided based on two dimensions: the readiness of firms to invest in I4.0 and favourable structural conditions. The assessment shows a group of alert regions as opposed to a group of unprepared, mostly linked Northern and Southern differences. Assuming that the “alert regions” are more likely to effectively manage and overcome the post- COVID-19 crisis, we provide a picture of how the Italian Regions have sought to encourage the adoption of digital technologies to improve resilience after the shock. The analysis shows that supporting measures mainly address Small and Medium-sized Enterprises. Furthermore, the tenders encouraging the adoption of I4.0 suggest that collaboration among stakeholders will become imperative.



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## 1. Introduction

The spread of COVID-19 worldwide has turned into an economic and labour market shock, impacting both the supply of goods and services and the demand in consumptions and investments [1] and challenging global trade [2]. With the easing of restrictive measures related to the emergency and the progressive reopening of production activities, the adoption of Industry 4.0 (I4.0) technologies will contribute to the survival of many companies [3–7].

In the COVID-19 era, I4.0 technologies are also expected to accelerate the shift towards sustainable manufacturing [8]. Above all, achieving sustainable development will become a priority for economic recovery, which will need to address biodiversity loss, climate change, and promote the principles of circular economy [9]. In addition, increasing attention will be paid to the production and consumption of sustainable items [10,11]. In fact, awareness of environmental and social issues is increasing, as is the appreciation of brands that pay more attention to the environmental impact of the supply chain [12].

Italy could be a showcase for Europe, as businesses are being hit by the effects of the spread of the coronavirus [13]. Before COVID-19, I4.0 technologies were considered only for increasing productivity and competitiveness [14], but today they are becoming

a prerequisite for keeping companies open. Policy makers and managers considered AI applications to balance the unavailability of workers as a first response to the lockdown [3]. Indeed, technology has been vital during global lockdowns for ensuring business continuity through remote working. However, the acceleration of I4.0 trends is likely to expose the digital divide in Italy, as the pandemic is expected to enhance this divide within and between countries [15]

In this context, the paper aims to understand if COVID-19 will be the catalyst for higher levels of technology adoption and act as an enabler for sustainable production.

To address this aim, we propose and apply an assessment framework to measure the I4.0 readiness of Italy before the pandemic, focusing on the regional level, which corresponds to the Nomenclature of Territorial Units for Statistics (NUTS) level 2 (For each EU member country, a hierarchy of three NUTS levels is established by Eurostat in agreement with each member state; the subdivisions in some levels. For Italy NUTS2, the level corresponds with its regional division). Therefore, six variables are selected to measure the readiness of Italian regions towards I4.0: (1) the firms' readiness to invest in I4.0 and (2) favourable structural conditions for I4.0. The identification of these two dimensions allows recognizing some relevant trends and differences among regions that could be exposed by the pandemic. Leveraging on this preliminary analysis, the novelty of the paper lies in the investigation of the responsiveness of Italian regions in encouraging the adoption of I4.0 technologies as a means to enable sustainable development.

The results show that among these variables there is a low focus on collaboration agreements on innovation, which are expected to be crucial during the economic recovery after COVID-19. In the second part of the analysis, we show how COVID-19 is a catalyst for higher adoption levels of digital technologies by providing a picture of how the Italian Regions have sought to encourage the adoption of digital technologies to improve resilience and adaptability to the shock while incentivizing sustainable practices. The findings show that measures are mainly targeting Small and Medium-sized Enterprises (SMEs) and that a growing number of financial measures link I4.0 to sustainable development. Furthermore, the collaboration between stakeholders is becoming imperative in supporting firms to implement digital and sustainable models.

The paper is structured as follows. First, after reviewing the I4.0 applications in the post-COVID 19 phases, we present the Italian context for I4.0 before the pandemic. Second, after describing the methodology used, we evaluate through selected variables, the Italian regional readiness for I4.0 considering their potential role in managing the post-COVID 19 phases. Third, we present the best practices adopted by regional administrations to promote the introduction of I4.0 to better deal with the effects of the pandemic in two stages: immediately after the outbreak (Phase 1) and after the end of the first lockdown (Phase 2). Lastly, we conclude, focusing on practical implications and on a future research agenda to exploit the connections between I4.0 and sustainability.

## **2. Industry 4.0 Applications Promoting Sustainable Manufacturing in the COVID-19 Era**

I4.0 stresses the importance of data collection and exchange throughout the value chain [16] by introducing production systems that are increasingly intelligent, autonomous, and automated [17].

I4.0 can be described as the integration of information and communication technologies (ICT) with industrial technology [18]. Many companies are adopting technologies such as Cyber-Physical System (CPS), The Internet of Things (IoT), robotics, Big Data, Cloud Manufacturing, and Augmented Reality to improve products and processes, increase efficiency and productivity, reduce costs, and increase customer satisfaction [19,20]. There are many benefits that firms can capture from I4.0: greater flexibility and speed from prototype to series production; increased productivity due to shorter set-up times, reduced errors and machine downtime; better quality and less waste [21]. Moreover, accidents in the company can be prevented by integrating I4.0 technologies into safety management systems [22].

Since the beginning of the pandemic, researchers have been considering how I4.0 can mitigate the effects of the crisis. First of all, I4.0 can change the way we work. The shift towards remote working will increasingly take hold and may be facilitated by I4.0 [23]. Nevertheless, remote working is not synonymous with working from home but implies a radical innovation in organizational structure [24].

The dematerialization of the workplace is the most radical consequence of I4.0, which means that some activities can be performed through digital tools that are connected to the Internet, enabling workers to perform their services in places that are not necessarily company buildings [25].

Kaushik and Guleria [7] show that before the pandemic, working from home was an acceptable practice only in the IT and Technology sectors. During the last months, companies in different sectors have found benefits in working at home and are considering this option as a new business model.

Before the lockdown, remote working was on the rise in Italy: the Smartworking Observatory [26] of the Politecnico di Milano estimated that about 305,000 people worked in remote mode in 2017. According to the survey, the main benefits are savings in travel time, greater satisfaction in organizing work, and the development of leadership and teamwork skills.

The “smart working” survey by the Italian General Confederation of Labour (CGIL) and the Di Vittorio Foundation [27] integrates this data, according to which about 500,000 people worked in remote mode before the epidemic. Before the lockdown caused by COVID-19, remote work in Italy involved a low percentage of workers with 1.2% of company employees. With the quarantine, the percentage rose to 8.8, with peaks of 50% for sectors such as communication and information and 40% for technical and scientific activities. However, the choice depended on size and sector: in the smallest firms, remote working was adopted only in 18.3% of cases, while in the largest it was adopted in up to 90%. In recent months, the Smartworking Observatory of the Politecnico di Milano estimated that 8 million Italians are working from remotely.

Remote working is also expected to support sustainable development. Kylili et al. [28] identify indicators to demonstrate the contribution remote working may have in tackling energy and environmental challenges.

In this scenario, digital technology for remote working can ensure that more businesses survive and return to normal activities [5].

Melluso et al. [29] propose an analysis that discusses how I4.0 technologies can impact the industry, labour market, and society during the pandemic, demonstrating how the virus has spurred advances in digital technologies. The acceleration of I4.0 trends will also unlock major opportunities for sustainable manufacturing. Lin et al. [30] emphasize that in the future of I4.0 applications, Big Data will drive sustainable development, especially in relation to the Sustainable Development Goals introduced by the United Nations (UN) in 2015. Braccini and Margherita [31] confirm, through a single case study of a manufacturing company, that I4.0 applications can support the economic, social, and environmental dimensions of sustainability. More specifically, by enabling virtualization, digitization, and integration, I4.0 can enhance environmental awareness contributing to waste minimization, and the efficient use of natural resources, raw materials, and energy [32].

However, despite the benefits that I4.0 brings to smart and sustainable manufacturing, most companies have made little progress in implementing it [33].

Table 1 summarizes the possible applications of I4.0 technologies for companies in the pandemic era, based on very recent literature discussing the relationship between I4.0 and COVID-19.

Table 1 shows how I4.0 can contain COVID-19 effects exploiting the use of data, computing power, and connectivity. The rapid transformation requires rethinking the current business models. Casalino et al. [13] argue that it is fundamental to improve “digital resilience,” as a critical factor for firms’ success. SMEs could think about sharing the costs required by technology investments relying on collaborative networks, as a means

to access innovation and larger knowledge bases [34]. I4.0 trends can drive the introduction of sustainable models in SMEs with a positive impact on their performance [35].

**Table 1.** Industry 4.0 applications for the post-COVID-19 recovery.

4.0 Enabling Technologies	COVID-19 Applications
Advanced Manufacturing Solutions	Robots can be implemented and trained for repetitive tasks, ensuring social distancing. Sensor applied to employees can monitor in real-time COVID-19 symptoms. Chatbots can answer the large number of questions from the general public and customers.
Additive Manufacturing	3D printing can produce high-demand products and critical parts that are momentarily not produced by suppliers. The technology can contain the spread of the virus from the production of face masks. 3D scanning can be used for motion capture, robotic mapping, and industrial design.
Augmented Reality	Virtual and Augmented Reality devices close the physical distance between people able to work together and provide instructions in an almost “real-life” environment.
Simulation	AI-enabled platforms can help companies simulate live-work environments and create on-demand labour forces. Virtual Reality (VR) improves efficiency in team working, reduces travel costs, and the impact of pollution on the environment. VR is a tool for communication and collaboration.
Horizontal/Vertical Integration	Intelligent knowledge management systems using AI integrate and disperse knowledge along the supply chain, empowering employees.
Industrial Internet and Cloud	Cloud-based control software allow companies to maintain and monitor operations and equipment remotely. IoT can be used in combination with drones applied for surveillance or for tracing the origin of an outbreak or for searching patient zero. Then, IoT can be used by medical staff for remote monitoring patients at home.
Cyber-security	Companies can improve cybersecurity at all levels when asset downtime is high or operations are shut down.
Big Data and Analytics	IoT-based software provide a real-time dashboard of key performance indicators to support shop-floor performance dialogs and increase transparency. The data captured can include information on real-time and historic machine conditions, as well as customer records. Big data can be useful for forecasting the impact of the virus on business, collecting real-time data and providing this data to managers to plan a strategy to face the crisis.

Authors' elaboration based on [5,6,21,24,25].

Given these premises, we investigate the readiness of the Italian Regions with respect to I4.0 concepts, assuming that those with a high readiness will be able to better cope within the COVID-19 era. For these reasons, in the following sections, after presenting the I4.0 Italian context before COVID-19, we discuss the methodology used to assess the readiness and responsiveness of Italian regions.

### 2.1. The Italian Industry 4.0 before COVID-19

Italy is characterized by significant territorial differences in terms of economic development and entrepreneurial dynamics within its regions. Ideally, we can divide Italy into the wealthy and advanced North West, the North East and The Centre, and the South. The regions of NEC (North East Central), including Trentino-Alto Adige, Veneto, Friuli-Venezia Giulia, Emilia-Romagna, Tuscany, Umbria, and Marche, form an area known as Terza Italia [36]. This area is characterized by a strong manufacturing presence, a high number of SMEs with a family character [37], and industrial districts [38]. Unlike the NEC, the South is characterized by a high unemployment rate and an entrepreneurial activation rate in the declining manufacturing sector [39].

Italy has been one of the last countries to introduce a governmental plan on I4.0 in 2016, becoming part of the Stability law in 2017. The national plan “Piano Nazionale Industria 4.0,” renamed “Piano Nazionale Impresa 4.0,” was introduced to boost investment and innovation for the period 2017–2020. In 2019, the updated version of the Plan “Transizione 4.0” gave more importance to environmental sustainability. The plan also

fosters the development of Digital Innovation Hubs (DIHs) and Competences Centres (CCs), supporting the introduction of I4.0 in a collaborative perspective, especially among SMEs. DIHs, as a European instrument launched in 2016, help companies approaching I4.0 by acting as a first regional contact based on the technological infrastructure of CC, connecting firms to external sources (i.e., universities, businesses, institutions).

An investigation of the Ministry of Economic Development (MISE) and the Economic and Territorial Monitoring research centre (MET) [14] on 24,000 Italian companies between 2017 and 2018 tried to assess the level of maturity achieved by companies on I4.0 (Table 2). The results show that only 6% of micro-enterprises introduced I4.0 technologies, followed by 18.4% of small, 35.5% of the medium-sized, and 47.1% of big firms. Among the sample, it appears that I4.0 is expected to improve quality and minimize errors (63%) and increase production (46.3%). These results are expected to change considering the applications of I4.0 for the effective management of the production in the COVID-19.

**Table 2.** Adoption of Industry 4.0 among Italian Regions.

Regions	Traditional Enterprises	Traditional Enterprises with 4.0 Plans	Enterprises 4.0
Abruzzo	89.4	3.7	6.9
Basilicata	91.7	3.7	4.6
Calabria	88.3	4.8	6.8
Campania	88.7	5.3	6
Emilia-Romagna	85.1	4.3	10.6
Friuli V.G.	86.4	4.1	9.5
Lazio	86.7	5.3	8
Liguria	91.7	3.3	5
Lombardy	86.1	4.2	9.7
Marche	89.5	3.5	7
Molise	88.3	3	8.7
Piedmont	81.8	6.4	11.8
Puglia	90.2	5.1	4.6
Sardinia	91.5	2.6	5.9
Sicilia	91	2	7
Tuscany	92.1	3.6	4.3
Trentino AA	83.9	5.2	10.9
Umbria	90	3.2	6.8
Valle d'Aosta	91	2.6	6.4
Veneto	80.5	7.8	11.7
Italy	86.9	4.7	8.4

At the regional level, the highest percentage of I4.0 firms is identified in Piedmont (11.7%) followed by Veneto (11.7%). In this latter region, there is also the largest share of traditional enterprises that have 4.0 plans (7.8%). Contrary, the lowest share of 4.0 firms is found in Tuscany (4.3%) and Puglia (4.6%).

Based on the results of the survey, the highest percentage of 4.0 firms over the national average is identified in Piedmont, Veneto, Emilia-Romagna, Trentino, Lombardy, Friuli-Venezia Giulia, and Molise. Whereas the highest percentage of traditional enterprises that have 4.0 plans is found in Veneto, Piedmont, Campania, Lazio, Trentino-A. A, Puglia, and Calabria.

### 3. Methodology

The measurement of the I4.0 readiness and responsiveness of Italian regions with respect to the COVID-19 crisis relied on a quantitative and qualitative approach.

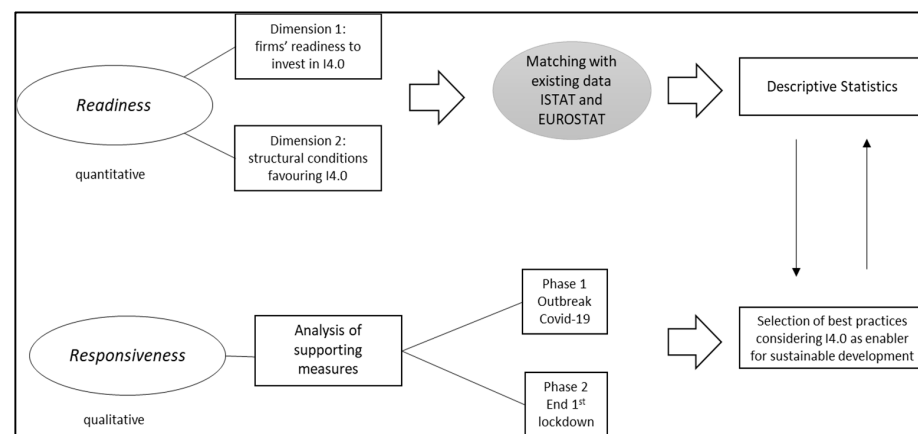
Firstly, to provide a measure of the readiness of Italian regions, the existing literature was considered for selecting accordingly dimensions that can express the firms' readiness to adopt I4.0 technologies and the presence of structural aspects that can favour the shift towards I4.0.

Data that can be used as a proxy of these dimensions was retrieved from the Italian National Institute of Statistics (ISTAT) and Eurostat considering the period 2014–2016.

Descriptive statistics on the national level are provided for identifying the best and worst performers. Then, through Ward's clustering, a multivariate analysis was conducted to partition the regions into significant groups based on standardized values computed for the last year under consideration. The results of the clustering were compared with the existing results on firms adopting I4.0 technologies as described in Section 2.1.

As a second step, for measuring the readiness of Italian regions in supporting the adoption of I4.0 technologies, we reviewed the main measures introduced in two periods: immediately after the COVID-19 outbreak, identified as Phase 1 (March to May 2020) and after the end of the first lockdown in Phase 2 (May till September 2020). Best practices were identified within the official websites of the regions.

The methodological approach is summarized in Figure 1.



**Figure 1.** Methodological approach.

#### 3.1. Step 1—A Framework Assessing Industry 4.0 Readiness for the Economic Recovery

Even though I4.0 is one of the most popular topics for the manufacturing sector within both industry and academia [40], the literature on assessing I4.0 maturity remains scarce [41]. The survey of Monitoraggio Economia Territorio- Ministry of Economic Development (MET-MISE) can be considered an attempt to assess the maturity level of Italian enterprises, but the analysis cannot be considered exhaustive, covering a sample of companies.

Since I4.0 introduces new concepts, it becomes difficult to define and measure its impact [42,43]. Furthermore, most organisations do not have the ability to assess their I4.0 maturity [19].

Two possible reasons for this gap are the difficulty in establishing the exact dimensions that characterize I4.0 and the lack of quantitative information on those dimensions [44]. Several I4.0 maturity models have been developed at the firm level to take a picture of the company, measuring its degree of adoption of I4.0.

Schumacher et al. [19] identified nine characteristics: strategy, leadership, customers, products, operations, culture, people, governance, and technology, as a means to determine the I4.0 maturity by focusing on organizational aspects. IMPULS [45] proposed a model with six foundations: strategy and organisation, smart factory, smart operations,

smart products, data-driven services, and employees. Another interesting attempt is that of Castelo-Branco et al. [44]. The authors developed a framework on two dimensions, including I4.0 Infrastructure, which is a combination of interconnectivity, interoperability, virtualization, and Big Data Maturity, expressing the ability to process information generated by I4.0 infrastructures.

Nevertheless, despite the attention on the digital divide, measuring the access and diffusion of ICT is complex. There is no standardized definition of digital development [46], and considerations about these topics differ between countries and organizations [47]. For these reasons, we attempt to assess the readiness of the Italian Region towards I4.0, identifying six variables (for which data is available at the regional level) that outline two dimensions.

### 3.1.1. Dimensions 1: Firms' Readiness for Industry 4.0

I4.0 is expected to improve firms' existing innovation capability [48]. Firms with a high propensity for innovation are more likely to be ready to integrate I4.0. As underlined by Sjödin [49], the core of the smart factory implementation is a process of innovation itself. I4.0 introduces new production modes in which the combination of manufacturing and innovation reinforces the usage of digital technologies [50]. Moreover, these new production models are expected to enable smart and sustainable manufacturing [33].

To measure firms' readiness, the percentage of firms that registered innovative activities of product or process and the resources addressed for innovation is considered, assuming that firms with a high propensity for innovation are more likely to be ready to integrate I4.0 concepts.

In addition to innovation propensity, collaborative networks are expected to encourage the adoption of I4.0 [51]. This is true especially for horizontal integration, like networking along the value chain from suppliers to customers. Such integration should be based on a reliable infrastructure supporting collaboration between manufacturing organizations and partners who can communicate and share information in real-time [52]. Furthermore, a collaborative supply chain in manufacturing may contribute to meet the requirements of sustainability in the sector [53]. Kornfeld and Kara [54] demonstrated that industry-university partnerships with the support of governments can favour the introduction of new approaches for sustainable manufacturing. These collaborative networks could be beneficial for SMEs, which are facing challenges in finding financial and knowledge resources for integrating I4.0 technologies and sustainable practices [55]. The need to share and combine knowledge and resources corresponds to important components of collaboration [52].

COVID-19 has already prompted a collaborative environment, mobilizing scientists, pharmaceutical companies, and governments to launch initiatives to find an effective response to the virus [56]. Further, the European DIHs are supporting firms that deal with the pandemic based on their collaborative ecosystems.

Thus, aware of the collaborative role of I4.0 for overcoming the pandemic challenges, we include as a proxy the presence of cooperation agreements of firms for innovation (Table 3).

**Table 3.** Indicators of Industry 4.0 readiness.

Indicator	Dimension
Firms with innovative activities (%)	Firms' readiness for Industry 4.0
Expenditure for innovation per worker (1000 € per employees)	
Firms cooperation agreements for innovation (%)	
Firms with broadband connection (%)	Favourable Structural conditions
People with tertiary education (%)	
Employed in Science and Technology (%)	

### 3.1.2. Favourable Structural Conditions for Industry 4.0

Together with the first dimension, there are structural conditions that characterize the orientation of territories towards I4.0 and that may contribute to widening the digital gap between and within countries after the pandemic [15]. Differences in digital readiness hamper the ability of large parts of the world to take advantage of these technologies. The first to be considered is the broadband connection, which is a measure included by previous studies as relevant for I4.0 adoption [57]. In this context, Gerlitz et al. [58] confirm that public support and ownership are the main drivers for broadband infrastructure. Moreover, as presented by Maude [59], high-speed broadband networks can enhance municipality attractiveness for company creation and have a positive effect on the value creation within the tertiary sector. Connectivity through fast-speed broadband is becoming relevant during the pandemic as confirmed by the increasing usage of the internet in Italian regions, especially in the Northern area [60].

Then, looking at the human dimension of I4.0, tertiary education is expected to hold a crucial role in ensuring that curricula are in line with the I4.0 needs of companies [61]. The skills of the workforce will become the key to success, especially to accelerate the introduction of I4.0 in a sustainable direction in the post-COVID-19 phase. Smart and sustainable manufacturing requires synergies among functions and technologies, including organizational structures, skills, and employee empowerment [62]. Requirements for employees will be higher due to the use of new technologies. The integration of technologies and scientific innovation will require a thriving science and technology community [63,64]. This also means that smart companies should invest in training and reconsider their human resource models [65].

In reference to structural conditions, the first variable considered is the percentage of enterprises with a broadband connection. Then, looking at the human dimension of I4.0, we include the percentage of people with tertiary education and those employed in the Science and Technology sectors.

## 4. Empirical Evidence

### 4.1. Descriptive Statistics

As presented in Table 4, in 2016, 33.5% of firms had innovative activities on average and invested 7100 euro per worker in innovation. Looking at collaborative partnerships within innovative firms, only 12.8% of Italian firms established cooperation agreements with third parties on innovation in the last year under examination. The minimum values for innovation activities are found in Valle d'Aosta (22%), expenditure in Sardinia (2900 euro), and Molise for cooperation agreements (7%). Contrarily, the highest percentage of firms with innovation activities is in Emilia Romagna, where nearly half of the firms engage in product or process innovation; Basilicata holds the lead for expenditure in innovation with 12600 euro per worker. Regarding cooperation agreements, Marche holds the highest percentage of firms (18.7%). On the contrary, Molise records the lowest levels (7% in 2016; 30% in 2014). Looking into structural conditions that may favour I4.0, low performances are scored at the national level considering the percentage of employed in S&T (27.3%) and people with tertiary education (17.5%). Basilicata, which was leading in expenditure for innovation, recorded one of the lowest scores in terms of people with tertiary education against the leading position of Lazio. The highest number of employees in S&T is in Lombardy (33.4%) while the lowest is in Puglia and Calabria with around 19.5%. Instead, the percentage of firms having access to broadband connection has remained stable in the period under examination.



**Table 4.** Readiness at national level (ISTAT build data from samples of firms according to the methodology, [https://www.istat.it/it/files//2011/01/strategia\\_campionamento.pdf](https://www.istat.it/it/files//2011/01/strategia_campionamento.pdf) (accessed on 15 May 2020)).

Variable	Firms with Product or Process Innovation Activities (%)		Firms Expenditure for Innovation (1000 € for Employees)		Firms with Cooperation Agreements for Innovation (%)	
	2014	2016	2014	2016	2014	2016
Average	28.7	33.5	5.3	7.1	21.8	12.8
Median	28.4	33.1	5.4	7.1	12.1	20.6
Max	40.1	46	9.5	12.6	18.7	34.8
Min	17.4	22.2	2.4	2.9	7	11.5
Dev Standard	6.15	6.88	1.61	2.07	3.13	5.67
Coefficient of Variation (%)	21%	21%	30%	29%	24%	26%
Variable	Access Broadband connection (%)		Tertiary Education (%)		Employees in Science and Technology (%)	
Year	2014	2016	2014	2016	2014	2016
Average	94.4	94.1	16.78	17.5	26.7	27.3
Median	95.4	95.0	16.5	17	26.4	27.2
Max	99.31	98.16	23.3	23.1	32.3	33.4
Min	86.24	86.94	13.1	13.1	21.2	20.9
Dev Standard	3.06	3.30	2.40	2.54	3.32	3.45
Coefficient of Variation	3%	4%	14%	15%	12%	13%

#### 4.2. Regional Comparisons

Comparing the performance of each region in two years under examination, remarkable differences can be found in the regional positioning with respect to the national mean (Figure 2). It can be noticed that for innovation activities and innovation expenditure, Tuscany, Bolzano, and Trento record an innovation capability over the national mean, but in terms of innovation, expenditure are positioned below.

Moreover, for Tuscany, while there has been an increase in the firms' innovative activities, the region has registered a reduction in innovation expenditure of 29%. Even if most Northern regions are positioned over the mean for the innovative performance of their firms, there are some exceptions such as Valle d'Aosta in the North below the national mean and Basilicata in the South over the mean with the highest increase for innovation expenditure.

Instead, looking at cooperation agreements, most regions reported a decrease in firms with cooperation agreements on innovation. The most relevant decrease was recorded in Sardinia shifting, from 34.8% to 9.9%. The only increases in this variable are registered in Tuscany (+2.6%) and Valle d'Aosta (+1.4%), which are both over the national mean.

On the other hand, considering variables linked to structural conditions, most regions are over the mean for broadband access. Decreasing trends are recorded in broadband access in Marche (−9%) while a positive variation is found in Basilicata (+7%). Lastly, within the human resource dimension, Lazio continues to be a top performer in this variable.



Figure 2. Cont.

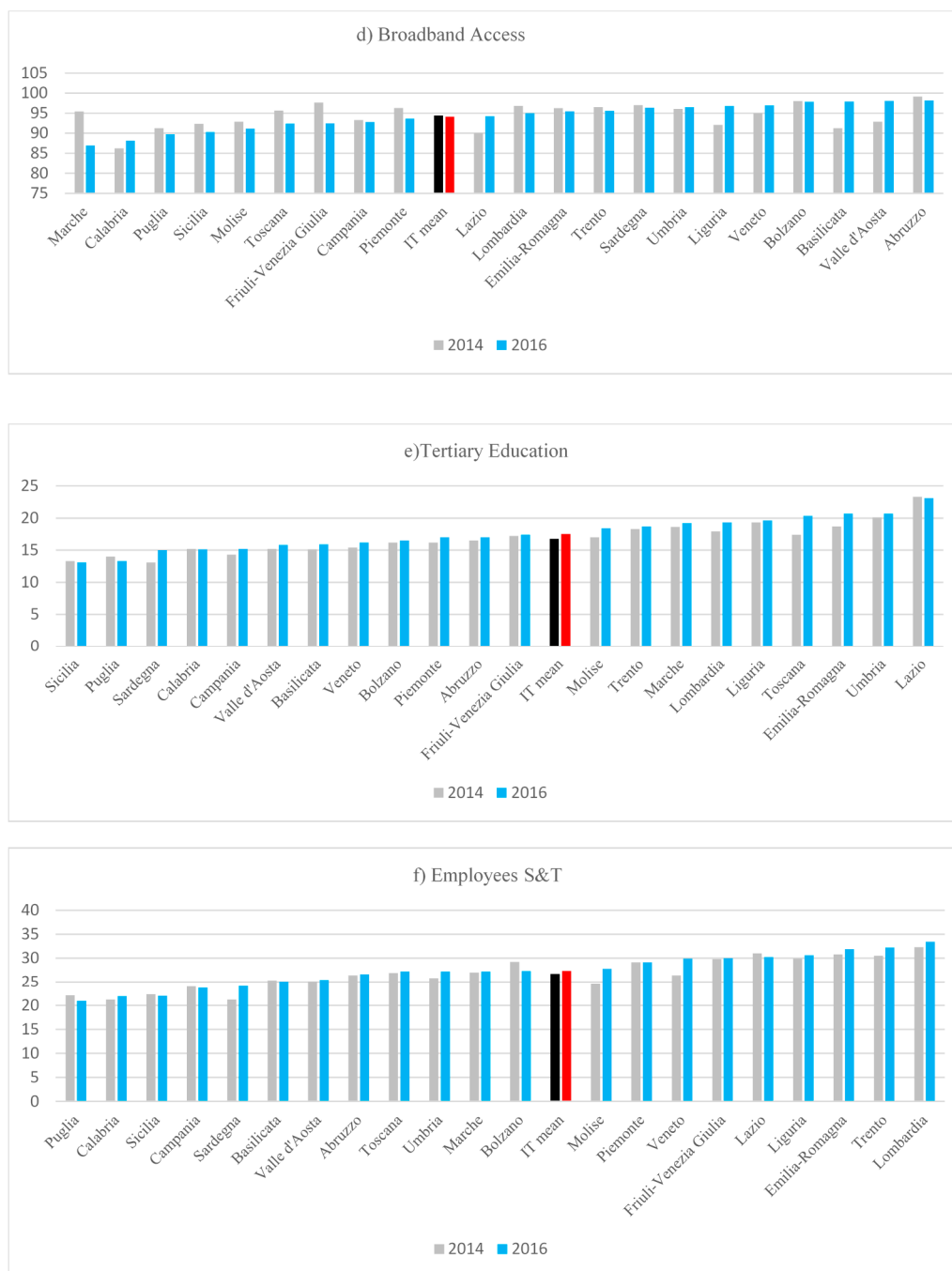


Figure 2. Regional comparisons.

#### 4.3. Cluster Analysis

Cluster analysis was performed on standardized values following the Ward methodology and Euclidean distance to group regions for 2016 (Figure 3). Three main groups can be identified, whose averages are reported in Table 5.

The first cluster includes the best performing regions, where the highest average values are recorded. In particular, the group including Lombardy, Emilia-Romagna, Veneto, Piemonte, and Friuli-Venezia Giulia corresponds to the one with the highest percentage of I4.0 firms, according to the MISE-MET investigation. The group at the bottom corresponds to the intermediate group, while the middle cluster with only three regions is the low-performing one. This cluster, including Calabria, Puglia, and Sicily, records the lowest

values on variables selected, except for the percentage of collaboration agreements among innovative firms. This group includes Sicily, where the highest percentage of traditional firms was found, and Calabria and Puglia, where I4.0 firms are still low but there is a relevant percentage of traditional firms that have I4.0 plans.

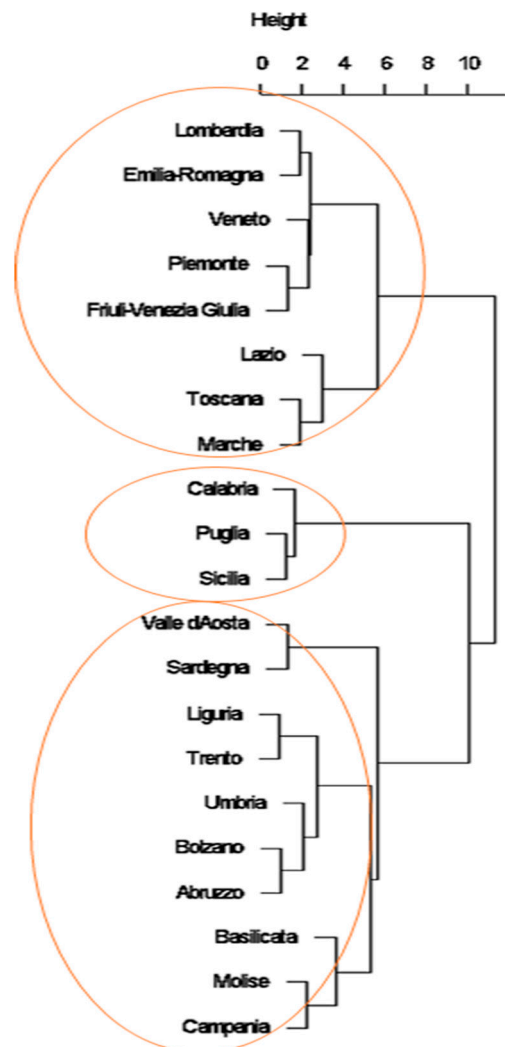


Figure 3. Dendrogram from cluster analysis 2016.

Table 5. Averages values of the three clusters.

	Cluster 1	Cluster 2	Cluster 3
Innovation product/ process	40.3	27.97	29.76
Innovation expenditure	8.2	6.00	6.58
Collaboration	14.5	15.67	10.57
Broadband	93.4	89.37	96.09
Tertiary Education	19.2	13.83	17.28
S&T employees	29.9	21.60	27

Therefore, the cluster analysis shows that Emilia Romagna, Lombardy, Friuli, Piedmont, and Veneto are the readiest regions in Italy and, considering the MET-MISE survey, also the most mature ones for I4.0 before COVID-19. This best performing group was iden-

tified already by De Marchi and Grandinetti [66] considering the innovative performance of regional firms in the period 2006–2008. The clusters confirm the regional disparities discussed by Rungi and Biancalani [67] in their analysis of firms' productivity considering data from the period 2004–2012.

At this point, it is interesting to understand whether these regions have further encouraged the adoption of enabling technologies or whether the pandemic drove regions that were less prepared to boost digitalization and contain the effects of the crisis.

## 5. Step 2—The Responsiveness of Italian Regions towards Industry 4.0: The Emerging Best Practices in Post-COVID

With the Budget Law 2020, before the pandemic, the Italian government already recognized the role of digital technologies, introducing tax breaks and subsidized financing tools like vouchers for innovation managers. Incentives for research and development (R&D) and training were added to the regional incentives present in many territories.

COVID-19 has put Italy under stress for the unexpected growth in the demand for digital services. The country showed different degrees of resilience. Areas with high-speed broadband and companies and public administrations that had invested in digitalization in the past have found themselves equipped to face the situation. On the contrary, areas without adequate coverage and businesses and administrations without a consolidated digital culture have been caught unprepared [68].

At the national level, new measures were included in the Industry 4.0 plan “*Transizione 4.0*” to support firms in the post-COVID-19 phases. The plan introduced financial measures that specifically address the development and experimentation of innovative and sustainable solutions.

In the following sections, the measures introduced by Italian regions for supporting the adoption of I4.0 among firms are reported in two periods: immediately after the outbreak, identified as Phase 1 (March to May 2020) and after the end of the lockdown in Phase 2 (May till September 2020).

### 5.1. The First Support Measures after the Outbreak

The first initiatives adopted by the regional administrations can be classified into three categories including those strictly linked to remote working, those I4.0 oriented, and those encouraging the development of an I4.0 ecosystem. Among these categories, the link between I4.0 and sustainable manufacturing is found in selected tenders and financial incentives that encourage the adoption of I4.0 technologies as a means to enable sustainable products and processes.

The first category includes support measures related to training and purchase of digital tools for enabling firms to shift to remote working. This is the case of Friuli-Venezia Giulia providing a training kit to facilitate the transition of the public administration (PA) and firms towards remote working. The package, which was already used by the PA as part of a previous regional project, aimed at increasing productivity and flexibility in the PA. Lombardy, instead, introduced digital vouchers for employers with at least three employees to purchase technological equipment or ask for consultancy for remote working. Lazio addressed these incentives even to firms with one employee. Furthermore, Puglia promoted “family-friendly” plans for SMEs to enhance the quality of life through remote working, allocating funds to facilitate the adoption of new organizational models. The expenses that can be eligible relate to consultancy, investments (equipment and software), and training. Basilicata included incentives for remote working in the firm's new development plans, refunding 70% of expenses. The financial resources, which are addressed to SMEs and large enterprises, cover investments in material and immaterial goods.

Looking into the second category aimed at supporting the widespread adoption of I4.0, best practices are found in Liguria, allocating resources for the purchase of technologies for the digitalization of micro and SMEs as non-repayable funds. Similarly, Lombardy together with the Chamber of Commerce introduced a tender to promote the development of I4.0

technologies for micro and SMEs. The tender includes tools to manage the emergency or that promote green-driven oriented systems.

Besides, the region Piedmont postponed the deadline of previous tenders favouring innovation in productive processes, only for micro and SMEs, with a focus on artisan firms. The tender integrates changes to production systems with respect to the new measures of social distancing and remote working.

With its "Cura Umbria," Umbria provided digital vouchers to micro and SMEs for investing in e-commerce, Business-to-Business (B2B) platforms, business intelligence, cybersecurity, cloud technologies, digital infrastructure, digital showrooms, and data management techniques.

In a complementary way, networking initiatives started to take place in line with the European guidelines. One of the main signals is represented by the Framework Agreement between regional DIHs and CCs of the 3rd of April 2020. The agreement recognizes the role of these actors in supporting the recovery phase through digital investments. Indeed, webinars were organized by regional DIHs, as in the case of Campania DIH that together with Cisco and Cisco Academy provided free training to organize working remotely. The DIH Ancona, Pesaro, and Urbino launched online training in collaboration with the regional University, focusing on digital transformation and human resource management. Similarly, in March, DIH Vicenza with Schneider Electric presented a webinar on I4.0 tools that can be used to overcome the challenges led by the pandemic.

### 5.2. The Second Analysis after the Lockdown

The second analysis considers the initiatives that Regions promoted after the lockdown (18 May 2020).

These support measures foster the adoption of I4.0 technologies exploiting their new role as described in Table 1. Financial support is mainly targeted to micro-enterprises and SMEs, which were the ones struggling the most in the adoption of I4.0 before the pandemic. Initiatives are found mainly in Northern regions that were identified in the cluster of the best performing.

Looking into new functions of I4.0, Liguria, Piedmont, and Lazio with their Chamber of Commerce introduced digital vouchers for purchasing technologies with 70% of repayable expenses. The technologies include solutions to automate the production and selling systems, favouring social distancing. Further, there are incentives for broadband connection and remote working. Similarly, Tuscany introduced non-repayable funds for micro, SMEs, artisan, and industrial manufacturing firms and those in tourist, commercial, cultural, and tertiary sectors. The measure considers investments for ensuring security and organizing work remotely for firms that have not fired employees. By considering specifically the tourist industry, the tender underlines that digital innovation can be a solution to overcome the main challenges that have impacted the sector after the pandemic.

Indeed, due to the restrictions in travelling, the pandemic has had a big impact on the organization of tourist trips while also highlighting the importance of digital marketing strategies [69]. Furthermore, the pandemic has underlined the role of sustainable tourism, described as an indicator measuring the ecological impact on the environment [70]

On the other hand, Marche introduced a tender to support micro-enterprises and SMEs in the process of reorganization due to COVID-19 including investments in I4.0 and new working models in different functions. The tender includes extra points if the firm has certificates proving the environmental and ethical sustainability of products and processes. Moreover, in the Southern part of the country, Campania Calabria, Basilicata, Puglia, Sicilia have allocated funds for micro-enterprises and SMEs for supporting the purchase of innovative machinery that enables production processes to become more sustainable.

Looking into structural conditions, Emilia-Romagna focused on guaranteeing high speed-connection to firms in mountain areas through the use of vouchers. Moreover,

the region adopted a long list of tenders for innovation and industrial research due to COVID-19 by postponing the deadlines and focusing on enhancing competences for I4.0.

The dimension of collaboration is explored in Veneto, Lombardy, and Valle d'Aosta. Veneto, through a tender, supports collaborative activities in R&D conducted in regional innovation networks and industrial districts. The tender considers not only innovations to manage the health emergency but also those favouring the transition towards new sustainable business and productive models. Precisely, the tender favours projects that include innovative technologies that foster environmental sustainability and sustainable production and consumption processes. In the meantime, Lombardy allocated resources as non-repayable expenses of 50% for micro and SMEs that will develop innovative solutions to face the healthcare emergency in a 4.0 perspective. Among these expenses, there is the possibility to ask for a consultancy from the I4.0 Ecosystem. Valle d'Aosta included vouchers for micro and SMEs for encouraging the usage of I4.0 technologies and remote working. Even in this case, it is possible to seek support from CC together with other supporting structures such as technopoles, scientific parks, innovative startups, and Fablabs.

## 6. Discussion: Accelerating I4.0 and Sustainable Trends through Collaborative Networks

The analysis of the Italian I4.0 plan and regional measures in the post-COVID phases shows that sustainability is becoming a criterion for accessing financial aids that address the "firms' readiness to invest in I4.0." Such trends are more evident in the second stage of analysis, after the lockdown and in the Northern part of the country that corresponds to the best performing group.

The new production models deriving from the introduction of I4.0 technologies are fostering smart and sustainable manufacturing as presented by Abubakr [33]. Furthermore, the support measures target micro-enterprises and SMEs, which are the ones facing more challenges in adopting both digital technologies and sustainable models [35].

In unlocking I4.0 potential in a sustainable direction, the collaboration between stakeholders as demonstrated by Kuik et al. [53] and Kornfeld and Kara [54] is becoming a key driver. In this regard, two best practices are identified in the Northern part of Italy. Veneto addressed financial resources to regional innovation ecosystems and districts favouring sustainable technologies, while Lombardy and Valle d'Aosta called on the support of the emerging I4.0 ecosystem, composed of DIHs and CCs. To this aim, the collaborative ecosystem of DIHs and CCs is expected to hold an active role in unlocking the potential of I4.0 for sustainable manufacturing. As reported in Phase 1, the network of DIHs has responsively provided tools to support firms, especially SMEs, in their digital transition by organizing training courses for firms.

## 7. Conclusions

This paper shows how Italian regions with different levels of I4.0 maturity and readiness are supporting the adoption of digital technologies in companies during the post-COVID-19 stages with a growing interest in sustainable manufacturing. The study analyses and discusses the current and potential role of I4.0 for companies, focusing on their impact in industrial and social fields.

In this study, we consider variables for assessing the readiness towards I4.0 at the NUTS 2 level in Italy, starting from the premise that I4.0 will contribute to the economic recovery in the COVID-19 crisis.

I4.0 measurement is difficult with no closed definition of the term and lacking data for measuring it, especially in terms of readiness of territories. Even if these circumstances introduce recognizable limitations, there is enough evidence to form a preliminary judgment on the readiness of countries to adopt I4.0. Using available data of 2014 and 2016, we consider proxy variables to measure the "firms' readiness to invest in I4.0" and the presence of "favourable structural conditions" considering their role in the recovery phase. The cluster shows a group of best performing regions in the North that corresponds to those recording the highest percentage of I4.0 firms, according to the MET-MISE investigation.

Furthermore, it should be noted that in the last year examined, the percentage of firms establishing cooperation agreements is the highest for the least performing cluster, located in the South, including Puglia, Sicily, and Calabria. This may be related to the intentions of Southern firms of increasing their level of readiness towards I4.0 by exploiting greater cooperation agreements, which will become fundamental in managing the pandemic from an I4.0 perspective.

The novelty of the study relies on comparing the readiness of Italian regions with respect to their responsiveness in supporting firms towards a digital and sustainable transition.

Analysing the support measures introduced by the regions after the outbreak (Phase 1), a focus is identified in aids promoting remote working, especially for micro-enterprises and SMEs both in the Northern and Southern areas of the country. Contrarily, after the end of the lockdown (Phase 2), the Northern regions placed more attention on the adoption of I4.0 technologies by exploiting collaborative networks. In the area of collaboration, financial incentives are foreseen for investing in I4.0 technologies that favour sustainable practices. This is the case of Veneto, Lombardy, and Valle d'Aosta.

## 8. Limitations and Future Avenues of Research

The analysis presented holds several limitations. The initial mapping does not consider the dimension of firms, which could impact their innovation potential. Furthermore, collaboration agreements do not consider whether these collaboration agreements were promoted by European projects or were related to firms' private initiatives. Nevertheless, the variables proposed for assessing the readiness towards I4.0 may still represent a starting point for defining effective instruments for regional policymakers to project and develop specific initiatives at the local level to overcome the main challenges of COVID-19 at the firms' level. Targeted investments in digital technologies will allow the expansion of professionals who will be able to work remotely. Considering the low values recorded in tertiary education and S&T employees, policies should increase training for I4.0 to build a local context of highly qualified people. The regional measures and initiatives that have been identified during the pandemic for promoting the use of digital technologies may increase the degree of openness of firms and the shift towards sustainable manufacturing.

The framework could provide regional policies with indications on how to support the innovation process of the production system and to define technological and production areas where to concentrate interventions and resources for the development of the regional territory. In terms of practical implications, managers should accelerate the digital transformation of their firms exploiting on the one hand the opportunity of additional financial funds and on the other the consultancy, training, and networking activities of the emerging I4.0 network. This means that the I4.0 ecosystem needs to map the needs of these companies to provide appropriate support, which should be tailored to the levels of readiness of firms and regions. Above all, the emerging I4.0 ecosystem can support the enabling role of I4.0 in favouring sustainable production and consumption processes.

The future line of research will be to determine the effectiveness of the measures incentivizing smart and sustainable manufacturing and whether the Italian regions that are most advanced in the adoption of the I4.0 paradigm have shown a greater resiliency during the crisis after the pandemic and wherever the less prepared have started to catch up. Moreover, it would be of interest for future studies to map and compare the supporting measures that have been introduced by different regions in Europe and compare their level of readiness and responsiveness.

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