The role of innovation ecosystems in Industry 4.0 adoption

Dominik T. Matt
Faculty of Science and Technology, Free University of Bozen-Bolzano, Bolzano, Italy and
Fraunhofer Italia Research s.c.a.r.l., Bolzano, Italy
Margherita Molinaro
Polytechnic Department of Engineering and Architecture, University of Udine, Udine, Italy
Guido Orzes
Faculty of Science and Technology, Free University of Bozen-Bolzano, Bolzano, Italy, and
Giulio Pedrini
Faculty of Science and Technology, Free University of Bozen-Bolzano, Bolzano, Italy and
Faculty of Economics and Law, Kore University of Enna, Enna, Italy

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Abstract

Purpose – The purpose of this paper is to identify actions and guidelines for enabling and fostering the Industry 4.0 adoption, as well as to understand the role of three ecosystem actors in these actions (i.e. companies, educational organizations and regional policy makers).

Design/methodology/approach – 52 semi-structured expert interviews in the Tyrol-Veneto cross-border macro-region were carried out and interpreted using the innovation ecosystem concept. In particular, drawing from this latter, six ecosystem building blocks were identified and used to analyze the interviews' content.

Findings – The findings allow not only to build a comprehensive framework for action to support Industry 4.0 adoption, but also to confirm the importance of exploring Industry 4.0 through the lens of the ecosystem concept. Indeed, the authors show that R&D activities should be complemented with interorganizational actions, such as training and networking, and that all ecosystem actors should be involved in the Industry 4.0 adoption.

Originality/value – This is among the few studies that adopt the innovation ecosystem perspective to explore best practices for Industry 4.0 adoption, thus overcoming the weakness of existing papers based on a firm-level perspective. It also complements previous ecosystem-based research on Industry 4.0 by exploring the technology adoption side, rather than the technology provision one, and by considering the adoption of a wide set of technologies.

Keywords Industry 4.0, Innovation ecosystem, Digital transformation

Paper type Research paper

1. Introduction

Industry 4.0 is one of the most disruptive phenomena examined in recent literature (Galati and Bigliardi, 2019). Addressed with many different labels such as "smart manufacturing" or

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"fourth industrial revolution," it is characterized by a growth of data and connectivity, an increasing need of analytical and business-intelligence capabilities and the development of human-machine interactions (Sung *et al.*, 2018).

An important message that several recent papers are expressing is that, despite its importance from a firm-level perspective, Industry 4.0 is a broad phenomenon that requires the involvement of a diversified set of actors, including firms, government, regulators, universities and research centers (de Vasconcelos Gomes *et al.*, 2018; Benitez *et al.*, 2020). A rapidly developing research stream is thus exploring Industry 4.0 through the lens of the innovation ecosystem concept. The rationale of this approach is that value cannot be created by a stand-alone firm and that knowledge and innovation are developed, thanks to the links and interactions among different institutions and organizations (Pino and Ortega, 2018; Reynolds and Uygun, 2018). The papers adopting this perspective focus on a wide variety of issues, such as describing an IoT-based business ecosystem (Rong *et al.*, 2015), understanding how an Industry 4.0 ecosystem evolves during time (Benitez *et al.*, 2020), exploring the characteristics of the ecosystems for the development of smart products (Kahle *et al.*, 2020) and analyzing the importance of collaborating with supply chain partners and R&D centers to improve the provision of Industry 4.0 solutions (Benitez *et al.*, 2021). Even if not explicitly mentioning the ecosystem concept, other contributions also highlight the importance of cooperating with external actors in the Industry 4.0 context. An example is Sung *et al.* (2018), who propose a theoretical roadmap for Industry 4.0 implementation including actions to be carried out by companies and government.

However, despite the number of contributions on the ecosystem-grounded Industry 4.0 literature, several research areas worth deepening still exist. In particular, as highlighted by Benitez *et al.* (2020), it might be interesting to explore this topic in industrially diversified ecosystems and in different regional ecosystems to understand the potential heterogeneity of Industry 4.0 profiles. Moreover, a specific focus on Industry 4.0 adopters, rather than on technology providers, is still missing.

Overall, a relevant contribution that could still be provided is the construction of a multi-dimensional framework including suggestions and best practices on how the adoption of Industry 4.0 can be properly supported by all potential actors in ecosystems characterized by the prevalence of technology adopters. Addressing this issue is important for many reasons. First, it could shed light on the main actions needed to support the adoption of Industry 4.0, both at individual and ecosystem level. Second, it could clarify how these actions should be carried out, stimulating a debate on the best practices that allow to maximize the actions effectiveness. Third, it could disentangle the role of different ecosystem actors, namely companies, universities and government, clarifying their complementarity for Industry 4.0 adoption. This information further allows to avoid potential mistakes, such as underestimating the importance of some actions and actors.

The research question addressed in our paper is thus the following:

RQ. How can ecosystem actors (companies, educational organizations and regional policy makers) support the adoption of Industry 4.0?

To answer this question, we carried out 52 expert interviews in the Tyrol-Veneto cross-border macro-region (straddling Italy and Austria), collecting information on actions and guidelines for Industry 4.0 adoption and on the role of specific categories of actors (i.e. companies, educational organizations and regional policy makers). To analyze and interpret the content of these interviews, we identified the main ecosystem building blocks, drawing from ecosystem literature, and used them to categorize the proposed actions. This activity allowed us not only to build a comprehensive framework with specific actions and sub-actions for Industry 4.0 adoption, but also to verify the suitability of ecosystem concept to address Industry 4.0 issues.

The paper is structured as follows. In Section 2, we provide an overview of the relevant literature and we theoretically develop the ecosystem building blocks that were used to interpret the expert interviews. Then, we describe our research methodology (Section 3) and provide a description of the research results (Section 4). Finally, we thoroughly discuss the findings (Section 5) and we conclude the paper with implications, limitations and future research directions (Section 6).

2. Theoretical background and research framework

This section is divided in two parts. First, we present the ecosystem-grounded literature on Industry 4.0, highlighting the research areas that could still be explored. Then, we create the research framework, including the main ecosystem building blocks used for the empirical analyses.

2.1 Industry 4.0: an innovation ecosystem perspective

As highlighted by recent literature reviews (e.g. Galati and Bigliardi, 2019; Chauhan and Singh, 2020; Wagire *et al.*, 2020), several research streams can be identified in Industry 4.0 literature. These streams can be distinguished according to the scope of applications of digital technologies (Meindl *et al.*, 2021), which can be either internal (i.e. Smart Manufacturing and Smart Working) or external (i.e. Smart Supply Chain and Smart Products and Services).

While many contributions on Industry 4.0 mainly adopt a firm-level perspective (e.g. Ghobakhloo, 2018; Matt *et al.*, 2018; Müller, 2019; Santos and Martinho, 2020), some scholars have started highlighting that Industry 4.0 is a wider phenomenon that goes beyond company's boundaries and requires the contribution of other actors, such as government and universities, which must adapt their work and mission (Reischauer, 2018; Horváth and Szabó, 2019). A useful lens to explore Industry 4.0 from such a perspective is the innovation ecosystem concept.

Drawing on the science of ecology, an innovation ecosystem can be defined as a set of institutions and organizations, including all the links and interactions among them, which supports knowledge creation and innovation development (Edquist, 2005; Pino and Ortega, 2018; Reynolds and Uygun, 2018). The core idea behind this concept is that value cannot be created by a stand-alone firm and that contributions from a wide set of diverse actors, including firms, universities, research centers, regulators and governmental organizations, are needed (de Vasconcelos Gomes *et al.*, 2018; Reynolds and Uygun, 2018).

One of the first contributions adopting the ecosystem concept to study Industry 4.0 and its related technologies is Rong *et al.* (2015), who identify six structural elements necessary to describe the evolution of an IoT-based business ecosystem and show that this latter is a complex network supported by different stakeholders. In the same vein, Kahle *et al.* (2020) propose a conceptual framework depicting the features that an innovation ecosystem must have to properly develop and offer smart products and identifying the complementary capabilities needed in this context.

A more theoretical approach is adopted by Reischauer (2018), who develops a conceptual paper highlighting that (1) Industry 4.0 is not a purely technological issue and (2) different actors co-support Industry 4.0 adoption. The important contribution of different stakeholders is also supported by Rocha *et al.* (2019), who study start-ups in the Brazilian context and conclude that the innovation ecosystem is a key enabler of digitalization.

Benitez *et al.* (2020) adopt instead a wider view of Industry 4.0 and investigate how innovation ecosystems co-create Industry 4.0 solutions, consolidate, and evolve, highlighting the changes in the ecosystem structure occurring during the different ecosystem lifecycle

stages. The basic idea of this work is that Industry 4.0 consists of an interconnected set of technologies and information systems that is difficult to be developed independently by single organizations, especially small and medium-sized enterprises.

A further contribution worth discussing is that of Benitez *et al.* (2021), who explore, through a quantitative research, the contribution of different actors (i.e. supplier, competitors, customers and R&D centers) for the improvement of Industry 4.0 provision.

Finally, even if not explicitly mentioning the ecosystem concept, Sung (2018) and Brunetti *et al.* (2020) propose a roadmap, including a wide set of actions going beyond company's responsibility, to support the digital transformation in specific geographical areas (i.e. Korea and Italy respectively).

Overall, as shown by the summary of previous studies above, the ecosystem-grounded Industry 4.0 research has a remarkable level of development, but there are still some unexplored aspects that could provide important theoretical and managerial contributions. For instance, the extant studies (e.g. Benitez *et al.*, 2020; Benitez *et al.*, 2021) consider only the technology providers, not the technology adopters of Industry 4.0, thus looking at the role of external actors from only one side of the coin. Moreover, they consider the way such actors can support the ecosystem governance and development, but there might be complementary capabilities that they can also provide. Finally, some previous studies do not consider the influence of regulatory aspects (Benitez *et al.*, 2021), while others have a very specific focus, such as the development of smart products (Kahle *et al.*, 2020), which makes the related results not easily extendable to the adoption of a wide set of Industry 4.0 technologies.

More in general, what could still be explored is how the adoption of Industry 4.0 can be properly supported by laws and regulations, mutual interactions, information sharing, and inter-organizational cooperation between the actors belonging to the same ecosystem namely companies, business associations, universities, research centers and governments (see Benitez *et al.*, 2020; Kahle *et al.*, 2020). Not by chance, some of the most prominent lines of future research proposed by Galati and Bigliardi (2019) in their review include the role of governments in supporting technological renewal within Industry 4.0 environments, the training programs needed for the new Industry 4.0 skills and the organizational structures required for Industry 4.0 exploitation. Such thematic areas, which may fall in the interface between Smart Supply Chain and Smart Working, are considered future research priorities also by the recent review of Meindl *et al.* (2021). The development of a comprehensive framework providing these types of suggestions in a context characterized by technology adopters would not only clarify the role of the different ecosystem actors, but also establish best practices to maximize the exploitation of Industry 4.0. This is exactly what we aim to provide with the present research.

2.2 Conceptual framework

In order to answer our RQ and propose a comprehensive framework with a set of actions that should be performed by the different ecosystem actors to foster Industry 4.0 adoption, we first need to identify a set of ecosystem characteristics to build the framework. Thus, starting from the six interrelated dimensions proposed Rong *et al.* (2015) to describe an IoT-based business ecosystem (i.e. Context, Configuration, Capability, Cooperation, Construct and Change), we develop six ecosystem's building blocks that may be useful to categorize the actions for fostering Industry 4.0 adoption (see Table 1). In particular, compared to the dimensions of Rong *et al.* (2015), we exclude those that are more linked to the description of the ecosystem (i.e. Context and Change) and we divide the others into specific sub-dimensions, better tailored to our purposes. As in Rong *et al.* (2015), our proposed building blocks include the supportive infrastructure of the ecosystem, the external relationships, the mechanisms of interactions between ecosystem actors, the governance systems and the development of

Building block	Description	Key references
Resources	Financial assets and physical infrastructures needed to support innovation development	Rabelo *et al.* (2015), Oh *et al.* (2016), Reynolds and Uygun (2018), Walrave *et al.* (2018), Granstrand and Holgersson (2020)
Public policies	Laws, rules and legal policies that regulate the ecosystem environment	Tödtling and Trippl (2005), Rabelo *et al.* (2015), Oh *et al.* (2016), Ritala and Almpanopoulou (2017), Reynolds and Uygun (2018), Walrave *et al.* (2018), Granstrand and Holgersson (2020)
Knowledge	Skills, knowledge and capabilities developed and shared inside the ecosystem	Tödtling and Trippl (2005), Ritala *et al.* (2013), Rabelo *et al.* (2015), Dedehayir *et al.* (2018), Pino and Ortega (2018), Granstrand and Holgersson (2020)
R&D activities	Research actions and initiatives that trigger innovation in the ecosystem	Dedehayir *et al.* (2018), Reynolds and Uygun (2018), Granstrand and Holgersson (2020)
Culture	Mind-set of both industry and society that supports innovation and problem-solving	Rabelo *et al.* (2015), Reynolds and Uygun (2018)
Interactions	Linkages between different actors, inside and outside the ecosystem, linked to the interdependencies among them	Tödtling and Trippl (2005), Rabelo *et al.* (2015), Oh *et al.* (2016), de Vasconcelos Gomes *et al.* (2018), Reynolds and Uygun (2018), Walrave *et al.* (2018), Granstrand and Holgersson (2020)

Table 1.
Conceptual framework

unique capabilities. Below, we provide a through description of these aspects, highlighting their linkages with the literature on innovation ecosystems.

One of the first elements that characterize an innovation ecosystem are the *resources*, which concern both infrastructures and financial assets. Indeed, the ecosystem actors need not only appropriate physical and technical conditions to trigger innovation (Rabelo *et al.*, 2015), but also a proper access to capital (Oh *et al.*, 2016).

A further need of the innovation ecosystem is the so-called protection (Walrave *et al.*, 2018) that can be provided in both financial (e.g. subsidies, tax reductions) and nonfinancial forms (e.g. policy support). The latter brings us directly to the second building block of an innovation ecosystem, i.e. the *public policies*, which include all the rules, laws, legal and task policies that regulate the environment where the ecosystem is located (Rabelo *et al.*, 2015). A supportive regulatory framework is fundamental to guarantee the success of innovation initiatives (Ritala and Almpanopoulou, 2017) and, according to Oh *et al.* (2016), this is exactly what distinguishes innovation from natural ecosystems.

The innovation process does not work without the enhancement of human capital (Tödtling and Trippl, 2005) and *Knowledge* is thus the third building block identified in this study. Knowledge creation and dissemination are fundamental not only to build an innovation ecosystem, as described by Dedehayir *et al.* (2018), but also to preserve it and create the conditions to harness future opportunities that may emerge (Ritala *et al.*, 2013).

The fourth building block concerns *R&D activities*, namely those innovation-based actions and initiatives that represent the core components of ecosystem definitions (see Granstrand and Holgersson, 2020). R&D initiatives are mostly undertaken by the private sector (Ritala and Almpanopoulou, 2017) and, according to Reynolds and Uygun (2018), they represent the most critical aspect, especially for SMEs.

However, R&D investments are not enough if the innovation ecosystem is not concurrently permeated by an appropriate *culture*. For the innovation process to be successful, it is necessary to promote an open and positive mental attitude towards future technological challenges (Brunetti *et al.*, 2020).

A final important building block is represented by the *interactions* among the actors. Interactions refer to all the internal connections and interdependencies that support the accomplishment of the ecosystem's value proposition (Walrave *et al.*, 2018) and the development of collaborations not only among firms, but also between firms and universities or research centers (Reynolds and Uygun, 2018). Besides internal collaboration, many authors also underline the importance of connecting the ecosystem with external actors (Rabelo *et al.*, 2015). Walrave *et al.* (2018) propose the concept of inter-local learning, a process of knowledge sharing across different ecosystems that allows to learn lessons from other contexts.

These six building blocks represent a valuable starting point to guide the analysis of the expert interviews, as described in the following sections.

3. Methodology

3.1 Research design

We adopted a qualitative, exploratory approach based on expert interviews to achieve the research purpose. We chose this methodology to address our research question because it is particularly effective when researchers are investigating a new or emerging field (Bogner *et al.*, 2009).

The present study is part of a wider EU project carried out in the Tyrol-Veneto macro-region, a cross-border area including the Tyrol region in Austria and the two regions of South Tyrol and Veneto in Italy.

A multi-stakeholder approach, based on the involvement of experts from private and state-owned companies, educational organizations and regional institutions, was adopted due to the importance of having a variety of viewpoints from all the actors playing a potential key role in the Industry 4.0 ecosystem. The Tyrol-Veneto macro-region was instead selected for being an area with a mature economic system, a prevalence of technology adopters and several high-quality universities and research centers. Overall, the macro-region presents several properties of a nascent Industry 4.0 ecosystem. First, it is a relatively homogeneous industrial system (Eurostat, 2020), with an increasing concentration of manufacturing firms (+7.1% between 2015 and 2017), the potential adopters of Industry 4.0. Second, the share of R&D personnel and researchers in the ecosystem is also growing (+23.8% between 2015 and 2017).

The list of participants was developed trying to guarantee appropriate heterogeneity of actors within the ecosystem, thus selecting: (1) private and state-owned companies with different size and technological stages, operating in both the manufacturing and service industry, as well as business associations representing the main sectors operating in the macro-region (manufacturing and logistics, hospitality) [1]; (2) different educational organizations (i.e. universities, research centers, high schools and employment agencies); (3) regional institutions (i.e. policy makers such as municipality and provinces, chambers of commerce, public agencies for business development). However, since companies are the main adopters of Industry 4.0 technologies, a higher number of interviews in this category was carried out.

Since the EU project had multiple purposes and explored different aspects of digitalization and Industry 4.0, for this paper we selected only a subset of the information collected, focusing on the actions proposed to support Industry 4.0 adoption. Therefore, some of the interviews, which overlooked this aspect, were excluded from the analysis. The resulting sample includes 52 expert interviews, distributed among the three categories of actors and the three regions as shown in Table 2. Other results based on the same interviews, but focused on different research questions and results, are presented in Brunetti *et al.* (2020) and Matt *et al.* (2019).

		Tyrol	South Tyrol	Veneto	Total
Companies	*N*	*9*	*11*	*11*	*31*
	Size	Medium and large	Medium and large	Medium and large	
	Type	Firm, business association	Firm, business association	Firm, business association	
	Sectors	Automotive, machinery equipment, metal products, logistics, ICT, consultancy	Automotive, electronic products, transport equipment, cement, road and rail transports, logistics, ICT, consultancy	Electric bikes and scooters, textile, iron and steel, clothing, finishing garment technologies, entertainment, ICT, consultancy	
	Respondents' role	CEO or vice-president, partner (or board member), IT/digital director, marketing manager, HR manager	CEO or vice-president, managing director, partner (or board member), IT/digital director, R&D/ innovation manager, technical director	CEO or vice-president, IT/digital director, marketing manager, R&D/ innovation manager, HR manager, technical director, transparency manager	
Educational organizations	*N*	*3*	*4*	*3*	*10*
	Size	Medium and large	Medium and large	Medium and large	
	Type	University, high school, employment agency	University, high school, employment agency	High school	
	Respondents' role	University professor, high school professor, employment agency director	University rector, university professor, high school principal, employment agency director	High school professor	
Regional institutions	*N*	*3*	*6*	*2*	*11*
	Size	Medium and large	Medium and large	Medium and large	
	Type	Chamber of commerce, public agency	Province, municipality, chamber of commerce, public agency	Municipality, public agency	
	Respondents' role	CEO or Director, development/ innovation director	CEO or Director, department director, head of IT department, development/ innovation director	Department director, development/ innovation director	
Total		*15*	*21*	*16*	*52*

Table 2.
Overview of selected interviewees

3.2 Data collection

Data were collected using face-to-face semi-structured interviews, based on a predefined research protocol, as suggested by Yin (2014). A pre-test was conducted to validate the protocol with three external researchers working in the field. The protocol (reported in Appendix 1) consisted of some general questions about the interviewee and his/her company/ institution and of three simple open-ended questions about the actions that should be

implemented to properly support Industry 4.0 adoption by three ecosystem actors: companies, educational organizations and regional institutions (policy makers in particular). We used these open-ended questions to guarantee flexibility and openness so that unexpected and novel topics could easily emerge (Kasabov, 2015). Furthermore, during the interviews, we allowed the interviewees to give the preferred direction to the conversation. As a consequence, not all the interviewees specified an action for all the three actors and some of them preferred to focus on the role of some actors, considered as the most important.

Table 2 provides an overview of the interviewed experts, all of whom have specific competences in the implementation of Industry 4.0 technologies, in managing companies and organizations deeply involved in Industry 4.0 adoption, or in designing the regional policies for Industry 4.0.

The interviews had a duration varying between one and two hours and were carried out between September 2018 and March 2019 in Italian or German language, depending on interviewee's preference.

All the interviews were recorded, transcribed by a researcher and translated in English by an expert. Some of them were, finally, back translated in their original language by the researchers to check the meaning invariance.

3.3 Data analysis

The coding and data analysis of the interviews was performed using a combination of deductive and inductive processes, which allowed to create a framework summarizing the actions needed to support Industry 4.0 adoption. Two research teams, each comprising two researchers, were created. Each team independently manually coded and analyzed the cases to ensure inter-coder reliability (Duriau *et al.*, 2007). The results of the coding process were then compared to ensure consistency and, in case of misalignments, the two teams discussed till a convergence was found. The data analysis process included two levels of coding, as described by Wholey *et al.* (2010). The first one allowed to associate each sentence transcribed from the interviews to one of the building blocks reported in Table 1. The second one allowed instead to inductively identify, for each building block, categories and sub-categories of actions to support Industry 4.0 adoption. Additional details are provided in the following paragraphs.

In the first level coding, also referred to as descriptive coding, text segments (i.e. sentences or short paragraphs) referring to actions proposed by the respondents were identified in each interview and they were coded according to the building blocks they were mainly related to. The six categories drawn from ecosystem literature and summarized in Table 1 (i.e. resources, public policies, knowledge, R&D activities, culture, interactions) were used for the coding purpose. For instance, when an interviewee referred to "collaboration" or "cooperation" initiatives, the relative text segment was coded with the *Interactions* label. This activity was based on a content analysis approach using the meaning rule: thus, each relevant text segment was labelled as referring to a specific category of the framework according to the interpretation given to its meaning, which derives from the literature (Bardin, 1977). This activity was carried out independently by the two teams, which then compared the results and discussed the few misalignments till a convergence was reached. At the end of this process, the two teams acknowledged that at least one text segment was associated to each building block of Table 1 and that no additional building block was needed to categorize the proposed actions. All the text that did not refer to any specific actions was excluded from further analysis.

In the second level coding, also referred to as pattern coding, patterns of issues within and across text were identified. In particular, each team independently reviewed the text segments coded within each building block and inductively grouped them according to common themes, if any. This activity, based on multiple reading of the raw data following a process often called *in vivo* coding (Thomas, 2006), aimed at identifying categories and sub-

categories of actions to better classify and analyze the results. After that, the two teams met again to compare the identified themes. The results were similar, and an alignment was found quickly. After a brainstorming among the four researchers, the 19 identified themes were finally translated into 8 actions and 19 more specific sub-actions. The label and description assigned to all the actions were jointly decided by all the authors.

Appendix 2 reports, for each action and sub-action, a set of relevant quotations from the interviews, showing of how the coding process was realized.

4. Results

The results of the analyses are categorized in Table 3, where we show, for each ecosystem building block, the actions and sub-actions proposed by the experts, as well as the actors considered in charge of their execution. We provide below a through description of these results.

Two categories of actions linked to the building block *resources* emerged from the interviews. The first is *Fund*, which indicates the need to provide appropriate incentives and financial resources to the ecosystem actors for Industry 4.0 adoption. These incentives should have two purposes. First, they should support R&D activities targeted at Industry 4.0 technologies and boost workforce training dealing with related contents. According to many interviewees, an important target of these policies should be the implementation of energy efficiency or sustainable production systems. About workforce training, instead, incentives should be devoted to all courses dealing with Industry 4.0 technologies, as stated by the director of a business association in South Tyrol:

> At national level, it is necessary to support training, introducing tax deductibility of training expenses (i.e. tax credit to facilitate the training of companies in Industry 4.0).

Second, the incentives should be aimed at contrasting the brain-drain and attracting skilled workers into the region, which is often viewed as not particularly appealing given its local dimension and the lack of international companies. Among the suggestions proposed by the interviewees in this regard, we can mention the promotion of talents, the creation of innovative start-ups, the development of collaborations with internationally recognized companies and the improvement of life quality in the region.

The second action emerged from the building block *resources* is *Develop proper* (ICT) *infrastructures*. Indeed, according to the respondents, the regional institutions should guarantee an adequate connectivity in all the areas of the region, as highlighted, among others, by a researcher from South Tyrol:

> The development of proper infrastructures is a precondition for exploiting the trends of Industry 4.0. The related technologies require huge computational power, connectivity and energy, such as 5G and full-fiber networks. [. . .] It would be advisable to accelerate the ICT infrastructure construction projects and extend the broadband to the whole territory more quickly.

Regulate is the third action mentioned by the experts. According to them, appropriate laws and policies are needed to create a proper environment for Industry 4.0 adoption. Regional institutions should work in two directions. First, they should reduce bureaucracy in the administrative processes, which are often burdensome and require huge efforts and complex legal skills to be managed. This problem concerns not only the procedures to access digitalization or R&D incentives, but also those to develop European or cross-border cooperation projects. The existing overregulation may indeed inhibit entrepreneurial activities and hinder the efforts of both companies and research centers, as highlighted, among others, by a manager from Veneto:

> We are increasingly moving towards over-regulation. [. . .]. We could be very smart, but we are conditioned by this culture that leads us to regulate everything. We would be great if we did not have to regulate so much.

Building blocks	Actions and sub-actions	Ecosystem actors in charge of the proposed sub-actions			Aggregate results
		Companies	Educational organizations	Regional institutions	Total
Resources	*Fund*	*3*	*0*	*14*	*17*
	• Provide incentives and tax relieves to support digitalization investments and company's training	0	0	10	10
	• Provide incentives to contrast the brain-drain and attract skilled workers	3	0	4	7
	Develop proper infrastructures	*0*	*0*	*8*	*8*
	• Invest in ICT infrastructures and extend them to rural and peripherical areas	0	0	8	8
Public policies	*Regulate*	*0*	*0*	*15*	*15*
	• Smooth administrative processes and tools to make digitalization technologies more accessible and collaborations easier	0	0	4	4
	• Smooth administrative processes to access governmental and European incentives more easily	0	0	6	6
	• Update existing legislation	0	0	5	5
Knowledge	*Train*	*13*	*10*	*0*	*23*
	• Build awareness of new technologies and relative risks	1	3	0	4
	• Provide appropriate training for qualified personnel	12	7	0	19
	Develop a proper educational system	*0*	*29*	*2*	*31*
	• Develop higher education programs for new jobs	0	11	0	11
	• Innovate the current training system by promoting work experience and students' mobility	0	10	0	10
	• Train qualified teaching staff	0	5	1	6
	• Invest in innovative learning tools/platforms	0	3	1	4

Table 3.
Actions emerged from expert interviews

(*continued*)

Building blocks	Actions and sub-actions	Ecosystem actors in charge of the proposed sub-actions: Companies	Educational organizations	Regional institutions	Aggregate results: Total
R&D activities	*Innovate*	*17*	*0*	*0*	*17*
	• Invest in new technologies and their integration	8	0	0	8
	• Adapt and re-define strategy, business vision and organizational structure	9	0	0	9
Culture	*Promote an innovation culture*	*10*	*0*	*12*	*22*
	• Develop organizational leadership and appropriate digitalization culture	10	0	2	12
	• Promote a digitalization culture in both society and politics	0	0	10	10
Interactions	*Cooperate*	*4*	*20*	*33*	*57*
	• Promote networking activities inside the region	4	20	13	37
	• Promote information exchange inside the region	0	0	3	3
	• Promote the creation of transregional and European partnerships	0	0	17	17
Total		*47*	*59*	*84*	*190*

Note(s): The numbers in the table indicate how many times each actor has been considered in charge of the proposed sub-actions; the last column provides an aggregate count

Table 3.

Second, regional institutions should adapt the existing legislation (laws and regulations) to the new Industry 4.0 environment, introducing, for instance, cybersecurity legislations that may boost companies and organizations to protect their data and systems. Furthermore, by acknowledging the potential of blockchain but also the difficulties to exploit it on a large scale, they could also develop some local pilot projects regulating its use for the provision of local public services (e.g. healthcare, insurance, certificates). This action would subsequently allow to identify the potential opportunities of blockchain at a broader level (e.g. national).

Two actions recommended by the interviewees are linked to *knowledge* creation and sharing in the ecosystem. First, the suggestion is to *Train* all the ecosystem actors, starting from an improvement of their awareness and acceptance of Industry 4.0 technologies and the associated risks for both privacy concerns and cyber issues (including cyberbullying). Furthermore, company's workforce should be trained at all hierarchical levels. Indeed, while the employees must be able to exploit all the potentialities offered by the new digitalization tools, the executives must acquire a good knowledge and understanding of Industry 4.0 phenomenon to avoid mistakes in their strategic decisions. In this regard, a manager of a Tyrolean company stated:

> Digitalization has to be understood in companies. First of all, through education, because many believe that they are already digitally knowledgeable through the use of technology. [. . .] Managers need to become mature in order to be able to classify technologies. [. . .] Only then strategic decisions can be made.

As highlighted by some other respondents, companies need not only vertical specialists of the various technologies, such as artificial intelligence or machine learning, but also people able to combine them and integrate their use with the internal IT system. Firm-provided training should thus be developed in this direction.

The responsibility of these actions is mainly attributed to the companies themselves even if for some respondents, educational organizations are also in charge of this task.

The second action associated with the building block *knowledge* is *Develop a proper educational system*. This action is particularly important for a remote/peripheral area such as the Tyrol-Veneto one. Attracting talents in this macro-region from abroad and keeping them for a long time is not an easy task: once they have exploited the work opportunity in the Tyrol-Veneto ecosystem, they might indeed prefer to continue their career elsewhere. Thus, it becomes fundamental to develop a proper local educational system that trains the new (and old) workforce and supports fresh graduates that decide to seek job within the macro-region. In particular, according to the experts, the educational organizations should introduce new degrees aimed at training and developing experts that are currently lacking in the labor market, making future graduates able to collect, store, manage and analyze huge amounts of data. Internet of things, big data and artificial intelligence are the technologies that, more than others, require such an upgrade of the education system, according to our respondents. A rector and a manager from South Tyrol suggested respectively "*degree courses in digitalization themes*" and "*training paths for data architects and data scientists*," while a manager from Tyrol also mentioned the need to strengthening degrees like "*math, which could handle AI and data analysis differently*." Besides degree courses, the educational organizations should also complement education with working experience and introduce e-learning in both schools and workplaces (e.g. for professional refresher courses). The creation of small factory labs for the technical high schools, with the inclusion of 3D printers, robots and simulators, is another example of how the students can be introduced to a manufacturing sector characterized by the adoption of different Industry 4.0 technologies. A further interesting aspect is that the teaching staff often does not have the right capabilities to properly train newly hired workers. A direct consequence is the need to train teachers not only on technical subjects, but also on the opportunities offered by digitalized teaching tools (e.g. e-learning platforms).

In terms of *R&D activities*, the experts highlighted that companies should *Innovate* their environment in two directions. First, they should invest in Industry 4.0 technologies and in R&D activities, as it emerged from an interview with a private company in South Tyrol:

> Companies need first of all to make intense Industry 4.0 investments. After that, they should start processes of rationalization and optimization, aimed at exploiting the technologies.

In particular, for what concerns digital technologies (i.e. big data, IoT), managers should invest not only in tools for the collection and storage of information, but also in systems able to use and analyze these data for different purposes, such as predictive maintenance or energy efficiency. Such data types, exchanged with the company's suppliers through appropriate IoT networks, may also be useful to improve the quality of products bought from the upstream network, as highlighted by a manager from Tyrol.

Second, companies should also update their strategy and organizational structure, reflecting on how Industry 4.0 is going to change their business vision and considering the possibility to introduce new roles in the organization, such as the "*innovation manager figure*." According to a manager from South Tyrol, a further relevant technological innovation would also be the possibility to equip all employees with a portable device for the on-time reporting of events, failures or anomalies.

As far as the building block *culture* is concerned, the ecosystem actors should *Promote an innovation culture*. Some respondents highlighted that companies have to develop an appropriate

mindset because digitalization is changing the way in which they do business and interact with their partners. In this regard, a manager of a private company located in Tyrol stated:

> Companies need an appropriate mind-set so that the employees do not only understand that without digitalization the company will not survive, but they become also ready to participate in the development of competencies.

Other experts focused instead on society and politics, claiming that this latter has to develop an innovation-oriented culture to better understand companies' needs for Industry 4.0 implementation and properly support them in their efforts.

Finally, the last category of actions emerged from the interviews is *Cooperate*. According to the respondents the various actors should create collaborative networks, both at local and international level. As regards local collaboration, the interviewees mentioned different types of cooperation, starting with that between companies and educational organizations. As highlighted by many interviewees, universities play a key role in supporting companies along their digitalization path: they can provide best practices, promote new management thinking and support the implementation of new technologies, especially in SMEs. According to the respondents, this cooperation can be developed by financing PhD or research scholarships within companies, promoting students' internships or developing strategic partnership for specific goals (e.g. cloud solutions development). Other proposed cooperation activities are those among firms and those among educational organizations. Firms should collaborate with each other to complement and recombine the different skills that they already have (e.g. hardware, software, data or AI competences). Moreover, they could share data and information about common products or machineries. This last aspect is widely discussed by a manager from South Tyrol:

> Companies using the same machineries, vehicles or systems could create a network to share and update information and knowledge. For instance, they may create a common platform to upload data on maintenance problems, unexpected failures, human mistakes and so on, and then cooperate to find optimal solutions and improvements that may be useful for everyone.

Educational organizations should instead coordinate with each other to improve the overall educational level, in both high schools and universities:

> Not only the exchange between university and business practice should be promoted, but also the exchange within the university – with other faculties, thus with physicists, with humanists, etc. This usually results in new insights.

As regards instead the international cooperation, it should aim at sharing data and information, acquiring new competences, identifying best practices and learning from them. "*International cooperation is always enriching, from both corporate and human points of view*," stated the president of a public company located in South Tyrol.

We summarize the results concerning actions and actors' role in Figure 1.

5. Discussion

This study provides several indications on how Industry 4.0 adoption can be properly addressed through the innovation ecosystem concept. Indeed, our results confirm the idea that Industry 4.0 is not a purely technological issue and, along with R&D and digitalization investments, it requires additional supporting interventions and a significant contribution from all the actors belonging to a certain ecosystem/environment (Sung, 2018). Besides supporting this view, our study offers an original and comprehensive framework indicating (1) the actions to be carried out to support Industry 4.0 adoption and (2) the role of the ecosystem actors. The following paragraphs discuss these two issues.

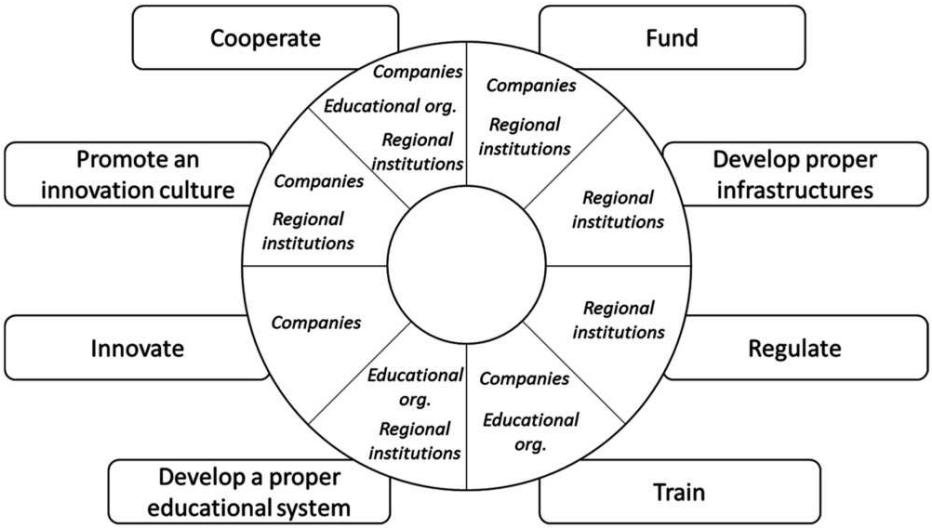

Figure 1.
Framework for action to support Industry 4.0 adoption in an innovation ecosystem environment

5.1 Actions to support Industry 4.0 adoption

All the actions suggested by the interviewees were categorized using the building blocks drawn from the literature on innovation ecosystems, with no need to add any additional category. This result confirms not only the building blocks' validity, but also the suitability of this theoretical lens to investigate Industry 4.0 adoption. In particular, thanks to the 52 interviews, 8 actions and 19 more precise sub-actions were identified, thus providing detailed indications on how Industry 4.0 adoption should be properly supported. Here we provide a thorough discussion of the identified actions and sub-actions, in light of the existing literature on Industry 4.0.

Some identified actions confirm the messages already provided by some scholars in the literature, such as the importance to *innovate* by adopting the new technologies and reviewing both strategy and organizational structure (Veile *et al.*, 2019; Cimini *et al.*, 2020); the *promotion of an innovation culture* (Jain and Ajmera, 2021); the development of *training* activities through knowledge management programs (Kahle *et al.*, 2020; Veile *et al.*, 2019); and the need to *develop proper* (ICT) *infrastructures* (Moktadir *et al.*, 2018).

Original contributions that complement existing literature can be derived in the other four actions.

In the *fund* action, the suggestion to provide incentives and tax relieves to support digitalization is in line with the view of several scholars who highlight the need to invest significant financial resources in Industry 4.0 technologies (e.g. Horváth and Szabò, 2019: Kahle *et al.*, 2020). However, this study also proposes to coordinate such investments with other financing schemes aimed at contrasting the brain-drain and attracting high-skilled workers into the region. Indeed, given the complex and advanced skills required for the implementation of new technologies, an innovative Industry 4.0 ecosystem should be able to attract skilled workers and avoid the risk that a substantial share of trained workforce leaves the region, making the educational efforts fruitless. This is an important aspect to take into consideration, especially for mountain/peripheral regions like the Tyrol-Veneto one.

A further contribution is provided in the *regulate* category. In this regard, our study does not limit the discussion to the need to update existing legislation to keep pace with advancements in technology, as illustrated by Moktadir *et al.* (2018) and Kahle *et al.* (2020). The interviewed experts also mention the importance of smoothing the administrative processes to simplify the access to incentives and facilitate digitalization initiatives, such as

collaborative projects supporting the creation of open supply chains. This bureaucratic aspect is particularly critical for SMEs, which are typically less structured, lack technological competences and have fewer financial resources to invest in digitalization technologies (Benitez *et al.*, 2020).

Develop a proper education system is a further action deserving a thorough discussion. Besides the issues already highlighted by scholars, such as the use of innovative approaches to train students (Salah *et al.*, 2019) and the need to change the educational system (Horváth and Szabó, 2019), original suggestions emerge from the interviews. The first is the need to train also the teaching staff, which is often not sufficiently prepared on the new technological trends. The second is related to the adoption of the learning-by-doing approach to support Industry 4.0, according to which the best way for students to acquire all the required knowledge is to get a more active role in their own learning and to directly participate to the implementation of those non-routinary tasks that will not be automated in the next years (Frey and Osborne, 2017). The creation of small factory labs in the high schools is a further exemplary way to prepare students to get accustomed with Industry 4.0 technologies.

Finally, the last contribution concerns the *cooperate* category. The importance given by the interviewees to various types of collaborations confirms what scholars already discuss in the literature (e.g. Kurdve *et al.*, 2020); however, a new clear distinction between cooperation at local and inter-regional level emerges. The role of local cooperation strengthens the idea that the concept of regional innovation ecosystems is applicable to Industry 4.0 adoption because such transition is eased by geographical proximity and lower bureaucratic and cultural barriers. Companies within the ecosystem should collaborate with each other to share data, skills and competences, while universities should support them in the adoption of new technologies. At the same time, the demand for inter-regional linkages suggests that access to non-local capabilities can become of increasing importance to pave the way to Industry 4.0, since the complexity of this technological transition increasingly requires external knowledge sourcing (Pino and Ortega, 2018). In addition, according to our results, such cooperation should be specifically targeted to develop appropriate skills and competences through complex training programs, rather than on stand-alone investments in Industry 4.0 technologies.

5.2 Role of the ecosystem actors for Industry 4.0 adoption

Table 3 shows how the proposed actions and sub-actions are distributed among the three ecosystem actors.

In some cases, there is a *one-to-one* relationship between actors and actions. For instance, *fund*, *regulate* and *develop proper infrastructures* are mainly associated with regional institutions, as it happens also in other Industry 4.0 studies (e.g. Sung, 2018; Benitez *et al.*, 2020). A less foreseeable result is instead linked to the *innovate* action, which is associated only with companies and not with educational organizations, which could play a role too in innovation development according to many scholars (e.g. Markkula and Kune, 2015). This result may be interpreted considering the goal of this research as well as the context where the interviews were carried out. Indeed, on the one hand, we focused only on actions to support the adoption of Industry 4.0 and not the development of new technologies. On the other hand, the Tyrol-Veneto macro-region itself acts mainly as "user" and not as "developer" of Industry 4.0 technologies. This may be the reason why the role of universities and research centers is mainly associated with the provision of training and does not include also investments in developing advanced technologies, contrary to what happens in highly innovative regions such as Massachusetts (Reynolds and Uygun, 2018).

The other four actions of the framework are associated with different actors, even if it is often possible to assign different responsibilities to them. For instance, a new digital culture

must be promoted among the workforce by companies and among politicians and society by regional institutions. As far as *training* is concerned, while companies are mainly in charge of developing new technical skills, the educational organizations should work to build awareness on the new technologies and their risks. Educational organizations should guarantee also the updating of all the other cognitive and horizontal skills, through the creation of new degree programs and through the adoption of innovative training tools and methodologies (*developing a proper educational system*). Finally, collaboration initiatives should be promoted mainly by regional institutions, especially for what concerns the inter-regional partnerships, even if also universities and research centers should be involved in such activity.

Some final considerations can be done by considering the variety of actions assigned to the three types of actors. Looking at Table 3, we noticed that regional institutions are characterized by the widest variety of proposed sub-actions. Like in previous technological revolutions (Mazzucato, 2013), these actors seem therefore to play a key role in actively creating new industrial landscapes and formulating a vision for the exploration of new products and services, going beyond a standard market-fixing intervention.

Overall, these observations confirm again the importance to explore Industry 4.0 through the lens of the ecosystem concept. The adoption of a linear supply chain approach instead of an ecosystem one would indeed overlook the role of regional institutions and educational organizations, failing to properly describe the Industry 4.0 adoption dynamics.

6. Conclusions

6.1 Synopsis

This study provides a set actions, grouped into a systemic and comprehensive framework, with different levels of detail, for Industry 4.0 adoption. It also provides indications on the role of three main ecosystem actors (companies, educational organizations and regional policy makers) in executing the identified actions. To achieve this result, we first explored the innovation ecosystem concept and identified its main building blocks. We then used these elements to analyze and classify the information collected through semi-structured interviews with 52 experts of the Tyrol-Veneto macro-region. The results allowed to develop a systemic framework for Industry 4.0 adoption and to confirm the importance of looking at Industry 4.0 through the ecosystem concept.

6.2 Contribution to scientific literature

The paper contributes to the scientific literature in at least four ways. First, we develop a complete framework for Industry 4.0 adoption, applying the innovation ecosystem concept. For each action included in the framework, we further provide concrete examples that suggest how the proposed actions can be carried out by various ecosystem actors. By putting the spotlight on the adoption of Industry 4.0 and by considering this latter a broad socio-technical paradigm including a set of interrelated technologies, we complement previous literature considering only the technology provision side (e.g. Benitez *et al.*, 2020; Benitez *et al.*, 2021) or focusing on specific applications of Industry 4.0 (e.g. Kahle *et al.*, 2020). Second, this research sheds light on the importance of developing a wide variety of actions to support Industry 4.0 adoption. Indeed, our results suggest that extensive R&D activities and strong investments in Industry 4.0 technologies are not a silver bullet, at least in an initial phase of Industry 4.0 adoption. The ecosystem actors should complement these activities with actions such as training, cooperation, cultural evolution, educational system development, regulation, funding and infrastructure development. Third, we explicitly consider the role of three ecosystem actors, namely companies, educational organizations and regional policy makers, in carrying out the eight actions of the framework. This allows not only to identify

the relationship between actions and actors but also to understand the overall actors' importance for Industry 4.0 adoption. Fourth, this study confirms the importance to look at Industry 4.0 phenomenon through the lens of innovation ecosystems at a macro-regional scale. Indeed, the importance attributed to all the ecosystem actors and the resulted need to carry out a wide variety of actions confirm the belief that Industry 4.0 is both a technological and a socioeconomic phenomenon.

6.3 Contribution to practice and policy

As regards the managerial contributions, different suggestions and guidelines for all the ecosystem actors can be provided. Regional institutions should be aware that they play a key role for Industry 4.0 adoption and they must be prepared to carry out a wide variety of actions, such as the provision of a wide set incentives; the development of proper ICT infrastructures; the updating of existing legislation along with the simplification of administrative processes; the promotion of a digitalization culture in both society and politics; and the promotion of networking activities at both local and international levels. Accordingly, the existing technology policies, which still target a limited set of areas of potential comparative advantage (Gianelle *et al.*, 2016), should broaden their scope and targeted actors. In this respect, they should look at the entire ecosystem, acknowledging for instance that the need of upgrading the quality of governance and promoting an innovation culture may become a pillar of future policies.

Educational organizations must instead focus their efforts on training adult teaching staff, developing new higher education programs, improving teaching methodologies, introducing new learning tools and building a widespread awareness on digitalization risks and opportunities. They should also collaborate with companies and other educational organizations to implement these actions.

Finally, companies should not dedicate all their efforts to innovation activities but develop appropriate plans also to promote a digitalization culture among employees, adapt their organizational structure and make both workforce and executives fully aware of the opportunities offered by Industry 4.0.

6.4 Limitations and future research

Despite the theoretical and managerial contributions previously discussed, the present research has some limitations that can be addressed by future research.

First, the expert interviews were executed in a single geographical context, the Tyrol-Veneto macro-region, which is characterized by many peculiarities that may have influenced the results. Further studies in similar and different contexts should be carried out to corroborate or complement the findings and to compare the needs of different areas.

Second, this research does not adopt an evolutionary perspective and does not distinguish the results between the different ecosystem life-cycle stages. It would be interesting to investigate, in future research studies, if and how the actions and the role of the different actors change during the ecosystem evolution.

Third, we considered only three innovation ecosystem actors. Future studies could extend our analysis also to other actor typologies, such as start-ups or business incubators, which can play a role in the Industry 4.0 ecosystem according to many authors (e.g. Rocha *et al.*, 2019).

Note

1. The inclusion of business associations among the interviewees is in line with Benitez *et al.* (2020) and justified by our aim to involve all the actors of the ecosystem.

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Appendix 1

The interview protocol

(1) Section 1: General information about the company and the interviewees

1.1. Interviewee: Name, current and previous position, seniority.

1.2. Company: Number of employees, industry (NACE code), main source of competitive advantage, customers types and location, company's structure, plants location, R&D investments.

(2) Section 2: Actions to support Industry 4.0

2.1. What are the main actions that have been done or should be done by companies to enhance the digitalization level and support Industry 4.0 adoption? Can you thoroughly explain how?

2.2. What are the main actions that have been done or should be done by educational organizations (i.e. universities, research centers, high schools) to enhance the digitalization level and support Industry 4.0 adoption? Can you thoroughly explain how?

2.3. What are the main actions that have been done or should be done by regional institutions, and in particular policy makers, to enhance the digitalization level and support Industry 4.0 adoption? Can you thoroughly explain how?

Appendix 2

Table A1. Quotations from the interviews for each action and sub-action included in the proposed framework

Action	Sub-action	Ecosystem actor in charge of the proposed sub-action	Exemplary quotations
Fund	Provide incentives and tax relieves to support digitalization investments and company's training	Regional institutions	• "At national level, it is necessary to support training, introducing tax deductibility of training expenses (i.e. tax credit to facilitate the training of companies in Industry 4.0)." (Business association, South Tyrol) • "Policy makers should generate better investments and research projects, and, in a second step, they should make available more financial resources. In this way, companies can reduce the risk in such projects." (Private company, Tyrol) • "The provision of an incentive system (e.g. digitalization vouchers, non-repayable loans) is fundamental. These tools are important because companies do not always have the necessary resources to carry out R&D. Therefore, incentives could make it possible for them to approach Industry 4.0 through consultancy companies or to invest in new technologies." (Business association, Veneto)
	Provide incentives to contrast the brain-drain and attract skilled workers	Companies	• "From the point of view of the Tyrolean companies, the low salary structure compared to Germany and also the non-wage labor costs are disadvantageous. In addition, we also find a linguistic problem here – in only a few SMEs English is the company language. That's what makes the integration of international talents only for large companies possible. There is almost nothing left for us to do but to get the enjoyment of leisure and the high quality of life to lure talents to the region. Measures could therefore be to promote challenging task areas in a company and the quality of life here in Tyrol." (Private company, Tyrol)
		Regional institutions	• "What is needed is to attract more people with IT skills to work here and transform South Tyrol in one of the richest and most modern regions in Europe" (Public agency for business development, South Tyrol)
Develop proper infrastructures	Invest in ICT infrastructures and extend them to rural and peripheral areas	Regional institutions	• "The development of proper infrastructures is a precondition for exploiting the trends of digitalization. The related technologies require huge computational power, connectivity and energy, such as 5g and full-fiber networks. [. . .] It would be advisable to accelerate the ICT infrastructure construction projects and extend the broadband to the whole territory more quickly." (Employment agency, South Tyrol) • "It is important to provide infrastructures so that regions are not depopulated." (Public agency for business development, Tyrol) • "The policy maker must accelerate the construction of broadband (ultra-fast Internet) making it accessible throughout the territory. This would also favor the spread of 'smart working'." (Business association, South Tyrol)

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Table A1.

Action	Sub-action	Ecosystem actor in charge of the proposed sub-action	Exemplary quotations
Regulate	Smooth administrative processes and tools to make digitalization technologies more accessible and collaborations easier	Regional institutions	• "There is a need for less bureaucracy regarding investments in R&D in a company." (Public agency for business development, Tyrol) • "We are increasingly moving towards over-regulation. [. . .]. We could be very smart, but we are conditioned by this culture that leads us to regulate everything. We would be great if we did not have to regulate so much. Therefore, deregulation is a fundamental action to be carried out." (State-owned company, Veneto)
	Smooth administrative processes to access governmental and European incentives more easily	Regional institutions	• "European Union projects could be better exploited and implemented if they were de-bureaucratized and simplified. Past projects have had good results, but we need to make this tool more accessible to schools and the education system." (University, South Tyrol) • "A cross-regional, transnational cooperation is today a major bureaucratic challenge (tax complexity), which is difficult. The requirements for companies (tax, legal, IP-attribution) are hindering our efforts a lot, especially in an international context. Legislative framework conditions lag behind and this inhibits entrepreneurial activities. These things must be changed." (Private company, Tyrol)
	Update existing legislation	Regional institutions	• "In general, a necessary action is a constant updating of the institutional structure and of the legislative system that make it possible to implement new digital tools in both private and public organizations. One example is a regulatory intervention for the use of Blockchain in the administrative procedure." (Consortium of municipalities, South Tyrol) • "Specific regulations need to be introduced. They would allow not only to improve the quality of life of people, but also create market opportunities and a higher quality of real estate, thus benefiting the economy and the environment." (Private company, Tyrol)

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Table A1.

Action	Sub-action	Ecosystem actor in charge of the proposed sub-action	Exemplary quotations
Train	Build awareness of new technologies and relative risks	Companies	• "A potential action concerns the promotion of information campaigns aimed at making employees aware of the risks associated with IT tools." (Municipality, South Tyrol)
		Educational organizations	• "The social side is important in Industry 4.0. There are many who do not trust artificial intelligence. This topic is also about acceptance and awareness building." (Public agency for business development, Tyrol)
	Provide appropriate training for qualified personnel	Companies	• "Above all, companies need to build competencies to tick and then implement technology suitability." (Private company, South Tyrol) • "Every single user should be informed about specific and concrete benefits it could have from the digitalization. Employees should know what digitalization could do for them. There is nothing worse than to introduce digitalization bureaucratically by force without increase in efficiency or process optimization. This only stigmatizes digitalization. On the other hand, confidence-building is needed." (Hospital, South Tyrol) • "Companies need high qualified personnel, able to introduce and implement the new technologies, like IoT and machine learning, but also to integrate them with the internal system. They must develop different competencies: not just data scientists, but also people able to develop a proper technology fit." (Private company, Tyrol) • "Companies must learn how to use and exploit all the potentialities offered by virtual communication. Let's take for example Skype. Nowadays, it can be used not only for videoconferences, but also for data sharing. We have to invest in the development of these knowledge and competencies." (Private company, Veneto)
		Educational organizations	• "Above all, universities and technical colleges should be innovation drivers and trainers for highly qualified personnel." (Private company, Tyrol)

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Table A1.

Action	Sub-action	Ecosystem actor in charge of the proposed sub-action	Exemplary quotations
Develop a proper educational system	Develop higher education programs for new jobs	Educational organizations	• "Educational organizations should develop training courses for new professions, such as data architects and data scientists." (Private company, South Tyrol) • "Universities must adapt the training offer to the needs of digitalization, introducing new degree courses on digital subjects." (University, South Tyrol) • "More university areas need to be implemented. This is easier in the technical arena, but other areas – such as math, which could handle AI and data analysis differently – are still very limited." (Private company, Tyrol)
	Innovate the current training system by promoting work experience and students' mobility	Educational organizations	• "Right now, education is focused on the accumulation of knowledge without the development of manual skills and experience. It follows that more practical and empirical parts have to be included in the education. The main reason for this is that by experimenting during the early years of school a person learns many things that will help him or her avoid mistakes in the future, mostly at work." (Chamber of commerce, South Tyrol) • "The alternation between school and work is fundamental. We hope for more interaction between those who educate, are educated and the world of work." (Business association, Veneto)
	Train qualified teaching staff	Educational organizations	• "Schools must inform and train teachers of the opportunities offered by distance learning and provide them with support in using the available platforms." (University, South Tyrol) • "My educational life has shown me that unfortunately the most conservative part was often the one that had to educate me to change. And it is not easy. It is difficult to learn innovation from a person who is not innovative. This obstacle must be overcome." (State-owned company, Veneto)
		Regional institutions	• "Policy makers should provide more investments in teacher training, making it effectively mandatory. Each teacher at the beginning of the year should outline a personal training plan and then report it at the end. This would result into a more widespread training." (High school, Veneto)
	Invest in innovative learning tools/platforms	Educational organizations	• "If a student is at home, he/she should have the opportunity to follow lessons and be updated remotely. This is an important field to invest." (High school, Veneto) • "An interesting activity would be the creation of a factory lab to help (high school) students approaching a real digital working environment. This is a project that we are willing to implement in the next future. We would like to buy 3d printing machines, simulators and robots to reproduce such environment." (High school, Veneto)
		Regional institutions	• "The policy maker should define new and clear guidelines for publishers in terms of innovative learning tools and encourage their use." (University, South Tyrol)

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Action	Sub-action	Ecosystem actor in charge of the proposed sub-action	Exemplary quotations
Innovate	Invest in new technologies and their integration	Companies	• "Companies need first of all to make intense digitalization investments. After that, they should start processes of rationalization and optimization, aimed at exploiting the technologies." (Private company, South Tyrol) • "There are investments to be made regarding digitization. Companies should try to anticipate the times and not to follow current trends." (Private company, Tyrol) • "Companies should fully exploit the digitalization opportunities. It is not enough to invest in cloud and IoT solutions to collect and store extensive data, if there is no tool to analyze and understand such data. Let's think to the data on maintenance and repair work. Companies need to invest in intelligent systems to fully exploit these data (e.g. for early detection of defects), instead of using them just to make reports." (Private company, Tyrol)
	Adapt and re-define strategy, business vision and organizational structure	Companies	• "The development of a big picture plays an important role. That is, questioning the purpose of the company: why do we want to be there in three years and what do we want to achieve with it? This requires the courage to re-think processes, to let rid of old processes. Companies need to rethink their roles, including in the organizational structure – such as at board level and redefine all bureaucratic hurdles." (Private company, Tyrol) • "Companies have to introduce new roles in the organization. It would be useful to encourage the introduction of an innovation manager role, a figure with a strong mandate from above, to start on a digital transformation path." (Business association, Veneto)
Promote an innovation culture	Develop organizational leadership and appropriate digitalization culture	Companies	• "Companies need a cultural change in the company and, in particular: openness to enter into partnerships, agility to implement new methods, strategic partnerships." (Private company, Tyrol) • "Companies have the opportunity to develop new business models. However, this requires a new attitude and mindset." (Private company, Tyrol) • "Certainly, it is important to move everything in the Cloud. In this sense, our culture must change." (Municipality, Veneto)
	Promote a digitalization culture in both society and politics	Regional institutions	• "Policy makers can contribute to the system by bringing young people closer to technical and technological subjects." (Private company, South Tyrol) • "In politics, the necessary skills are often lacking to understand the effects of digitalization. We have some important areas in the political landscape that cannot boast of know-how – they bring old examples such as Airbnb and Uber. I think a stronger understanding of digitalization is necessary." (Private company, Tyrol)

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Table A1.

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Action	Sub-action	Ecosystem actor in charge of the proposed sub-action	Exemplary quotations
Cooperate	Promote networking activities inside the region	Companies	• "The company alone cannot do research and development. This is why it needs to get closer to the University. The difficulty of the company is to invest in the right directions, without losing the few available resources. The University could be the perfect solution." (State-owned company, Veneto) • "Different companies have different competences and, for this reason, they have to cooperate more. Especially when it gets digital, they need a service competence, they need a hardware competence, a software competence, a data competence, an AI competence, a business model competence. They can be shared through strategic partnerships." (University, Tyrol)
		Educational organizations	• "Research centers and academic institutions should collaborate with the industry. There is a contradiction here: basic research and what industry needs, the gap is sometimes large." (Private company, South Tyrol) • "There should be a promotion of collaboration and exchange activities between high schools, research centers and universities, for instance in the field of mechatronics." (High school, Veneto)
		Regional institutions	• "There must be greater contact between companies and regional/national governments, especially the discussion on certain issues." (Private company, Tyrol)
	Promote information exchange inside the region	Regional institutions	• "Companies using the same machineries, vehicles or systems could create a network to share and update information and knowledge. For instance, they may create a common platform to upload data on maintenance problems, unexpected failures, human mistakes and so on, and then cooperate to find optimal solutions and improvements that may be useful for everyone." (State-owned company, South Tyrol)
	Promote the creation of transregional and European partnerships	Regional institutions	• "Future trans-national collaborations could be fruitful to become aware of best-practices and to share information, in particular on issues regulated at European level. [. . .] We need a control room with political and administrative power aimed at fostering transversal collaborations." (Consortium of municipalities, South Tyrol) • "Too strong clustering of similar competences across regions should be avoided. Transregional cooperation is the only chance to cover an important role in the long-term." (Public agency for business development, Tyrol)

About the authors

Dominik T. Matt holds the Chair for Production Systems and Technologies and heads the research department "Industrial Engineering and Automation (IEA)" at the Faculty of Science and Technology at the Free University of Bozen-Bolzano. Moreover, Prof. Matt is the Director of the Research Center Fraunhofer Italia in Bolzano. He has authored more than 200 scientific and technical papers in journals and conference proceedings and is member of numerous national and international scientific organizations and committees (e.g.: AITeM–Associazione Italiana di Tecnologia Meccanica | WGAB–Academic Society for Work and Industrial Organization | EVI–European Virtual Institute on Innovation in Industrial Supply Chains and Logistic Networks).

Margherita Molinaro is Research Fellow at the University of Udine (Italy). She graduated in Management Engineering and holds a PhD in Industrial and Information Engineering from the University of Udine (Italy). Her research interests include the areas of Industry 4.0, Supply Chain Integration, Sales and Operations Planning and Inventory Management.

Guido Orzes is Associate Professor in Management Engineering at the Free University of Bozen-Bolzano (Italy). He was also Honorary Research Fellow at the University of Exeter Business School (UK) and visiting scholar at the Worcester Polytechnic Institute (USA). His research focuses on international sourcing and manufacturing and their social and environmental implications. On these topics, has published more than 100 scientific works in leading operations management and international business journals (e.g. *International Journal of Operations and Production Management*, *International Journal of Production Economics*, *International Business Review* and *Journal of Purchasing and Supply Management*) as well as in conference proceedings and books. Prof. Orzes is involved in various EU-funded research projects on global operations management and Industry 4.0, including SME 4.0 – Industry 4.0 for SME (Marie Skłodowska-Curie RISE), European Monitor on Reshoring (funded by the EU agency Eurofound) and A21Digital Tyrol Veneto (Interreg V-A Italia-Austria). He is also Associate Editor of the Journal of Purchasing and Supply Management and member of the board of the European division of the Decision Science Institute. Guido Orzes is the corresponding author and can be contacted at: guido.orzes@unibz.it

Giulio Pedrini is currently Assistant Professor of Economic Policy at the Kore University of Enna. He holds a Degree in Economics, a Master's of Science in Law and Economics, and a PhD in Law and Economics. He was Visiting Research Fellow at the Institute for Employment Research (IER)-University of Warwick, and at the Universitè Libre de Bruxelles. His primary research areas are economics of regional development and economics of education and training.