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Articles

Actions fostering the adoption of Industry 4.0 technologies in manufacturing companies in European regions

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Abstract:

Industry 4.0, a concept comprising a range of promising innovations enabled by the recent advancements in digital technologies, has become a priority of industrial policy in many European countries and regions. In this paper, we present actions undertaken by regional organisations (including the so-called Digital Innovation Hubs), fostering the adoption of Industry 4.0 technologies in manufacturing companies. Using examples from Germany, Italy and Poland, we show actions that enable the creation of general conditions for such implementations and help companies develop an individual strategy for adopting Industry 4.0 innovations.

Keywords: Industry 4.0; support; actions; regions; Digital Innovation Hubs.

JEL classification: L6; O31; O33; O38.

Acciones de fomento de la adopción de tecnologías Industria 4.0 en empresas manufactureras de regiones europeas

Resumen:

La Industria 4.0, un concepto que comprende una serie de prometedoras innovaciones posibilitadas por los recientes avances en las tecnologías digitales, se ha convertido en una prioridad de la política industrial de muchos países y regiones europeos. En este documento presentamos las acciones emprendidas por organizaciones regionales (incluidos los denominados Centros de Innovación Digital) para fomentar la adopción de las tecnologías de la Industria 4.0 en las empresas manufactureras. Utilizando ejemplos de Alemania, Italia y Polonia, mostramos acciones que permiten crear condiciones generales para tales implementaciones a nivel regional, pero también ayudan a las empresas individuales a crear una estrategia individual para la adopción de las innovaciones de la Industria 4.0.

Palabras clave: Industria 4.0; soporte; acciones; regiones; Digital Innovation Hubs.

Clasificación JEL: L6; O31; O33; O38.

1. Introduction

Industry 4.0 (I4.0), a concept comprising a range of innovations enabled by the recent advancements in digital technologies, is believed to create a range of opportunities for the manufacturing sector all over the World (Schwab 2016; Hervas-Oliver, Di Maria, Bettiol 2021a). With many possible positive outcomes

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outcomes for the structure of firms, regional economic development or job markets, in recent years, scholars and scholars and policymakers started debating the necessary actions to be undertaken at various administrative levels to foster the implementation of I4.0 technologies (De Propris, Bailey 2020a).

Given the recent introduction of these technologies, it is still little known what elements at various territorial levels can represent better conditions for their implementation in manufacturing firms. Not surprisingly, the early adopters of I4.0 innovations differ between countries and regions and sectors and firms depending on their size (Capello, Lenzi 2021; OECD 2021). In the European Union alone, it is estimated that 58% of large enterprises are highly digitised, but only 20% of Small and Medium Enterprises (SMEs); 56% of computing companies and just 8% of metal product companies (EC 2021a). Therefore, policy instruments and special funding schemes at the supranational, country and regional levels have been introduced (CoR 2021) to reduce disparities in digitalisation and help SMEs, in particular, to discover and invest in I4.0 solutions that best fit their needs. Some of the most important, Europe-wide initiatives implemented were the Digital Innovation Hubs (DIH) – units offering consultancy and support in making I4.0 investment decisions and contributing to the digital transformation of regional economies (Rissola, Sörvik 2018; Hervas-Oliver et al. 2021b). Although having similar goals, regional organisations operate in different socio-economic conditions, and as a consequence – must face different challenges.

Therefore, the paper's aims are 1) to analyse framework conditions for the implementation of Industry 4.0 in the manufacturing sector in the diverse European regions and 2) to investigate actions undertaken by regional organisations and Digital Innovation Hubs to foster the adoption of Industry 4.0 technologies in manufacturing companies – to overcome their implementation barriers.

For the analysis, we selected three areas for case studies: Baden-Württemberg (south-western Germany, hereafter in this paper "G"), Veneto and Friuli Venezia Giulia (North-Eastern Italy, "I"), and Wielkopolska (western Poland, "P"). Selected regions are characterised by strong manufacturing sectors in terms of gross value added and their share in overall regional employment (both exceeding average values for the European Union), but at the same time differences in the GDP and innovativeness level (which may lead to different actions undertaken to facilitate I4.0 implementation and varying prospects for this type of technology). To address the research aims, we analysed available statistics and composite indicators and conducted in-depth individual interviews with representatives of regional organisations and Digital Innovation Hubs.

The paper's novelty lies in the comparative investigation of regional approaches toward I4.0. As an international study, it is based on the original data obtained in regions located in three countries during the first author's research visits and written by an international team of researchers. After the introduction, we explain the idea of I4.0, ways of measuring regional preparedness for implementation of I4.0 technologies in manufacturing and what role DIHs can play in this process. It is followed by an empirical part consisting of the chapter devoted to analysing conditions for I4.0 development and two sections on the actions undertaken to implement the I4.0 solutions (in regions in general and by outstanding DIHs). In the end, we present conclusions and limitations, indicating possible further research.

2. Industry 4.0 as a policy priority

Industry 4.0 describes the process of increasing digitalisation and automation of manufacturing along the value chain (Lasi et al. 2014; Capello, Lenzi 2021). Its characteristic features include integrating various information and communication, network technologies in the production process, and utilising digital innovations and the Internet functionality in all elements of the business models, allowing higher involvement of suppliers, customers, and business partners (Liao et al. 2017). A systematic literature review by Culot et al. (2020) showed that the understanding of I4.0 in science and business contains a range of physical-digital interface product and process technologies (based on hardware applications) and also network and data-processing technologies (software applications).

Due to its high potential, I4.0 and, more broadly, digitalisation has recently become essential priorities of innovation policy in Europe. First impulses came from the national governments (starting from the German strategy Industrie 4.0 – Kagermann et al. 2013) and various actions at the European

Union level, aiming at stimulating, accelerating and monitoring Industry 4.0 (Dosso 2020). Also, in the next ten years, digitalisation and I4.0 will remain one of the most significant policy priorities at the European Union level. Under "the Digital Decade" framework, supporting initiatives will focus on digital infrastructures, skills and digitalisation of public services and businesses (DIGITAL 2021; EC 2021a).

While European and national strategic policies clearly indicate that the I4.0 is a primary issue, the regions seem the most appropriate territorial level to undertake actions fostering the implementation of I4.0 technologies. At the regional level, it is possible to discover or shape a regional innovation system and indicate organisations that can be made responsible for specific actions (Asheim, Coenen 2005), including those creating conditions for implementing innovations. The regions succeeded in devising governance structures to foster learning in the knowledge-based economy, utilising four mechanisms based on physical and cognitive proximity among actors: knowledge spill-overs, spin-offs, intra-regional labour mobility and networks (Cooke et al. 1997). At the regional level, it is possible to program and conduct innovation policy adjusted to the local conditions, needs and institutional infrastructure (Tödtling, Trippl 2005).

First studies on the regional dimension of I4.0 show that it creates a development potential for all types of regions (even given differences in defining the I4.0 scope – De Propris, Bailey 2020b; Abonyi et al. 2020; Capello, Lenzi 2021). On the one hand, the production of I4.0 technologies counted by patents and the largest share of their first applications in Europe has concentrated, so far, in the most innovative and economically strong regions (Castelo-Branco et al. 2019; Balland, Boschma 2021). Moreover, I4.0 technologies, allowing automation of processes and higher production efficiency, could encourage firms from high-income and innovative countries to re-shore activities that were previously offshored (Cosimato, Vona 2021). Lagging regions may perceive this as a threat considering their often-weak innovation systems. However, on the other hand, I4.0 creates encouraging perspectives to maintain or raise competitiveness through fast technological upgrading (Szalavetz 2019). The specificity of many I4.0 innovations, especially software-related ones, lies in the possibly rapid implementation, which may be treated as a chance for firms in less-developed regions to raise production efficiency, increase production and sales – also in the international markets (Barzotto et al. 2019; Capello, Lenzi 2021).

3. CAPTURING TERRITORIAL PREPAREDNESS

Although Industry 4.0 is a promising concept for all territories, countries and regions may have different conditions for implementing I4.0 innovations in companies. In the international and interregional comparisons, one of the valuable tools to assess such characteristics is the European Innovation Scoreboard and its regional counterpart – Regional Innovation Scoreboard. It is one of the well-known measures to investigate innovation drivers and performance in territorial innovation systems (Zabala-Iturriagagoitia et al. 2007). The measurement framework includes 32 (or 27 at the regional level) indicators divided into four groups: 1. Framework conditions (human resources, attractive research systems, innovation-friendly environment), 2. Investment (finance and support, firm investments, use of information technologies), 3. Innovation activities (innovators among SMEs, linkages, intellectual assets), and 4. Impacts (employment sales, sales impact and environmental sustainability) (EC 2021b; Regional Innovation Scoreboard 2021).

Two other indicators explicitly used to analyse territorial differences in digitalisation – as a precondition or manifestation of implementation of I4.0 technologies in manufacturing – are: the DESI Index (at the national level) and the Digital Preparedness in Regions – the DPR (at the regional level).

The Digital Economy and Society Index (DESI) is a composite index developed by the European Commission to monitor the digital performance of European countries. The DESI overall index is calculated as the weighted average of the five main dimensions: 1. Connectivity (25%), 2. Human Capital (25%), 3. Use of the Internet (15%), 4. Integration of Digital Technology (20%) and 5. Digital Public Services (15%). Dimension no. 4 concerns manufacturing firms and is calculated as the weighted average of the two sub-dimensions: business digitisation, 60% and e-commerce, 40% (EC 2021c).

Comparing current digitalisation at the regional level has not been easy due to the lack of data (so far, the DESI index has no equivalent at the regional level, CoR 2021). Firm-specific data on obtaining

and using particular digital technologies in regions are usually collected through surveys, albeit only by a few regions (for example, the Digital Maturity Survey for Wales 2020 by Henderson et al. 2020). However, in 2021, a framework commissioned by the European Committee of the Regions was created to measure and compare the digital preparedness of regions (DPR)[1]. DPR measures conditions necessary for the regional digitalisation – shows factors that are drivers for I4.0 investments. Currently available indicators for all EU regions that can be used for measuring DPR by component groups include[2]: a) human capital (employment in information and communication and people who graduated and are employed in science and technology), b) business environment (presence of Digital Innovation Hubs, number of ICT companies, number of unicorns), c) public and private investment (money spent in purchasing digital goods and services through public procurement, intramural R&D expenditure by source of funds), d) digital infrastructure (fast broadband coverage and broadband access) and e) digital economy and services (GVA at basic prices in the ICT sector)[3] (CoR 2021).

Apart from the regional conditions that may foster or impede the implementation of I4.0 technologies in companies, the process also has certain common barriers at the firm level. Among the most important, both in developed and developing economies, are lack of a digital strategy alongside resource scarcity (Raj et al. 2020). Cugno et al. (2021) indicate four groups of barriers hampering the introduction of I4.0 technologies: knowledge (insufficient know-how within companies, few skills, little information on public facilities to support investments in I4.0), financing (insufficient financial resources within the firm, scarcity of external financing), culture (inadequate information on the potential offered by I4.0 technologies, the perception that investment in I4.0 is not required, organisational resistance) and system (legal uncertainties, insufficient economic infrastructure). Therefore, special actions undertaken by regional organisations are needed to create conditions for implementing Industry 4.0 technologies and help companies in this process.

4. Digital Innovation Hubs as a tool to disseminate Industry 4.0 technologies in European regions

One of the most important Europe-wide initiatives facilitating the popularisation of Industry 4.0 is Digital Innovation Hubs (DIHs). They were first introduced in 2016 as one of the priority policy initiatives of the EU Strategy Digitising European Industry. The program aimed at broad digitalisation of European regions in the public and private sector (Kalpaka et al. 2020). DIHs are organisational structures providing firms with one-stop-shops services needed to introduce digital innovations. Their key tasks include individual consultancy on the digitisation of business model elements (including the so-called digital assessment and advice on the investment strategy); organisation of webinars, training, workshops, innovation camps, hackathons and other events where the potential of digital technologies is explained (creating awareness about I4.0 and shaping skills needed for the digital transition at the company level); as well as provision of specialised infrastructure, for example for "testing before investments" (Miörner et al. 2019a). Digital Innovation Hubs are a specific type of Knowledge-Intensive Business Service (KIBS, Opazo-Basáez et al. 2020), supporting firms to innovate in terms of I4.0 technologies or digitalisation. Still, the broader effects on regional digitalisation and economic development are also important aspects of their activity.

The idea behind introducing DIHs as a policy instrument consisted in providing broad support for the availability of digitalisation in the European regions, with locations close to potential recipients, especially small and medium enterprises (Rissola, Sörvik 2018). The framework for designating DIHs has been formulated in a general way by the European Commission to enable its creation under various regional conditions. An analysis of DIHs in Europe showed a considerable variation between them,

[1] It was built based on the DESI Index, as well as two additional indicators: The Local and Regional Digital Indicator LORDI, constructed by ESPON (at the time of the research under consultations), as well as the Cisco's digital readiness framework.
[2] Many indicators suggested in this report, showing regional digitalisation or digital preparedness, are currently not available at the regional level.
[3] Similar indicators and few others were suggested by Abonyi et al. (2020) in counting the so-called Regional Industry 4.0+ Readiness Index.

including variations in their origins and way of formation (Miörner et al. 2019b). DIHs were constituted as a regionally anchored instrument, the first regional points of contact for existing industries' demand-side endeavours regarding digital technologies. Therefore, they were also intended to be linked strongly to other EU-wide initiatives supporting policy creation at the regional level. Their actions were supposed to influence the realisation of regional innovation strategies, particularly smart specialisation strategies, an instrument that helps align regional agendas and investments with EU priorities (Rissola, Sörvik 2018; Miörner et al. 2019a).

In the years 2016-2021, the launching and dissemination of DIHs were financially supported by the European Regional Development Fund, national funds, and often by Horizon 2020 research Programme. While basic services provided by DIHs for companies were usually free of charge, more specialised services were often commercialised or sometimes co-funded by public funds and membership fees (Rissola, Sörvik 2018). Also, the online Digital Innovation Hub Tool was launched as a part of the S3 Platform of the EU Joint Research Centre, aiming to facilitate contact between firms and DIHs and DIHs and policy-makers and other DIHs (S3 Platform – DIH tool 2021).

The first evaluations of the impact of DIHs on digital transformations in regions were conducted recently. Actions undertaken by DIHs in Spain seem to influence entrepreneurial discovery processes, networking, learning by interaction, open innovation generation, and new knowledge creation. As a consequence, they influence regional path creation or path modernisation through the cross-fertilisation of regional actors, industries and activities (Hervas-Oliver et al. 2021b). Another study among Italian DIHs proved that they are both knowledge brokers (facilitating access to external knowledge) and knowledge sources (facilitating knowledge transfer). They are embedded in local territories and generate a high level of trust, which helps them to plan individual digitalisation paths (Crupi et al. 2020).

In the years 2022-2027, the new programme enacted at the EU level – The Digital Europe Programme, is intended to foster selected DIHs – henceforth European Digital Innovation Hubs (EDIHs), by providing funding, especially for supercomputing, artificial intelligence, cyber security and advanced digital skills (EC 2021d; DIGITAL 2021). Given the tremendous political interest in supporting Industry 4.0, this paper aims to analyse actions undertaken by regional organisations and Digital Innovation Hubs to facilitate the adoption of I4.0 technologies in manufacturing companies, considering divergent framework conditions for implementing I4.0 technologies in different types of regions.

5. Data and methods

For the analysis, we chose three case studies among European regions: Veneto & Friuli Venezia Giulia regions in Italy, Wielkopolska in Poland and Baden-Württemberg in Germany. We chose the case study as a research method (Yin 2018) because we wanted to investigate how the current state of economy and innovativeness influences digitalisation and I4.0 implementation in the manufacturing sector in regions and how regional authorities are acting to facilitate the dissemination of Industry 4.0 technologies (what kind of actions they are performing to achieve that aim and why). The choice of case studies was purposeful (Swanborn 2010; Yin 2018): we wanted to compare indicators and contemporary actions (treated as cases) fostering Industry 4.0 adoption in selected European regions (three case studies) characterised by different GDP per capita and different innovativeness levels. The substantive criterion for selecting these regions[4] was a possible heterogeneity of digitalisation indicators and approaches towards fostering the dissemination of Industry 4.0 technologies in firms.

The research design consisted of two main steps. First, we performed desk research and analysed framework conditions and digital preparedness – statistics and indicators showing regional readiness to implement Industry 4.0 in manufacturing firms. In the second step, we conducted in-depth interviews (IDI) with representatives of regional entities responsible for Industry 4.0 programs or activities (as part of the innovation policy) and outstanding Digital Innovation Hubs located in each of the three selected

[4] Veneto and Friuli Venezia Giulia are two administrative units bordering each other (with different governing bodies); however, as they are characterised by similar level of socio-economic development and economic structure, and many business support organisations are common for firms located in both areas, we treat them as one case study.

regions (Table 1). To this end, we used an open interview scenario with three general issues: (1). Origins and scope of actions (initiatives, projects) undertaken to create conditions for Industry 4.0 dissemination. (2). Explanation of how the actions facilitated or facilitate the Industry 4.0 implementation in manufacturing companies. (3). Barriers and challenges to the implementation of Industry 4.0 in companies (currently and in the upcoming years), given the regional conditions.

TABLE 1.
The interviewees and codes of interview

Region	Organisation	Code
Baden-Württemberg	Regional Network Allianz Industrie 4.0 Baden-Württemberg (located at the VDMA Baden-Württemberg), International Relationships Management and Startups unit (Stuttgart)	G1
	Cyber Forum DIH, Innovation & Digital Ecosystems unit (Karlsruhe)	G2
Veneto, Friuli Venezia Giulia	Confindustria Veneto, Delegate for Policies of Innovation, Research and Industry 4.0 (Venezia / Padova)	I1
	IP4FVG DIH, Area Science Park, Business and Digitisation Office (Trieste)	I2
Wielkopolska	Wielkopolska Observatory of Innovation, The Marshal Office of the Wielkopolska Region (Poznań)	P1
	DIH4Future, Poznan Science and Technology Park, Commercialization and Business Development Department (Poznań)	P2

The interviews took place between June and December 2021, either in person or via videoconference or telephone. Each lasted around 1 hour, was recorded and then transcribed and analysed (speakers were given a code used later in this paper). After the interviews, the speakers sent additional materials and links via email that were used in the analysis to draw conclusions referring to the research questions (multiple sources of evidence were triangulated, as suggested by Yin 2018).

6. CONDITIONS FOR THE DEVELOPMENT OF INDUSTRY 4.0 IN MANUFACTURING IN BADEN-WÜRTTEMBERG, VENETO & FRIULI VENEZIA GIULIA AND WIELKOPOLSKIE: PRELIMINARY ANALYSIS OF REGIONAL PREPAREDNESS

For the purpose of analysis, regions were selected based on their location in Germany, Italy, and Poland – with very different characteristics in terms of Industry 4.0. The similarity between the three countries lies in the strong manufacturing sector (NACE section C), with the share in gross value added and employment exceeding the EU-27 average[5]. However, these countries differ significantly in terms of overall innovativeness and specifically, regarding I4.0 – in the number of industrial robots and hitherto integration of digital technology in firms (Germany – high, Italy – average, Poland – low). In terms of the overall digitalisation of the economy and society (counted by the DESI Index) and the percentage of ICT personnel in total employment, Italy and Poland show similar levels, below the EU average and far behind Germany, which is among the European leaders (Table 2). According to Castelo-Branco et al. (2019), in terms of Industry 4.0 readiness at the country level, measured by interconnectivity (infrastructure) and information transparency (big data maturity), Germany stands out (primarily due to the Industry 4.0

[5] Eurostat data (2021) show that the three countries are among the five principal states concerning employment in manufacturing in the European Union, together employing 50% of all its manufacturing workers.

infrastructure), Italy is somewhere around the European average, while Poland is among the continental laggards.

TABLE 2.
Framework conditions for I4.0 applications in manufacturing in Germany, Italy and Poland

No.	Indicator \ Country	G	I	P	EU-27	Source, year of data*
1	Share of manufacturing (NACE section C) in gross value added	35	33	32	29	Eurostat, 2018
2	Share of manufacturing (NACE section C) in employment	26	25	29	23	Eurostat, 2018
3	Innovativeness level	strong innovator	moderate innovator	emerging innovator	---	European Innovation Scoreboard, 2021
4	Number of industrial robots per 10000 employees	322	200	42	144	International Federation of Robotics – IFR, 2019
5	DESI Integration of Digital Technology in firms**	7,9	6,2	5,2	8,3	European Commission – Digital Scoreboard 2020
6	DESI Composite Index**	56,1	43,6	45,0	52,6	European Commission – Digital Scoreboard 2020

* All data (except for no. 3) is available for country-level (not for regional one). Source websites are listed in the bibliography at the end of the paper.
** DESI – explanations concerning the index are included in the text of the previous section of this paper.

The national governors of all three countries adopted strategies and special tools to propagate industry 4.0 and to foster the implementation of its solutions in the manufacturing sector.

Germany is believed to be the country that coined the term Industry 4.0. It occurred in 2011, during the Hannover Trade Fair, after which the Federal Government launched a Strategic Initiative Platform Industry 4.0 (DE: *Industrie 4.0*) – a high-tech strategy underlying the role of interplay between humans and machines and the significance of digital applications in manufacturing and production. It assumed the need for a joint effort of key national stakeholders, such as industry associations and Fraunhofer Institutes, for the industrial change (Kagermann et al. 2013; GTAI 2014; De Propris, Bailey 2020b). Today Germany is one of the leaders in the implementation of I4.0 in Europe (Götz 2021).

Italy's economy, especially in the North-Eastern part, is largely based on industrial districts (clusters), predominantly small and medium enterprises in traditional manufacturing sectors, known in the World and respected as "Made in Italy" products. Not surprisingly, the country is at the forefront of research on the possible impact of the fourth industrial revolution on industrial districts and their firms, with emerging examples, especially from the north part of the country (Bettiol et al. 2020). In 2016, the Italian Government enacted the Industry 4.0 National Plan (IT: *Piano Nazionale Industria 4.0*, later expanded

to *Impresa 4.0* and *Transizione 4.0)* to foster I4.0 innovations. One of its first executive instruments was the Voucher for digitising SMEs (*Voucher per la digitalizzazione delle PMI*), governed by the Ministry of Economic Development.

Poland is one of the post-socialist countries in Central and Eastern Europe, characterised by a dynamic GDP growth per capita in the last 30 years, primarily influenced by a strong manufacturing sector and growing export of goods to the EU markets (Rachwał et al. 2009; Rachwał 2015; Dyba et al. 2018). However, with its pre-1990 legacy, the country is below the European average in terms of innovativeness and digitalisation in manufacturing and is characterised by huge domestic differences between the more developed western part of the country and the east (Churski et al. 2021). To facilitate industrial digitalisation, the Polish Ministry of Enterprise and Technology established the Initiative for Polish Industry 4.0 – the Future Industry Platform (PL: *Platforma Przemysłu Przyszłości)* in 2019. Its projects included support for Digital Innovation Hubs acting as role models (FPPP 2021).

The differences in the framework conditions for the development of Industry 4.0 are also visible on the regional level – even if all three regions belong to the most industrialised and affluent in each country, with GDP per capita above the national average (Table 3).

TABLE 3.
General information about the economies of the regions under analysis

No.	Region / Indicator	Baden-Württemberg	Veneto	Friuli Venezia Giulia	Wielkopolskie	Source, year of data
1	Number of inhabitants (mln)	11,1	4,879	1,206	3,479	Eurostat, 2020
2	Persons employed in manufacturing (thous.)	1,461	531,6	105,6	360,3	Eurostat, 2019
3	Number of companies (thous.)	470,5	486,0	88,8	430,4	RIMP, 2019
4	GDP (mln euro)	525 197	164 860	38 772	52 576	Eurostat, 2019
5	GDP per capita PPS (euro)	42800	33 700	32100	24600	Eurostat, 2019
6	GDP per capita PPS (EU27 =100)	137	108	103	79	Eurostat, 2019
7	Innovativeness level	innovator leader	strong innovator	strong innovator	emerging innovator	Regional Innovation Scoreboard 2021

Baden-Württemberg [DE1 in the NUTS classification] is a land in south-western Germany consisting of four sub-regions (Stuttgart, Karlsruhe, Freiburg and Tübingen). For decades it has been one of the most affluent and innovative regions in Europe, characterised by strong manufacturing and institutional setting allowing technology transfer and industrial development (Hassink 1993; Heidenreich, Krauss 1997). The strengths of the regional economy are the automotive industry representing a quarter

of the industrial turnover, and mechanical engineering representing 20% of the industrial turnover, followed by the metal and electrical industries. The chemical, pharmaceutical, and optical industries account for much less than the three previous sectors, but their share in the overall national production has increased (RIMP 2016).

Veneto [ITH3] is a region in north-eastern Italy, with the capital city in Venice (other important industrial and service centres include Vicenza, Verona, and Padua). It is one of the leading industrial regional economies that saw an "economic miracle" of development in the 60s and 70s. The highly specialised and competitive manufacturing base is mainly comprised of SMEs operating in mechanics, textiles, agro-food, glasses production, gold and jewellery, electrical appliances and furniture (RIMP 2021). Friuli Venezia Giulia [ITH4] is a region bordering Veneto to the east, with the capital in Trieste and two other important centres in Udine and Pordenone. Its vital manufacturing sectors include the wood-furniture industry; manufacture of metal products; manufacture of machinery and equipment; manufacture of electrical and non-electric household appliances; food and beverage industry; manufacture of other non-metallic mineral processing products; metallurgy; shipbuilding. Some of these sectors converge in supply chains and sectors with a high capacity for growth and innovation: the agri-food chain; the home system supply chain; metalworking; the chemical-pharmaceutical supply chain; nautical, shipbuilding, and off-shore, the Bio sector and cultural and creative enterprises (Chiarvesio, Tabacco 2016; S3 Platform 2021; RIMP 2021).

Wielkopolskie [PL41] is a region in Western Poland, with the capital city of Poznan. Its strong manufacturing sector is based on machinery and equipment, motor vehicles, trailers and semi-trailers (and other transport equipment), furniture production, wood and cork products, paper products, manufacturing of food products and beverages, fabricated metal products as well as textiles, leather and related products (Czyż 2010; Churski et al. 2017; S3 Platform 2021; RIMP 2021).

Notably, all three regions included Industry 4.0 and ICT-related elements among development axes ("economic domains") in their smart specialisation strategies: in Baden Württemberg – under the ICT framework, green and intelligent products, in Veneto and Friuli – as a cross-sector innovation and the priority are advanced technologies for manufacturing, in Wielkopolska – within the priority manufacturing of the future, industry of tomorrow and ICT-based development. All three regions included improving industrial production and technology among the regional "scientific domains" and digital transformation among the "policy objectives" (Eye@RIS3 2021).

The analysis allows showing substantial differences in indicators proving the digital preparedness of the investigated regions (Table 4).

The data shows that the Italian and Polish regions have a similar situation regarding digital infrastructure and human capital. In contrast, Veneto and Friuli Venezia Giulia have more Digital Innovation Hubs (see Table 6), more investments in R&D and GVA in ICT. It suggests the business environment of the Italian regions is more advanced for the implementation of Industry 4.0 than the Polish region.

Considering all the presented indicators, Baden-Württemberg has the highest capacity for adopting further I4.0 technologies. Without substantial financial and organisational support in the Italian and Polish regions, we may expect a slower implementation rate of I4.0 technologies in the following years. As a consequence – we may observe growing disparities between the three regions.

TABLE 4.
Digital preparedness of the investigated regions – selected indicators (data for 2019)

No.	Group, indicators / Region		Baden-Württemberg	Veneto	Friuli Venezia Giulia	Wielkopolskie
1	Digital infrastructure	Households with broadband internet access (in %)	94	90	91	89**
2	Business environment	1. Presence of active Digital Innovation Hubs (listed on the S3 Platform of the EC's JRC)	14	7	4	2
		2. Number of enterprises in ICT (in brackets the number of manufacturing enterprises per 1 ICT enterprise)	21989 (21:1)	10256 (47:1)	2413 (37:1)	10610 (41:1)
3	Investment in R&D	The gross domestic expenditure on R&D (GERD) as % of GDP	5,6	1,39	1,71	0,82
4	Human capital	1. Persons employed in ICT* (number and number of employed in manufacturing per 1 employed in ICT)	205247 (7:1)	43160 (12:1)	8887 (12:1)	28057 (13:1)
		2. Persons with tertiary education (ISCED) and/or employed in science and technology (HRST) in thous. (and as a % of the total workforce)	3454,1 (50,2)	918,4 (35,4)	237,6 (37,6)	725,7 (39,7)
5	Digital economy and services	Gross value added at basic prices in the ICT sector (mln euro)	22 841,64	3535,9	884,4	1382,85

* ICT is a section J in a NACE classification and includes programming and broadcasting activities; wired, wireless and satellite telecommunications activities; computer programming and consultancy activities; information service activities such as data processing, hosting, web portals, news agencies, information search; and also publishing activities as well as motion picture and sound recording activities (the last two less relevant for the digital preparedness in terms of I4.0);
** Data for Makroregion północno-zachodni (województwa zachodniopomorskie, lubuskie i wielkopolskie).
Source: own elaboration based on Eurostat and S3 Platform – DIH tool (for 2.1).

7. TYPES OF REGIONAL ACTIONS FOSTERING INDUSTRY 4.0 ADOPTION IN MANUFACTURING FIRMS

The interviews and further information sent or mentioned by interviewees afterwards allowed us to collect and categorise various actions undertaken in regions to foster the adoption of Industry 4.0 in manufacturing firms in recent years. We aggregated these actions into 8 types, corresponding to five component groups of the "digital preparedness" framework (infrastructure – 1, business environment – 2, 3, 4, investments/ funding – 5, human capital – 6, digital economy and services – 7, 8). The scope of actions and their direct link to the I4.0 concept differ between the investigated case studies (Table 5).

TABLE 5.
Typology of regional actions fostering the adoption of Industry 4.0 technologies in manufacturing firms (in the years 2016-2021)

Type	Example of good practice	Description	Case study
1. Investments in the broadband internet infrastructure	Broadband internet expansion (Breitbandausbau)	Project financed from federal funds (in the years 2016-2020), where 2630 broadband projects plus additional 810 expansion projects in counties, cities and municipalities were supported	G
	Strategy for next generation access network (Strategia Nazionale per la Banda Ultra-Larga, SNBUL)*	Italy's national ultra-broadband plan that facilitated the rollout of fibre-based broadband internet networks. Several projects funded from state and EU regional funds were implemented in stages (in the years 2015-2020)	I
	Wielkopolska Broadband Internet Network (Wielkopolska Sieć Szerokopasmowa)	The project was conducted under a public-private partnership (EU regional funds and internet operator) allowed to deliver the next generation access to all communes in the region (basic infrastructure completed in 2015; afterwards, distribution nodes are used to provide the network to further areas and end-users by ICT operators)	P
2. Strategic planning and monitoring of I4.0 development	Allianz Industrie 4.0 (in particular the Steering Committee)	Network initiated and funded by the Ministry of Economics, Labour and Tourism Baden-Württemberg. Partners: high-ranking representatives from politics in Baden-Württemberg, businesses, applied research institutions, chambers and social partners advise on the actions fostering the adoption of Industry 4.0 technologies in companies	G
	Veneto Innovazione, Industry Platform 4 FVG **	Technical structure supporting the regional government in innovation-related activities (exploitation of innovations, organisational support with innovative projects, promotion of innovation)	I
	Regional Council "Industry of the Future" (Wielkopolska Rada 30) and Wielkopolska Innovation Observatory **	Two bodies: council of 30 experts representing regional economic organisations and the regional administration unit - advising regional authorities on strategic documents and initiatives related to the regional economy. The second commissioned two external expert's analyses on the possible impact of I4.0 on the regional job market.	P

TABLE 5. CONT.
Typology of regional actions fostering the adoption of Industry 4.0 technologies in manufacturing firms (in the years 2016-2021)

Type	Example of good practice	Description	Case study
3. Creation of awareness about available I4.0 technologies	Regional website dedicated to Industry 4.0	Dedicated information containing the main terms in Industry 4.0 or basic digital assessment tools	G, I
	Competence Atlas of I4.0	An online tool to find all suitable companies and organisations operating within the area of I4.0 (available in the initial phase of Allianz Industrie 4.0)	G
	Events, webinars, training, and workshops on I4.0 innovations, often followed by individual consultations on digital transformation	In G – Actions of Allianz Industrie 4.0 Baden-Württemberg In all – actions of DIHs	G, I, P
4. Promotion of good practices of I4.0 implementations in firms within the regions	100 locations for Industry 4.0 Baden-Württemberg	Competition promoting "outstanding ideas from business, science and education that fully exploit the potential of I4.0 in Baden-Württemberg"	G
	100 places of Industry 4.0 and sustainability	Competition promoting good examples of I4.0 technology implementations in firms	I
	i-Wielkopolska – innovative for Wielkopolska competition **	Competition aiming at promoting firms that implemented outstanding innovations: yearly editions since 2007, recently including those in the field of I4.0	P
5. Financial support for I4.0 implementations in firms	Funds for innovations in SMEs (grants, vouchers or loans), including dedicated sources for digital innovations* **	Grants or loans under the available funding schemes (including European, national and regional funds). In I and P include dedicated vouchers for digitalisation.	G, I, P
	Tax reductions*	Tax reductions for implementing innovations related to Industry 4.0	I
6. Preparing workers for the demands of I4.0 through education and training	Training centres	Organisations offering courses related to I4.0 for existing companies In all – actions of DIHs	G, I, P
	Learning Hubs 4.0 at Vocational Schools	Establishment of 37 training factories 4.0 at vocational schools – laboratories similar to industrial full-automatic solutions in layout and features, spots to learn and train up basic techniques of application-related processes.	G

TABLE 5. CONT.
Typology of regional actions fostering the adoption of Industry 4.0 technologies in manufacturing firms (in the years 2016-2021)

Type	Example of good practice	Description	Case study
	Industrie 4.0 Talents	Competition promoting training programs for students and apprentices, already introduced in companies	G
7. Supporting I4.0 start-ups	Consultancy of business models for start-ups in the field of I4.0 (or utilising I4.0 technologies) **	Standard consultancy for start-ups in the Knowledge-Intensive Business Services (technology parks, business incubators, chambers of commerce) and DIHs	G, I, P
	Startup the future	Matchmaking event where representatives of start-ups in sectors of Industry 4.0 meet directly with decision makers of industrial companies.	G
8. International promotion and networking of regional firms operating in the field of I4.0	Funding participation of firms in international fairs **	In G – one of the pillars coordinated by Allianz Industrie 4.0 (and dedicated to I4.0) Promotion of companies offering I4.0 on international fairs (financed by regional administration or chambers of commerce)	G, I, P

* Instruments at the national level, conducted in cooperation with regional authorities or promoted at the regional level.
** Activities supporting the adoption and popularisation of any innovative solution in companies (including I4.0, but not exclusively).
Source: own elaboration based on interviews, information sent by the interviewees and internet websites.

The most comprehensive approach towards I4.0 focused on the specific set of technologies included in the I4.0 framework is being implemented in Baden-Württemberg under the framework Allianz Industrie 4.0. The network, founded in 2015, aims "to establish Baden-Württemberg as a leading provider and lead market for Industry 4.0 technologies". As [G1] explains, "*Various projects and purposeful actions fostering Industry 4.0 implementation by regional companies are coordinated by the Allianz Industrie 4.0 Baden-Württemberg. The framework consists of 5 pillars, each with a dedicated project manager*: *Industry 4.0 Initial consultation, Learning & Qualification 4.0, AI & Cybersecurity, International Relationships Management and Startups as well as Networking & Data-based Business Models".* The Allianz Industrie 4.0 Baden-Württemberg is structured as follows: The coordination office, which is responsible for coordinating and implementing activities, is located at the VDMA Baden-Württemberg. Besides there is the core team which oversees operational coordination and alignment. This team consists of representatives from politics, businesses and applied research. In addition, the Allianz Industrie 4.0 works closely together with three main partners (bwcon, microTEC Südwest e.V. and Landesnetzwerk Mechatronik). The strategic orientation of the Allianz Industrie 4.0 is set by the Steering Committee, which consists of high representatives from the Ministry of Economics, Labour and Tourism Baden-Württemberg, businesses and applied research institutions (www1). The various actions undertaken within those 5 pillars are listed in Table 5.

First activities and initiatives facilitating Industry 4.0 development in the investigated Italian and Polish regions (support for Digital Innovation Hubs, financial vouchers for digitalisation) were managed and funded from the central, country level (or funded from external funds, including the EU funds). In Veneto and Friuli Venezia Giulia, the growing interest in the subject is confirmed by the pivotal project undertaken by the regional industrial association (*Confindustria*) – the "100 places of Industry 4.0 and sustainability". It takes the form of events – either via direct contact or online, each presenting one company. *These are promotions of the concrete Industry 4.0 solutions in firms, showing the most innovative*

implementations serving digital and sustainable transformation of companies (…). To encourage participants, each company receives a 2-days consultancy of digital assessment. Therefore, entrepreneurs are happy to show what they do, and each event arouses great interest, gathering up to 200 participants [I1]. Interestingly, it was undertaken based on the Baden-Württemberg 100 places initiative and proved to be a successful nation-wide initiative (used now by other local industrial associations; www3).

In Wielkopolska, activities fostering Industry 4.0 are an integral part of the regional innovation policy, which aims at fostering designated smart specialisations. As confirmed by [P1], Industry 4.0 technologies (ICT) are cross-sectoral innovations, so they are part of general innovation policy activities. The appointment of the Wielkopolska Council of 30 – Industry of the Future, an advisory body consisting of representatives of the most important regional business support organisations and firms (including experts in Industry 4.0), can be given as an example of good practice (www5).

8. Actions of Digital Innovation Hubs enabling manufacturing companies to adopt Industry 4.0 innovations

There are significant differences between the three case studies in the number of Digital Innovation Hubs and the overall variety of services they provide to regional companies (Table 6).

For the detailed analysis in this paper, we contacted and interviewed representatives of three Digital Innovation Hubs, one from each region: Cyber Forum (G2), IP4FVG (I2) and DIH4Future (P2). The Hubs were indicated by the regional representatives (G1, I1, P1) as active and relevant for the digitalisation and implementation of I4.0 technologies in the three regions. Cyber Forum is a non-profit organisation with a registered office in Karlsruhe. It was set up in 1997 and since then evolved from a network of stakeholders related to the IT industry in the region to become a Digital Innovation Hub in 2017. It received funding from the German Federal Government within the program De Hub as one of the 12 supported organisations in the country (www2). IP4FVG is an Industry Platform for Friuli Venezia Giulia, based in Trieste. It dates back to 2018, when it was set up as an industrial platform, part of Area Science Park, soon to be named a Digital Innovation Hub and receive funding from the regional administration budget (www4). DIH4Future, a consortium led by the Poznań Science and Technology Park in Poland, was established in 2019. In the first years, it received a subsidy from the national Ministry of Development as one of the 5 model Digital Innovation Hubs featured in the country (www6).

The origins and organisational structure of the three DIHs differ (as suggested by Miörner et al. 2019b), but the tasks and services they provide are similar and in line with the guidelines of the European Union (Table 6, as in Kalpaka et al. 2020). In the light of interviews [with G2, I2, P2], DIHs have strong and diverse connections with regional universities, administration, and other DIHs and provide access to specialised equipment and technology providers. Therefore, they are an important part of the regional innovation policy, facilitating the implementation of smart specialisation strategies (as in Rissola, Sörvik 2018).

According to the interviewees, an important role of DIHs is to help companies overcome digitalisation barriers at the firm level. As the interviewee [G2] indicates, "*it is lack of knowledge on the opportunities created by digitalisation and problems with financing. This is where we try to help the most*". The interviewee [I2], apart from these barriers, another barrier is "*necessary changes in business models, comprising a range of elements to be changed, (…) difficult because of the often reluctance to changes among the managers and other workers in many companies*". Finally, the speaker [P2] says that financing and lack of knowledge are problems; however, it is the "*overall human factor in the introduction and use of Industry 4.0 technologies that impede changes in companies. It includes lack of skills, willingness or potential to fully benefit from the introduced digital changes*". According to the speaker, in many regional SMEs, a significant barrier is also technological backwardness, but indeed only companies with a certain level of digitalisation, conscious of the I4.0 potential, use the DIH consultancy. In the light of the conducted research, the barriers to implementing Industry 4.0 technologies in European firms are similar (as in Cugno et al. 2021; Raj et al. 2020), but the lower the level of GDP per capita and innovativeness, the more they are connected with human and technology-related factors and more challenging to overcome.

TABLE 6.
Services provided by the Digital Innovation Hubs in Baden-Württemberg, Veneto & Friuli Venezia Giulia and Wielkopolska

Case study	Name and city	Services provided*													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
G	Mittelstand 4.0-Kompetenzzentrum (Stuttgart)		x				x		x							
	Smart Data Solution Center Baden-Württemberg (Stuttgart)		x	x		x		x	x					x	x	
	Fraunhofer Future Work Lab (Stuttgart)		x	x		x	x	x	x	x				x		x
	Application Center Industrie 4.0 (Stuttgart)	x	x	x		x	x	x	x					x	x	
	Center Digitisation District (Böblingen)	x	x	x		x	x	x	x	x					x	
	University Werk150 (Reutlingen)	x	x	x		x	x	x	x	x		x		x	x	
	Hahn-Schickard (Villingen – Schwenningen)	x	x	x		x		x	x				x	x		
	Cyberforum – Software Cluster (Karlsruhe)		x	x				x	x	x						
	FZI Research Center for Information Technology (Karlsruhe)		x	x		x		x						x		
	Smart Data Innovation Lab (Karlsruhe)		x	x	x	x		x	x	x				x	x	
	Steinbeis-Europa-Zentrum (Karlsruhe)	x	x	x				x	x		x	x			x	
	Institute of Reliable Embedded Systems and Communication Electronics (Offenburg)			x		x			x					x		
	Transfer Platform Industry 4.0 (Aalen)													x		
	Application Center for Automation in Healthcare (Mannheim)	x	x	x		x			x	x		x		x	x	
I	IP4FVG Area Science Park (Trieste)	x	x	x			x	x	x	x	x	x		x	x	
	Lean Experience Factory – DIEX Digital Experience (San Vito al Tagliamento)		x	x			x	x							x	
	Laboratory for Advanced Mechatronics – LAMA FVG (Udine)	x	x	x		x	x		x				x	x	x	
	DIH Udine – Data Analytics & Artificial intelligence (Udine)		x	x			x	x				x			x	
	SMACT Competence Center (Venezia)	x	x	x		x	x	x	x			x		x	x	
	Ecipa Nordest Hub (Venezia)	x	x				x	x	x			x				
	T2i – DIH Triveneto (Treviso)	x	x	x		x	x	x	x	x	x	x		x	x	
	Galileo Digital Innovation Hub (Padova)	x	x	x		x		x	x	x	x	x		x	x	
	Digital Innovation Hub Vicenza (Vicenza)		x	x		x	x	x	x	x	x	x		x	x	
	Speedhub (Verona)	x	x				x	x	x			x			x	
	DIH Belluno Dolomiti (Feltre)	x	x	x			x	x	x	x		x			x	
P	HPC4Poland (Poznan)	x		x		x	x		x	x				x		
	DIH4Future, Poznan Science and Technology Park (Poznan)	x	x	x	x	x	x	x	x	x	x				x	x

* 1. Access to funding and investor readiness, 2. Awareness creation, 3. Collaborative research, 4. Commercial Infrastructure, 5. Concept validation and prototyping, 6. Digital maturity assessment, 7. Ecosystem building, scouting, brokerage, networking, 8. Education and skills development, 9. Incubator / accelerator support, 10. Market intelligence, 11. Mentoring, 12. Pre-competitive series production, 13. Testing and validation, 14. Visioning and Strategy Development for Businesses, 15. Voice of the customer, product consortia.
Source: elaboration based on information on the S3 Platform – DIH tool (2021).

The interviewees in all three regions, representing regional organisations and DIHs, list similar challenges in the further dissemination of I4.0 technologies in the subsequent years. They include the need to: a) create awareness about the potential of I4.0, b) help managers find the best financing strategies for I4.0 implementation and c) shape the digital skills of workers, which among others, may include subsidised training or webinars for employees and changes in the study programs at universities and schools.

9. Conclusions, limitations and further research

The paper aimed to compare actions undertaken to foster the implementation of Industry 4.0 (I4.0) technologies in manufacturing firms in Europe. In particular, we analysed various initiatives and projects coordinated by regional organisations responsible for I4.0-related actions in three regional case studies: Baden-Württemberg in Germany, Veneto & Friuli Venezia Giulia in Italy, and Wielkopolska in Poland. They included activities of Confindustria Veneto (one of the Italian industrial associations), German Engineering Association VDMA (governing the flagship project Allianz Industrie 4.0 in Baden-Württemberg), Wielkopolska Innovation Observatory (unit of the regional administration) as well as three outstanding Digital Innovation Hubs – organisations, set up as a response to the European Commission's innovation policy, advising firms on the best strategies of digitalisation – implementation of I4.0 technologies.

In the first step of the analysis we proved major differences in regional backgrounds for implementing Industry 4.0 in enterprises: different initial GDP, innovativeness levels as well as various digitalisation indicators. Although operating in different conditions, representatives of all investigated organisations acknowledged in the second step the potential created by I4.0 technologies. Indeed it shows that I4.0 may significantly influence manufacturing in all types of regions in Europe (as in Barzotto et al. 2019; Capello, Lenzi 2021). In all investigated regions, the ICT-related elements are included in smart specialisation strategies, which as an I4.0 enabler, indeed should be a cross-sectional, basic element of all innovation policies (Hervas-Oliver 2021b).

Actions fostering the implementation of I4.0 technologies undertaken by regional organisations were divided into the following groups: infrastructural investments, strategic planning and monitoring, awareness creation, promotion of good practices, financial support for I4.0 implementations, preparing future workers for the demands of I4.0 through training and education as well as supporting start-ups and international networking. The most comprehensive approach, fostered by the most significant financial support from the regional budget, was observed in Baden-Württemberg in Germany, where a single organisation coordinates various I4.0 actions. The first activities presented dedicated to I4.0 in Veneto and Friuli Venezia Giulia seem to be the beginning of a comprehensive approach towards I4.0 in manufacturing; however, we should highlight that IP4FVG aims at becoming the point of reference for I4.0 actions in the region, able to coordinate actors and projects in this field. In Wielkopolska, activities are part of an innovation policy in general, and their number and scope have been so far smaller than in the other case studies. Importantly, regional authorities in the investigated Italian and Polish regions are aware of the potential created by Industry 4.0, as proved by the commissioning and funding of the publications: Bondyra, Zagierski (2019) and Potti (2020). Regional organisations including Digital Innovation Hubs have been playing an important role in overcoming I4.0 implementation barriers at the firm level, including lack of knowledge about I4.0 technology, no digitalisation strategy, lack of funds and insufficient skills among workers to implement I4.0 technologies (as in Cugno et al. 2021).

The policy recommendation – strategy to follow by regions less advanced in Industry 4.0 – is the replication of "good practices", that is, actions fostering I4.0 implementation that proved successful in regions in the forefront of this field. Most often, it will not be possible without substantial funds and establishing one entity in charge of I4.0 (like in Baden-Württemberg). As the analysis of indicators showed, there are significant differences in "digital preparedness" between European regions, primarily connected to regional GDP and innovativeness levels. It seems that without the significant financial and organisational involvement in all types of regions (under the industrial policy dedicated to I4.0), the gap in the industry advancement and productivity between the most innovative regions and the less affluent European regions will most likely widen (as in Orłowski, 2014).

We acknowledge that our research showed actions fostering I4.0 implementation that have been undertaken at the regional level recently. Many of their effects may be evaluated only after some time, creating the potential for further research. The paper's conclusion in the second half of 2021 coincided with the time scholars, policymakers and technology providers alike conducted the first analyses of the effect of the COVID-19 worldwide pandemic on the regional economies. It may also impact the further implementation of I4.0 technologies in manufacturing firms. Early evidence (CoR, 2021) shows that the pandemic slowed the pace of significant investments into I4.0 hardware like smart robots or the Industrial Internet of Things, but on the contrary, a higher propensity to implement software-related innovations (cloud solutions allowing remote working and online meetings). Further studies should investigate how the changes induced by the pandemic on the organisation and functioning of firms influenced the needs in terms of their support – and, therefore, what are the implications for the actions supporting the implementation of Industry 4.0 that should be performed under the regional innovation policies.

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Annex

Internet websites of regional organizations, innovation platforms and investigated Digital Innovation Hubs

(www1) Allianz Industrie 4.0 Baden-Württemberg (Stuttgart): https://www.i40-bw.de/

(www2) Cyber Forum (Karlsruhe): https://www.cyberforum.de/

(www3) Industria 4.0 Veneto (Padova, Venezia): https://www.industria40veneto.it/

(www4) IP4FG – Area Science Park (Trieste): https://www.ip4fvg.it/

(www5) Innowacyjna Wielkopolska (Poznań): http://iw.org.pl/

(www6) DIH4Future (Poznań): https://ppnt.poznan.pl/dih/