Measurement framework and data strategy.

**WP2 Quantitative assessment of skills and jobs
Task 2.1.**

Deliverable D2.1
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Document Summary

Document description

WP2 assesses the transformations of jobs in the context of the so-called "fourth industrial revolution" and the necessary workforce skills for the development of Industry 5.0. This document builds a measurement framework to determine whether the uses of digital and green technologies, related organisational practices and skills utilisation by organisations have been effective in moving towards the Industry 5.0 goals in terms of human-centricity, resilience and sustainability. The measurement framework allows to analyse various data sources from the same theoretical point of view and to compare obtained results from the various WP2 tasks. The work uses WP1 results and relies on a literature review and internal seminars. The framework has been translated into a data strategy based on the selection and combination of complementary data sources for the four tasks of WP2, that are conducted in interaction using and combining in innovative ways existing high-quality data.

Cite this deliverable as:

BRIDGES 5.0 partners*

List of abbreviations

AI	Artificial Intelligence
BEYOND 4.0	Inclusive Futures for Europe BEYOND the impacts of Industrie 4.0 and Digital Disruption
BRIDGES 5.0	Bridging Risks to an Inclusive Digital and Green future by Enhancing workforce Skills for industry 5.0
CIS	Community Innovation Survey
ECS	European Company Survey
EMS	European Manufacturing Survey
EST	Environmentally Sound Technology
EWCS	European Working Condition Survey
GVC	Global Value Chains
IoT	Internet of Things
IPC	International Patent Classification
IT	Information Technologies
LFS	Labour Force Survey
ML	Machine Learning
MNE	Multinational enterprises
NSI	National Systems of Innovation
OECD	Organisation for Economic Co-operation and Development
OSH	Occupation Safety and Health
RSI	Regional Systems of Innovation
SDG	Sustainable Develpment Goals
SME	Small and Medium-sized Enterprises
WIPO	World Intellectual Property Organization
WP	Work Package

Contents.

Executive Summary.

Bridges WP2 assesses the transformations of jobs in the context of so-called "fourth industrial revolution" and the necessary workforce skills for the development of Industry 5.0.

This document presents a measurement framework and a data strategy on which the WP2 partners have built a consensus, taking into account the results of WP1 and based on a literature review and internal seminars. It includes a first overview of the possible operationalisation of the concepts used in WP2 with the selected data sources.

WP2 mobilises the available statistical information to analyse the relationship between the digital and green transformation and its outcomes regarding human-centricity, resilience and sustainability.

We will conduct four tasks in interaction using and combining in innovative ways existing high-quality data sources. Two tasks will develop an EU-wide level statistical perspective at the sectoral (T2.2) and regional (T2.3) levels. Two other tasks will elaborate further through an in-depth statistical approach in five countries (T2.4) and in the manufacturing sector (T2.5). This report summarises the results of the first task of WP2 (T2.1), which objective is to analyse different data sources from the same theoretical point of view to be able to compare the results obtained from the various tasks and to draw clear conclusions from them.

The measurement framework develops around some key ideas:

I. **Technology requires a significant number of social and political choices**, signifying that it is neither deterministic nor neutral. As such, our focus lies on organisations strategic choices to increase their productive knowledge. The central idea of our measurement framework revolves indeed around the **role of knowledge, which we consider a collective resource** transcending the confines of individual firms

II. We identify Industry 5.0 practices as those that produce the **knowledge inputs** needed to achieve the objectives of Industry 5.0. They lie in tangible and intangible investments that increase the stock of knowledge about the production process. We identify four categories of investments**: in the learning capacity of the organisation, in the environment preservation capacity and in the adoption and use of digital and green technologies**. These investments are interdependent, and synergies can be created by combining them. These practices generate innovations resulting from the implementation of new ideas in the production process, which we describe as **knowledge outputs**.

III. We then look at the outcomes of the implemented Industry 5.0 practices grouped under the three objectives of Industry 5.0, **human-centricity, resilience and sustainability**, to assess whether and to what extent organisations' strategic choices are effective in **moving towards Industry 5.0**.

IV. We recognise that organisations are embedded in larger structures like Global Value Chains (GVC), sectors or territories, which influence their market power, production, adoption of technology, absorptive capacity, likely to orient their strategies. We therefore take into account the possible **levers and barriers to achieving Industry 5.0** by including **context scenarios** as transversal to our measurement framework.

1. Introduction.

Bridges WP2 assesses the transformations of jobs in the context of the so-called "fourth industrial revolution" and the necessary workforce skills for the development of Industry 5.0. It maps the learning capacity of organisations, how it orients the adoption and uses of industry 4.0 technologies, and the consequences for job restructuring, emerging occupations, skill requirements, labour shortages and mismatches.

We conduct four tasks in interaction using and combining in innovative ways existing high-quality data. An EU-wide level statistical perspective at the sectoral (T2.2) and regional (T2.3) levels is developed. Then, an in-depth statistical approach in five countries (T2.4) and in the manufacturing sector (T2.5) is elaborated.

For the implementation of these tasks, T2.1 builds a measurement framework and a data strategy, taking into account WP1 results. The aim is to develop a common strategy to analyse different data sources from the same theoretical point of view, to be able to compare the results obtained from the various tasks and to draw conclusions from them.

This document outlines the measurement framework developed to examine the interplay between the digital and green transformations and their impacts on human-centricity, resilience and sustainability. Our target is to assess, using the available statistical information, whether the adoption of emerging technologies such as AI (Artificial Intelligence), ML (Machine Learning), blockchain, big data, IoT (Internet of Things), and 5G, along with the corresponding organisational practices and skills utilisation within enterprises, have been effective in progressing towards Industry 5.0. Results from our analysis provide useful information to understand the transformation of jobs in the context of the "fourth industrial revolution" and help assess the workforce skills needed for Industry 5.0.

Methodologically, the work draws upon a literature review and internal seminars conducted by the participating Bridges partners. Six seminars took place at various stages of the project, specifically on the following dates: February 20th, April 17th, May 15th, May 22nd, June 12th and October 9th 2023. The seminars discussed ideas about:

- the key concepts that the teams intend to use for each task undertaken in WP2;
- how the envisioned analysis contributes to assessing the transformation of jobs;
- our understanding of Industry 5.0 objectives in terms of human and socio-centricity, sustainability and resilience (also in coordination with WP1 which were developing the general conceptual framework of Industry 5.0);
- how these key concepts relate to one another.

Section 2 presents the consensus around the measurement framework, based on literature reviews and on identification of the key dimensions in our analyses. Then section 3 discusses the related data strategy based on a selection and combination of complementary existing data sources at the regional, national and international levels. We propose operationalisations of identified concepts for each dimension of our measurement framework, which is also based on the availability of reliable data sources.

WP2 develops tools to understand the technological and social transformations of the past decade, relying on existing data from European official statistics. Consequently, it is constrained by the data that have been collected in the past. It is equipped to assess whether there have been shifts in industry practices and outcomes. These shifts will be evaluated within the context of Industry 5.0 policies. The research can also show whether companies are already aligning with the policy objectives.

In contrast, the other Bridges WPs to which WP2 is interrelated have a distinct nature. WP1 revolves around the exploration of the Industry 5.0 concept and considers potential future perspectives. WP3 concentrates on web scraping of job vacancies and other non-structured sources, generating significant big data to assess indications of Industry 5.0 in current practices. WP4 proposes new metrics for future policymaking.

This document uses results from WP1 and provides guidance for data uses in WP3 and WP4. Finally, it also feeds the data management plan coordinated in WP10.

2. The conceptual and measurement framework.

The measurement framework we build aims at understanding the transformation of jobs in the "fourth industrial revolution" and at assessing the workforce skills requirements for Industry 5.0. We mobilise the **available data from European official statistics** to analyse the relationship between the digital and green transformations and their outcomes regarding human-centricity, resilience and sustainability.

First, we emphasise the importance of social and organisational aspects within the realm of production. Organisations, when integrating technologies in their production process, make deliberate choices and formulate strategies to take advantage of the opportunities these technologies offer. We believe that **technology requires a significant number of social and political choices**, signifying that it is neither deterministic nor neutral.

We start from the framework proposed by Greenan and Napolitano (2023) and designed for analysing the socio-economic consequences of the technological transformation in the EU funded Beyond 4.0 project. We expand it for the needs of the Bridges 5.0 goals. The central idea revolves around the role of knowledge, which we consider a collective resource transcending the confines of individual firms. *Figure 1* provides a graphical representation of the conceptual and measurement framework we have developed in WP2, the specific dimensions of which are presented throughout this report in detail both in terms of reference literature from which we derive the concepts and possible operationalisations.

We focus on the investments made by organisations to implement **Industry 5.0 practices** likely to expand their **stock of productive knowledge**. These practices lead to the development of **innovations** resulting from the implementation of new ideas in the production process.

Along to R&D that is traditionally considered as driver of innovation, we identify key tangible and intangible investments as **knowledge inputs:** the **learning capacity of the organisation**, the **environmental preservation capacity** and investments in **digital and green technologies adoption and use**. In particular, the capability to learn, adapt, and orchestrate resources is seen as a crucial aspect to orient Industry 4.0 technologies towards Industry 5.0.

We also consider that tangible and intangible investments are interdependent, and synergies can be developed by combining them. Because of these **interdependencies and possibilities of coevolution**, the relationship between digital technologies, skills utilisation, organisation of work, and innovation is complex (Ciarli et al., 2021) and needs to be analysed. We thus explore the data possibilities that we have in terms of interactions, simultaneous estimation of multiple relationships or construction of composite indicators that may capture Industry 5.0 practices in a synthetic manner.

Figure 1: Conceptual and measurement framework
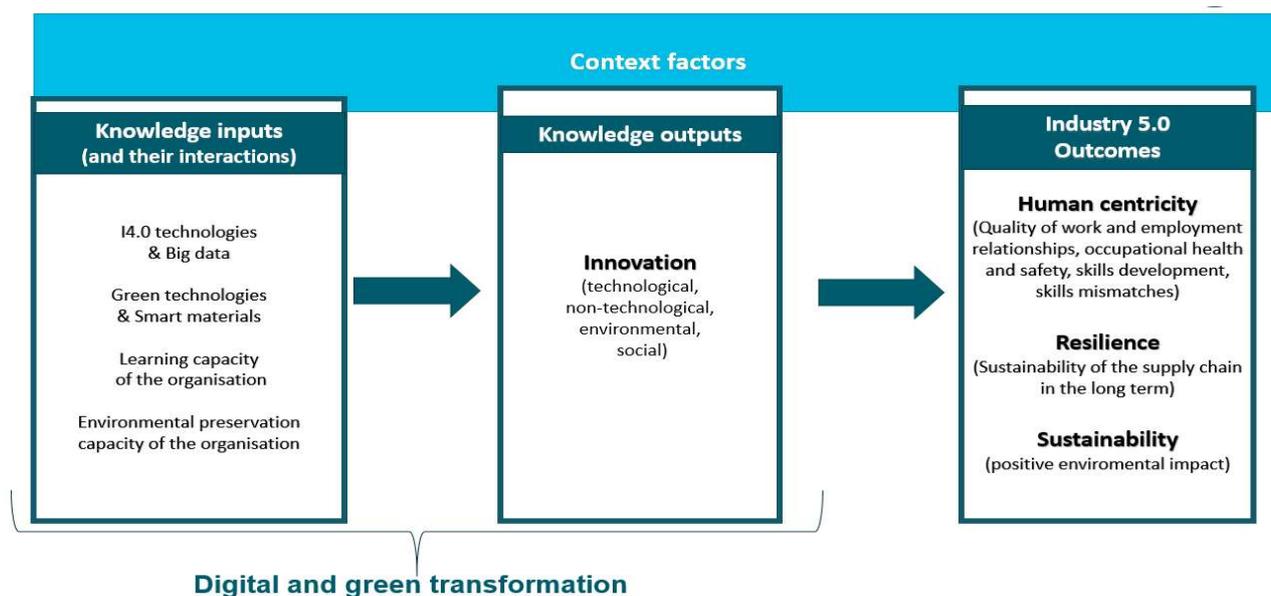
Second, **we consider the outcomes of the implemented Industry 5.0 practices**. In particular, we aim to assess whether organisational choices in terms of strategic investments have produced positive socio-economic and environmental outcomes. We group these socio-economic and environmental outcomes under the three dimensions of Industry 5.0 (human-centricity, resilience and sustainability) to assess whether and to what extent organisations' strategic choices are effective in moving towards Industry 5.0.

Organisations are key actors in the digital and green transformation, but not the only one. They are embedded in larger structures such as Global Value Chains (GVC), sectors or territories that influence their market power, production, adoption of technology, absorptive capacity, likely to orient their strategies with consequences on human-centricity, sustainability and resilience. We therefore take into account the possible levers and barriers to achieving Industry 5.0. We consider those context scenarios as transversal to our measurement framework.

In this section, we map the concepts we have selected and the indicators we are able to measure from the available EU-wide surveys to approach them.

a. Context factors.

At least three different and interconnected streams of literature have highlighted the relevance of 'context factors' in the process of technological change and its outcomes in terms of employment and job transformations.

A first stream of research, which we can roughly refer to as "innovation and management studies", explains why certain firms innovate more than others by explicitly considering the **role of interdependencies across businesses**. This tradition identifies several determinants of technological change, among which a key role is played by the 'absorptive capacity' of firms, defined as the ability to learn, assimilate, and use knowledge developed elsewhere through a process that involves substantial investments (Cohen and Levinthal, 1990). Indeed, individual firms and organisations – mainly SMEs – can have difficulty innovating independently (Freel, 2003). Instead, their innovation capacity largely depends on the ability to use and take advantage of an extended knowledge base accumulated and

developed through extensive networks and links with other organisations (e.g., other firms, universities and public agencies) and, therefore, through acquiring external knowledge.

Hence, among the contextual factors that shape a company's innovation capacity and performance, various elements are of importance. They include the **firm's industry, geographical location, networking, access to external resources, knowledge and technology acquisition, government policies, and the prevailing cultural environment**. Focusing on disruptive innovations, for instance, Antonio and Kanbach (2023) affirm that contextual factors go beyond the individual and firm levels encompassing "an industry, environment, markets, demand, society, or a nation" (p. 4). These determine the conditions under which disruption takes place.

In general, this environmental perspective complements the resource-based view of firms by emphasising the significance of (i) structural forces within the firm's operational environment; (ii) the firm's communication with external sources of knowledge and expertise, and consequently, collaborative connections between the firm and other external partners operating within the same environment. These connections may potentially emerge through the firm's participation in inter-organisational relationships and local networks (Rothwell and Dodgson, 1991). In fact, recent innovation models highlight that firms, particularly SMEs, increasingly engage in open search strategies, involving a wide array of external actors and resources to discover novel ideas, drive innovation, and shape the goals of new technology. These goals may include objectives such as replacing labour versus enhancing work quality, reducing the ecological impact of production, and more.

The framework of the "National Systems of Innovation" (NSI) research stream - developed in the 1980s and 1990s by Freeman (1987), Lundvall (1992), and Nelson (1993) - comprehensively evaluated all these aspects. The NSI approach places a strong emphasis on the interactions among actors involved in innovation and examines how social, institutional, and political factors influence these interactions (Fagerberg and Verspagen, 2009). Particularly, the regionally focused perspective of innovation systems, known as the "**Regional Systems of Innovation**" (RSI) approach, which has been further developed by scholars in the field of geographic economics (Asheim et al., 2003; Asheim and Gertler, 2005), highlights the intricate relationship between innovation/technology and firms' geographical location. It stresses the pivotal role of spatial concentration of industrial organisations and institutions (e.g. universities/research institutes and public agencies) in driving the regional clustering of innovative activities. The entrepreneurial ecosystems approach, introduced as part of the RSI framework (Stam and Spigel, 2018), underscores the importance of comprehending how interactions among various actors and factors within regions stimulate entrepreneurial activities. Consequently, several critical elements that are worth consideration include **(i) the interactions among various actors within the innovation system concerning the exchange of knowledge; (ii) the establishment and functions of institutions that facilitate knowledge exchange and innovation within a given region; (iii) the formulation of regional innovation policies**.

Among institutional context factors shaping innovation dynamics and possibly influencing the 'human-centricity' of technologies, the role of trade unions and more generally the relevance of social dialogue linked to the specific settings of national industrial relations should be acknowledged. The degree and direction according to which the introduction of digital and automation technologies – and the ensuing transformation of organisational practices – emerge are the result of the interaction between employers and employees (Cirillo et al., 2023). Empirical research suggests that **trade unions** have played a crucial role in influencing the implementation of technological and organisational practices (among others,

Jürgens and Krzywdzinski, 2016). However, the role of trade unions varies across firms and over time: in some instances, trade unions foster the adoption of technology and high-performance work practices (Gill, 2009; Gill and Meyer, 2013); while in others they hamper the implementation of new forms of coordination, when it is perceived as a threat by trade unions (Herrigel and Sabel, 1999). According to Eurofound (2015, 2017), companies that encourage their employees to participate in broad decision-making around operations or strategic direction improve job satisfaction and raise the level of innovation. Therefore, from a policy perspective, the European Commission claims that 'it is essential to have workers' (and their trade unions') trust and contributions at all relevant levels and in all relevant bodies – be it at the local level and/or on management or supervisory boards' (EU, 2019 - SOC/577-EESC-2018-02162-00-00-AC-TRA). The European social partners' autonomous framework agreement on digitalisation, signed in 2020, is an interesting initiative to frame the actions of social partners on digitalisation issues.

All these considerations bring us to the second research stream that examines the influence of context-related factors in the process of innovation/technological change. This research is rooted in **economic geography** and places significant emphasis on regional clusters (Porter, 1990), industrial districts (Becattini, 2004; Scott, 1988), technopoles (Benko, 1990), learning regions (Florida, 1995), entrepreneurial ecosystems (Stam and Spigel, 2018), and innovative milieus (Maillat, 1995; Crevoisier, 2004). More recently, Grilliitsch and Asheim (2018) have highlighted the role of regional industrial diversification in fostering the development of industrial paths, leading to economic growth and the creation of new jobs as a sustainable alternative to a downward spiral of cost competition.

As a result, regional conditions play a significant role in shaping an innovation strategy aligned with the principles of Industry 5.0. Taking a broader view, Hassink (2020) stresses that "context-related factors should also include place-specific informal institutions, such as norms and values affecting the regional economy, in the sense of risk-taking or risk aversion, place-specific drivers of actors, which go beyond technological innovations, as well as the untapped, endogenous potential for development in regional economies" (p. 10).

A third stream of research acknowledges the significance of **macro-level "context-factors"** by recognising aggregate demand as a driving force in the innovation process. From this perspective, the key arguments supporting the importance of demand for innovation trace back to the contributions of Schmookler (1962) and Myers and Marquis (1969). They emphasise the critical **role of demand dynamics** in influencing investments in inventive activities, including those related to green and human-centric innovation, across various products and industries: the expected profitability and the potential expansion of market demand serve as incentives for inventive activities and innovation (Kleinknecht and Verspagen, 1990; Mowery and Rosenberg, 1993).

Evolutionary scholars have further developed these ideas, highlighting the **relevance of demand conditions** as a determinant of innovative performance (Andersen, 2001; Metcalfe, 2001; Saviotti and Pyka, 2004). Post-Keynesian perspectives on structural change also underscore the significance of demand in driving economic growth and shaping a country's sectorial structure. According to this view, industries are expected to grow, or decline, based on the intertwined evolution of technology and demand (Pasinetti, 1981). A substantial expansion of both domestic and foreign demand provides opportunities for creating new economic activities and jobs, along with job displacement resulting from technological advancements. New products are often introduced during periods of expansion when they can more readily meet new demand (Pianta, 2020).

On this line, recent contributions point to the **degree of concentration of the products and labour markets** (usually proxied by the Herfindahl-Hirschman index on sales, profits or employers' shares in a given narrowly defined industry, occupation and geographical region) as other contextual factors that are likely to shape industry 5.0 scenarios. For instance, focusing on the US economy, De Loecker et al. (2020) highlighted that firms have increasingly exerted market power over the last decades charging higher prices and obtaining higher profits. Such increase in market power led to labour share contraction, decrease in low-skilled wages and labour market participation. Similarly, focusing on Europe, Arkai et al. (2023) show that European labour markets are no more competitive than North American ones, despite the much stronger labour market institutions in Europe. Higher concentration and monopsony power exerted by 'leading' companies are likely to affect the adoption of Industry 5.0 organizational practices since these corporations are able to compress wages, impacting also on employment and nonwage attributes. Therefore, we should expect a negative correlation between higher market (and labour) concentration and 'human-centricity' type of technological practices. For instance, the researcher should investigate this relation considering the concomitant reduction of collective bargaining and the weakening of trade unions recorded in Europe over the last decades.

b. Knowledge inputs.

i. Industry 4.0 technologies and Big Data

Industry 4.0, often referred to as the "fourth industrial revolution", signifies the next stage in the digital transformation of the manufacturing sector and therefore has a significant impact on the transformation of jobs and tasks of workers. It represents a paradigm shift, offering heightened control across the entire product life cycle value chain (Lasi et al., 2014). At its core, Industry 4.0 envisions the creation of smart factories, where machines are augmented with web connectivity to both enable communication between them as well as enable decentralised, independent decision-making which allows for execution of tasks with minimal human intervention (Rejikumar et al., 2019).

Industry 4.0 is propelled by disruptive technological trends such as the proliferation of data and connectivity, cloud computing, AI, improvements in production technologies or tools such as robotics, additive manufacturing (3D printing), all to promise real-time decision-making, enhanced productivity and flexibility in production processes (Brettel et al., 2014; Dalenogare et al., 2018; Oztemel and Gursev, 2020).

The impact of Industry 4.0 extends across the entire range of industries. Within manufacturing, cyber-physical systems facilitate the connection of physical devices with digital systems, empowering computers to autonomously configure and dynamically adjust facilities (e.g. industrial robots on the shop floor) to align with production plans (Wang et al., 2015). This potentially minimises the need for human intervention throughout the production process and at the same time asks for new skills and job profiles of employees.

Since the improvements of operations and processes hinge on smart decisions, the growing research emphasis lies on the convergence of Industry 4.0 and data analytics (Jagatheesaperumal et al., 2022; Lee et al., 2014; Qi and Tao, 2018). At the heart of Industry 4.0, therefore, is the concept of **Big Data**, which refers to extensive data sets characterised by their growing volume, variety, and velocity. Big Data analytics plays a central role within Industry 4.0, offering invaluable insights for smart factory management and encompassing a wide range of technologies designed to efficiently manage big data (Duan and Da Xu, 2021).

Table 1: Key identified Industry 4.0 technologies and big data

INDUSTRY 4.0 TECHNOLOGIES AND BIG DATA
Collaborative/mobile robots
Cyber-physical systems
Big data analytics
Internet of Things (IoT)
Augmented reality
AI and machine learning
Cloud computing
Edge computing
Cybersecurity
Digital twin

Table 1 provides an overview of technologies that need to be identified in our survey material to describe the digital intensity of organisations, by taking into account the diversity of the adopted technologies as well as their constant renewal. In this regard, AI technologies are more difficult to capture with lists: AI is often not a standalone technology, but it is embedded in other technologies or objects. Additionally, international comparability can be an issue (Montagnier and Ek, 2021).

ii. Green technologies and smart materials

Several terms can define '**green technology**' - including Environmentally Sound Technology (ESTs), Cleaner Production Technology, Energy-efficient technology, and Climate technology - although there is no worldwide-shared criterion for their classification (WIPO, 2019). The lack of a standardised classification system leads to high uncertainty of green technology selection (Ru Guo et al., 2020). Moreover, green technology is a dynamic concept covering a wide range of fields and assuming different classifications according to geographical regions. Historically, "Environmentally Sound Technology" (EST) can be considered the earliest concept related to green technology, introduced by Agenda 21 in 1992 (UNEP, 2012) and referring to all systems promoting environmental sustainability. Over the years the understanding of green technology has widened from a narrow focus on pollution control and resource conservation (Braun and Wield, 1994) to integrated sustainable solutions that consider the environment, the economy, and society (UNCTAD, 2018). Therefore, the understanding of green technology has undergone a change from solving purely environmental problems to tackling integrated sustainable challenges.

The core idea of green technologies relies on the value attributed to nature. Consequently, "the purpose of green technology is to achieve harmony between human and nature": only those technologies considering the needs of both humans and nature according to local conditions can be considered green technologies (Ru Guo et al., 2020, pp. 2-3).

The definition of green technology is also gradually broadening to intersect with modern technologies, such as nanotechnology, information technology, or bioengineering technology (Lee et al., 2015). From the perspective of different environmental elements, we can distinguish technologies related to water quality, air quality, solid waste and other aspects of the environment. Focusing on life cycle analysis, green technology can also be classified into

different stages, including production, use, recycling, and disposal (Dangelico and Pontrandolfo, 2010).

One of the main attempts to categorise green technology focuses on their practical applications proxied by **patents' information**. The Environmental Sound Technology Concordance table developed by the US Patent and Trademark Office provides a valuable example. It classifies environmentally sound technologies into six categories (USPTO, 2018). The US Bureau of Labor Statistics proposes a classification into seven types of Green Goods and Services. A European example is the classification developed by the Environmental Technology Verification Pilot Program for Europe[1]. An extensive summary of existing green technology classification systems is provided in Table B1 of Ru Guo et al. (2020).

Therefore, a common approach in the literature is to estimate the influence of green technologies using indicators such as green patents, and specifically environmentally related patents (Shao and Cheng, 2022). In 2010, the World Intellectual Property Organization (WIPO) introduced the 'International Patent Classification (IPC) green list, an online resource meticulously crafted to streamline access to patent-related information concerning ESTs. This resource was integrated into WIPO's IPC system to enhance accessibility. The IPC Green Inventory encompasses a comprehensive list of approximately 200 subjects related to ESTs (Ru Guo et al., 2020)[2]. Leveraging this list, it is possible to construct a regional index of green technologies, utilising data from the PATSTAT database of the European Patent Office. This index can be computed as the ratio of authorised green patents to total authorised patents[3].

Table 2: Key identified green technologies and smart materials

GREEN TECHNOLOGIES AND SMART MATERIALS
Green patents
Environmentally-related patents
Renewable energy power plants

Smart materials are also known as advanced materials or intelligent materials that have the properties to recoil their original shape to specific stimuli or, more generally, to adapt to environment changes (Bogue, 2014). They can be "passive smart materials" having ability to transfer a type of energy (e.g. optical fibres are able to transfer electromagnetic waves) or "active materials". According to Nicolay et al. (2023), active smart materials can be further divided into two categories: (i) those which cannot change their properties when exposed to external stimuli (e.g., photo chromatic glasses when placed in sunshine they only change their colour); (ii) those that can alter one form of energy to another form (e.g., piezoelectric materials can produce an electric charge when exposed to external strain).

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[1] Following an internal assessment, the European Commission discontinued its work on the ETV programme in 2022 (https://green-business.ec.europa.eu/eu-environmental-technology-verification_en).

[2] Another valuable platform for the exploration of green technology is the Open-Power-System Data. The dataset collects information on renewable energy power plants for the Czech Republic, Denmark, France, Germany, Poland, Sweden, Switzerland, and the UK.

[3] Another valuable platform for the exploration of green technology is the Open-Power-System Data. The dataset collects information on renewable energy power plants for the Czech Republic, Denmark, France, Germany, Poland, Sweden, Switzerland, and the UK.

For their peculiar properties, smart materials are suitable to make cities smarter and more energy efficient. The intrinsic physicochemical properties of materials and their ability to react to external stimuli (e.g. increased temperature, increased sunlight, the appearance of a crack) allow reducing the environmental impact of the structures of which they are an integral part (Gracias et al., 2023). In any case, the integrated sensors are fully passive and wireless, with no embedded electronics or battery.

Table 2 provides an overview of relevant green technologies that we intend to map.

iii. The interaction between digital and green technologies

Green technologies are also interconnected with the last generation of digital technologies since the latter are often envisaged to allow firms to improve the environmental efficiency of the entire array of their business processes, from eco-design and new product development to transformative production processes, from the heating and cooling systems of plants to process re-engineering and waste disposal (Montresor and Vezzani, 2023). We thus expect Industry 4.0 technologies to allow firms to achieve higher efficiency and minimise their negative environmental impacts (Jena et al., 2020; Azadi et al., 2021).

New **green IT**s are constituted by eco-innovation in the IT sector encompassing a wide range of product and process innovations that can attenuate the environmental damages caused by IT, for example, less energy-consuming cloud systems or new secondary material-based robotics. According to Montresor and Vezzani (2023), green ITs are represented by opportunities to eco-innovate obtained through the adoption and development of IT even by firms in other sectors than digital ones. This entails rendering IT functional to the discovery and exploitation of new eco-innovation opportunities in terms of more energy and resource-efficient production processes; this, in particular, within sectors such as transport, construction and energy, which are among the most significant contributors to carbon emissions (Faucheux and Nicolaï, 2011). Several studies - among them Jena et al. (2020) and Liao et al. (2021) - have also highlighted that, by building up internal digital capabilities, firms can make the same technologies functional to environmentally sustainable production processes; therefore, digital technologies facilitate the process of knowledge recombination fundamental for the development of eco-innovation (Barbieri et al., 2020).

New digital technologies also show some disadvantages. For instance, they entail the need to manufacture and integrate millions of electronic circuits into objects able, in turn, to store and process a significant amount of data, which are energy-consuming operations. Moreover, the widespread use of electronics raises important issues of recycling. Therefore, other solutions are beginning to be explored, such as the use of intelligent materials, "capable of reacting on their own to external stimuli or performing useful tasks without the need for electronics or on-board energy" (Nicolay et al., 2023, p.1).

iv. The Learning capacity of the organisation

The green and digital transition requires changes to find organisational solutions and business models that can better respond to rapidly changing environments (Bodrožić and Adler, 2018; Dosi et al., 2000; Teece, 2018). The learning capacity of the organisation is a critical element of the innovation process, able to foster adaptation and low-cost competition through learning (Arundel et al., 2007; Greenan and Lorenz, 2010). The economic and management literature stress that learning is achieved when organisations are able to question the norms and values that guide their strategies and modify them accordingly (Argyris and Schon, 1978). Learning organisations, therefore, have the managerial ability to function without disrupting their structure (Prus et al., 2017; Teece, 2018), being successful

in solving the trade-off between exploration and exploitation objectives by dynamically renewing their strategies (Greenan and Lorenz, 2010; Greenan and Napolitano, 2021).

Learning develops at the organisational level (Senge, 1990). It is a collective process which involves individual learning, but which is different from the simple aggregation of individual behaviours because of the organised framework in which new knowledge is processed. A learning organisation is thus able to create, acquire, transfer and integrate knowledge and distribute it among its members (Jerez-Gómez et al., 2005). In so doing, a learning organisation can encourage employees to develop innovative work behaviours (Jerez-Gomez et al., 2005; Greenan and Lorenz, 2010; Greenan and Napolitano, 2021).

Greenan and Napolitano (2023) constructed a composite indicator of the learning capacity of the organisation using statistical data from Eurofound. They identified those management tools and organisational practices aimed at improving learning, at the individual, group and organisational level, simultaneously considered. Individual learning is favoured by supporting the cognitive dimension of work and the autonomy of workers, as well as by the provision of training opportunities for skills development. Group learning is fostered by the organisation of work around autonomous teams and by the encouragement of social support between colleagues and between managers/supervisors and workers. Learning at the organisational level is incentivised by a supportive supervisory style that authorises and encourages experimentation, provides feedback and helps resolve conflicts while respecting workers as persons, as well as by supporting employee motivation and offering opportunities for direct participation in the decision-making process.

In this framework, we additionally consider that the diversity of workforce may foster the learning capacity of the organisation. The idea is that a workforce that shows heterogeneity in terms of sex, age, cultural background, educational and national origins represent a strength for the organisation. On the other hand, workforce diversity also represents a big challenge for management to ensure that diversity does not hamper productivity by rising difficulties and conflicts between different groups but contributes to fostering innovation and good performance (for a review, see Capozza and Divella, 2023).

Table 3 provides the main indicators to measure the concept of the learning capacity of the organisation.

Table 3: Key identified practices relevant for the learning capacity of the organisation

LEARNING CAPACITY OF THE ORGANISATION
Preservation of the cognitive dimension of work
Autonomy of workers in cognitive tasks
Provision of training opportunities
Autonomous teamwork
Social support
Supportive supervisory style
Worker motivation backed up by the organisation
Direct participation
Workforce diversity

v. Environmental preservation capacity of the organisation

The concept of firms having environmental responsibilities is relatively recent. ISO standards such as ISO 14000/1 mandate corporate involvement in this area but generally align with government regulations. These regulations, however, often fall short of achieving ambitious environmental preservation goals (Buysse et al., 2003). While regulations are recognised as significant drivers of environmental innovation (Horbach et al., 2012), achieving compliance frequently demands only minimal effort and investment, as stipulated by the regulations themselves (Guerci et al., 2015). In essence, regulations do not compel companies to innovate; thus, investing in environmentally protective innovations requires voluntary, additional efforts.

Wang et al. (2019) discuss several economic theories that have a perspective on environmental responsibility. The traditional economic view, as expressed by Friedman (1970), posits that firms' voluntary environmental efforts incur costs without direct benefit to shareholders. In contrast, stakeholder theory (Freeman, 1984) argues that considering all stakeholders, including employees and customers, can lead to competitive advantages. This perspective aligns with instrumental stakeholder theory (Jones, 1995), which asserts that ethical behaviour enhances firm reputation and relationships with stakeholders. Resource theories, exemplified by the Porter Hypothesis (Porter and Van der Linde, 1995), link environmental goals to industrial competitiveness. Additionally, the theory of firm resources emphasises managing environmental assets for competitiveness (Russo and Fouts, 1997). Environmental responsibility can also serve as a strategy for product differentiation (McWilliams and Siegel, 2001) or a pre-emptive measure against stringent regulation (Maxwell et al., 2000). From a Coasian perspective, Heal (2005) argues that firm environmental responsibility reduces conflicts between firm and society, thereby reducing firms' costs.

Buysse et al. (2003) link to the resource-based theory of the firm to develop a more grounded typology of environmental strategies. From this resource-based view (Hart, 1995) they distinguish four types of resource-based environmental approaches: (1) the end-of-pipe approach, (2) pollution prevention or total quality management, (3) product stewardship and (4) sustainable development. Buysse et al. (2003) empirically assessed a comprehensive set of competencies and procedures for evaluating the extent of a management's focus on environmentally responsible policies. This includes **investments in green competencies, employee skills, organisational competencies, and specific management systems and procedures such as environmental planning, life cycle analysis, and reporting. It also includes examining the integration of environmental concerns in the strategic planning process**. This classification can be used for understanding the environmental preservation capacity of the organisation.

Many of these elements can be found in what policymakers advocate. The OECD Guidelines for Multinational Enterprises Corporate Responsibility (2004) gives guidance to develop an overview action. Sound environmental management is an important part of sustainable development, increasingly seen as both a business responsibility and a business opportunity. Multinational enterprises (MNEs) have a role to play in both respects. The OECD Guidelines encourage MNEs to raise their environmental performance through improved **internal environmental management** and better **contingency planning for environmental impacts** and emphasise the importance of integrating environmental considerations into businesses' core strategies and daily operations. These criteria, applicable at the company level, include conducting thorough environmental impact assessments, considering risks based on scientific understanding, and avoid using uncertainty as an excuse to delay

preventive measures. Additionally, companies are advised to have contingency plans for environmental and health emergencies, adopt high environmental performance standards across all operations and adopted technologies, and prioritise products and services with minimal environmental impact and which are efficient in their consumption of energy and natural resources, can be reused, recycled, or disposed of safely. Promoting customer awareness of environmental implications, conducting research for long-term environmental improvement, and providing comprehensive education and training for employees in environmental health and safety are also recommended. Furthermore, companies are encouraged to develop effective environmental policies, such as partnerships, to enhance public environmental awareness and protection.

While these guidelines are designed for MNE, smaller businesses, despite limited resources, also need to strive to implement as many of these measures as possible (economena.org). The strategies and policies that are required for environmental preservation are not only strategic management, they touch the employees in the organisation and they affect stakeholders. *Table 4* summarises the main concepts that need to be checked in surveys.

Table 4 Key identified practices relevant for the environmental preservation capacity of the organisation

ENVIRONMENTAL PRESERVATION CAPACITY OF THE ORGANISATION
Conducting thorough environmental impact assessments
Contingency plans for environmental and health emergencies
High environmental performance standards across all operations and adopted technologies
Prioritise products and services with minimal environmental impact (green products)
Promoting customer awareness of environmental implications
Conducting research for long-term environmental improvement
Providing comprehensive education and training for employees in environmental health and safety
Partnerships to enhance public environmental awareness and protection

vi. Industry 5.0 innovation capacity

The different knowledge inputs can be considered jointly. A composite indicator of "Industry 5.0 innovation capacity" allows a flexible combination of the multiple investments of the firm to increase its productive knowledge into one variable.

We consider the construction of this composite indicator in order to capture the multidimensionality of the organisation's strategic choices, which can arguably be proxied by the interaction of all knowledge input domains. The challenge in such a strategy is to select certain variables as well as to set specific weights per variable to yield a summary measure.

Each variable considered as a component of the composite indicator must be assessed for its properties to describe a latent variable – the I5.0 innovation capacity of the organisation. In order to test the validity of the indicator, an analysis of patterns and relationships among observable variables and the latent concept also needs to be conducted.

For these properties, a single source of information is needed. The European Manufacturing Survey (EMS) is a good data source for the construction of this composite indicator. Several studies have relied on it to answer related questions, using similar – albeit not identical –

variables and measurement approaches (Dachs, Kinkel, and Jäger, 2019; Dachs, Kinkel, Jäger, et al., 2019; Dachs and Palčič, 2020; Kinkel, 2014).

c. Knowledge outputs.

Knowledge outputs consist of the introduction of innovations resulting from the implementation of new ideas into the production process. Innovations can be technological, non-technological, environmental and social.

Technological and non-technological innovations have been the focus of the economic literature on the analysis of productivity and profitability. The Oslo manual has provided definitions of the terms, then applied to the development of the European Community Innovation Survey (CIS) that has been regularly conducted since 1993. While the first focus of the Oslo Manual was on technological product and process innovations in the manufacturing sector (OECD/Eurostat, 2005), definitions of non-technological innovations (organisational and marketing) have been subsequently included to better address the questions of innovation in service sectors.

However, the line between **technological and non-technological innovations** is increasingly blurred because of the pervasive role of GVC, the rapid emergence of new digital technologies, how these technologies are embedded in new business models and the growing importance of knowledge capital (OECD/Eurostat, 2018).

As a result, the 4th edition of the Oslo Manual (OECD/Eurostat, 2018) reduces the complexity of the previously listed types of innovation (product, process, organisational and marketing) to two definitions distinguishing between product and business process innovation.

The first defines a "**product innovation**" as a new or improved good or service that differs significantly from the firm's previous goods or services and has been introduced on the market. It includes, because of the close relationship between the two activities, significant design changes. It also includes digital goods or services. It excludes the resale in the same condition as new goods or services and changes of an aesthetic nature.

The second one defined a "**business process innovation**" as a new or improved business process for one or more business functions that differ significantly from the firm's previous business processes and has been brought into use by the firm. It includes the core business function of producing goods and services and supporting functions such as distribution and logistics, marketing, sales and after-sales services; information and communication technology services to the firm, administrative and management functions, engineering and related technical services to the firm, and product and business process development. It also includes the organisation of procedures, management of relations with suppliers, work organisation, decision-making processes, and human resources.

Recently, businesses have begun to consider social and environmental concerns in their innovation efforts. This trend is evident in their growing commitment to sustainable innovations (Scott, 2005; Boons et al., 2013; Adams et al., 2016; Varadarajan, 2017). Sustainable innovations have traditionally been associated with addressing environmental challenges. Except for eco-industries, whose primary focus is developing green technologies, most firms require expertise and capabilities that are outside their core competences to engage in eco-innovations (Rennings and Rammer, 2009; Horbach et al., 2013; Ghisetti et al., 2015; Gonzalez-Moreno et al., 2019). Given rising concerns about global warming, environmental pollution, and the diminishing availability of energy and resources, these

innovations have become central to both environmental policies and corporate innovation strategies.

The definitions of environmental innovation can be based on motivation or on performance (Kemp and Pearson, 2007). Definitions of eco-innovation based on its motivation and intended outcomes have been considered as confusing because what is of interest are the actual environmental effects deriving from the use of an innovation, not its purpose (Kemp and Pearson, 2007).

Definitions based on performance have hence been preferred for their focus on the positive environmental effects related to the use of innovation. An **eco- innovation** is defined as 'the production, assimilation or exploitation of a product, production process, service or management or business methods that is novel to the firm [or organisation] and which results, throughout its life cycle, in a reduction of environmental risk, pollution and other negative impacts of resources use (including energy use) compared to relevant alternatives" (Kemp and Pearson, 2007, p. 7).

Starting in 2008, the CIS included additional modules, varying from one edition to another. The 2008, 2014 and 2020 editions cover **innovations with environmental benefits**, defined as "new or improved product or business process of an enterprise that generates positive or lower negative environmental impacts, compared to the enterprise's previous products or processes, and that has been made available to potential users or brought into use. The environmental benefit can be the primary objective of the innovation or a by-product of other objectives. It can occur during the production of a good or service, or during its consumption or use by the end user of a product.".

Innovations addressing societal challenges are not limited to environmental and climate concerns, but also extend to a broad range of social issues, such as, for instance, the health and safety of workers in relation to diseases, accidents and hazards (Divella and Sterlacchini, 2021). These innovations encompass new technologies aimed at providing employees with enhanced safety measures and specialised equipment, as well as the application of new techniques, procedures, and tools that make work tasks less strenuous and more manageable. Numerous examples of such technologies exist, including digital "smart" signage and high-speed communication systems that increase employee awareness of potential dangers, wearable technologies like smartwatches and other devices (e.g., bracelets, hats, gloves, jackets, and clothing) that allow real-time monitoring of employee conditions and immediate feedback on changing environmental conditions (e.g. increasing temperatures or exposure to harmful substances), and personal protective equipment improved through technology (e.g. safety glasses with anti-fog and anti-scratch coatings that reduce glare and improve clarity, and new materials used to make uniforms, hats, or boots more comfortable while simultaneously enhancing protection). However, the implementation of these technologies raises concerns about the risk of workers losing their autonomy, being intruded into their personal lives and having their performance monitored more closely (Moro et al., 2019).

The definition of innovation provided by the 2018 Oslo Manual, as specified in paragraph 3.18, "does not require it to have a positive value for society, or a positive benefit for the firm. In the former case, an innovation can lead to a significant boost in the financial performance of the firm while providing fewer benefits to consumers » (OECD/Eurostat, 2018, p. 69).

By contrast, the OECD defines **social innovation** as "the design and implementation of new solutions that imply conceptual, process, product, or organisational change, which ultimately

aim to improve the welfare and wellbeing of individuals and communities"[4]. In this sense, social innovation is different from innovations that have a social impact.

In our framework, we aim to consider **green and social innovations** as defined by their environmental or social objectives to improve the welfare of individuals or communities. We then aim to assess their effectiveness in producing environmental and social benefits, which are rather the Industry 5.0 outcomes of our measurement framework.

d. Industry 5.0 outcomes.

i. Human centricity

Human centricity covers two core ideas (Oeij et al., 2023). First, technology can be human centred, meaning that technology is reconfigured to support not subordinate or substitute human decision-making and activities. This can lead to worker "augmentation", to technological developments servicing human activity, or to the control and reduction of the harmful impacts of technology. The socio-centric approach adds the perspective that humans should not only be subject to change, but should also co-drive it as a community. These approaches to technology development should be associated with improved job quality and quality of working life.

Some conceptual and measurement frameworks have already been developed to measure such worker outcomes. The **ILO's Decent Work Agenda**, for example, is articulated around four pillars: job creation, fundamental principles and rights at work, social protection and social dialogue. It uses 75 statistical and 21 legal framework indicators pertaining to ten main elements: (1) employment opportunities, (2) adequate earnings and productive work, (3) decent working time, (4) combining work, family and personal life, (5) forms of work that should be abolished, (6) stability and security of work, (7) equal opportunity and treatment in employment, (8) safe work environment, (9) social security and (10) social dialogue. The **OECD Job Quality framework** assesses job quality considering three dimensions: (1) earnings levels and distribution across the workforce; (2) labour market security in terms of risk of unemployment and duration of unemployment as well as unemployment insurance in case of job loss; (3) quality of the working environment in terms of job strain (Cazes et al., 2015). The **United Nations Economic Commission for Europe** provides a statistical framework to measure the **quality of employment** articulated around seven dimensions: (1) safety and ethics of employment, (2) income and benefits from employment, (3) working time and work-life balance, (4) security of employment and social protection, (5) social dialogue, (6) skills development and training, (7) employment-related relationships and work motivation. Finally, even if it does not provide a framework, every five years **Eurofound** conducts an employee survey in European countries, the European Working Condition Survey, to gather data about **working conditions**, relative to the physical environment, work intensity, working time quality, the social environment, skills development, carrier prospects and earnings.

In WP2, we identify human centricity outcomes in the following dimensions:

- **quality of work and employment relationship,** with a focus on those conditions of vulnerability to adverse working conditions that have potential adverse impacts on workers' wellbeing for what concerns quality of work (Greenan and Seghir, 2022) and

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[4] https://www.oecd.org/cfe/leed/social-economy/social-innovation.htm

a focus on forms of precarious employment for what concerns the employment relationship;

- **occupational health and safety,** with a focus on accidents at work and work-related health problem as well as on OSH (Occupation Safety and Health) risks perception and mental well-being;
- **skills development and skills mismatches**
- **labour market dynamics**, with a focus on employment and unemployment trends and wage inequalities.

As these dimensions refer to wide concepts covering a large number of aspects, some of which are difficult to measure, tasks in WP2 will focus only on a selection of possible indicators. We will ground our choices on the specific research question for each task and on data availability and quality in the selected data sources. Section 3.b.iv provides a first overview of possible operationalisation of the mobilised concepts.

ii. Resilience

The concept of resilience, as advocated by the European Commission, deals with **supply chain resilience**. The COVID-19 crisis and the Russian war on Ukraine have highlighted vulnerabilities in the EU related to the critical shortages of products, supply chain disruptions and technological dependencies. Implications of these vulnerabilities complicate the long-term challenges to achieve the digital and green transitions (Diodato et al., 2023). Going further, the European Commission has suggested the concept of "Open Strategic Autonomy" defined as the capacity to cope alone if necessary but without ruling out cooperation whenever possible.

In WP2, the core question is to analyse this concept at an organisational level and thus gather information about the degree to which companies are able to manage the longer-term sustainability of their supply chains.

As, at the policy level, the question is how to make sure that Europe is capable of **securing essential resources** for its future development, the operationalisation of the concept of resilience is quite complicated. It is clearly focused at the company and supply chain level and it will require time to understand if companies have developed a better grip on their main resources. Moreover, the classification of such resources is not a simple task. The EU continuously updates a critical raw materials[5]. Hence, to date, historical data may be difficult to obtain. In addition, given that the policy was implemented from 2022, it may not yet be visible in data that does exist. A measure combining different strategic choices at the company level, and actual resource measures would be best, but data are scant.

In face of the lack of information about the capacity of organisations to deal with rapid changes as well as with crises affecting their value chains, we could try to proxy the health status of organisations through the dynamics of their business activity, capacity utilisation, profitability, employment.

Employee shortages can also be considered as a proxy of resilience, by considering that most EU countries are experiencing it, bringing out that employees are also a scarce resource and that the supply chain of personnel should be better secured. The situation is complex because part of this issue may have to do with labour hoarding as was experienced after the Financial Crisis of 2008.

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[5] https://single-market-economy.ec.europa.eu/sectors/raw-materials/areas-specific-interest/critical-raw-materials_en

From an economic perspective, the major stress on the resilience of supply chains seems misplaced. As the globalisation relies on international specialisation, if all economic blocks insist on securing all of their critical resources, the risk is of a further downfall of the global economy and the rise of a multipolar economy. Huawei is a case in point. The United States and the European Union have described Huawei's G5 capabilities as a risk to future mobile communications capabilities. Huawei was excluded from strategic investments in Europe and advanced technologies in the West. The Chinese company has surprised the blocks by launching new products that appear to be based on new Chinese technologies. Dependence on the West seems to have been circumvented[6]. This is why the European Commission is stressing that the Open Strategic Autonomy emerges as a response to crisis, but it does not mean to fall into protectionism. It is indeed a question of finding a balance between strengthening economic security and enhancing Europe's competitiveness.

iii. Sustainability

Industry 5.0 places a strong emphasis on the integration of humans and machines within industrial processes, with a primary focus on sustainability and human-centric innovation.

The issue of sustainable development is central in economic and policy discussions, encompassing "the interdependence between social, economic and environmental dimensions of sustainability" (Silvestre and Tirca, 2019; p. 326). The sustainable Development goals (SDG) formulated in 2015 by the United Nations set ambitious targets to achieve a sustainable, fair and inclusive future for people worldwide. The European Statistical System releases scoreboard to monitor progress towards the SDGs in an EU context (Eurostat, 2023)

Referring to this conceptual and measurement frame, the outcomes of Industry 5.0 in terms of sustainability can encompass resource efficiency, circular economy principles, eco-friendly manufacturing, supply chain sustainability, carbon footprint reduction, human-centric design, localised production, customisation, collaborative ecosystems and regulatory compliance.

Collectively, these outcomes should contribute to a more sustainable and environmentally responsible industrial landscape.

3. The data strategy.

a. The selected data sources.

WP2's research starts at the EU level by analysing EU-wide data sources and providing insights on different sectors and heterogeneous regional contexts. The assessment is then enriched by research in five countries representing different institutional contexts and a deep dive into value creation processes in manufacturing.

The **period of reference is the 2016-2022**. The possibility of having more time points in the analysis depends on both data availability and the econometric strategy adopted to conduct the study. In any case, the focus in WP2 is to describe current trends, but to feed into WP4, we also design and measure relevant Industry 5.0 indicators that should be useful for the forecasting (task 4.1) and indicator and metric development (task 4.3) exercises.

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[6] https://www.bnnbloomberg.ca/huawei-s-mystery-phone-shows-wireless-speeds-as-fast-as-apple-1.1966103

For the analysis at the sectoral or regional level, we gather information from existing **EU-wide cross-country datasets**. We use data released in an aggregated manner by data providers or, when necessary, we collapse individual level data collected at the company, household or worker level at a sector within countries or at the regional level.

The **aggregation** leads to a loss of information but allows the use of complementary data sources in an integrated manner. Indeed, the combination of different sources of data is possible by linking them throughout a common cell constructed on standard harmonised variables (Greenan and Napolitano, 2022).

Despite this inevitable loss of information, the sector level analysis allows taking into account competition or cooperation mechanisms between firms. Such analyses on an aggregated level is impossible to conduct with most individual level data sources. The regional level analysis is further vital since many economic phenomena are context specific. Agglomeration and geographical distance are fundamental drivers of the location of economic activity. Firms interact among themselves and with other local actors and organisations in order to generate knowledge, innovation and economic dynamism.

Task 2.2 aims to provide an EU-wide overview of job transformations (see *Figure 2*). It gathers, at the employer level, information about the adoption and use of Industry 4.0 technologies from the yearly **Community survey on ICT usage and E-commerce in enterprises** (CICT: Eurostat). This data, however, does not provide information about organisational practices such as investments in the learning capacity of the organisation and in the environmental preservation capacity. We approach this information with the **European Company Survey** (ECS: Eurofound, 2019) that focuses on work organisation, human resource management and social dialogue. T2.2 also gathers company level information about knowledge outputs from the ECS 2019, which focuses on innovation and business strategies with retrospective questions over 2016-2018 or from the **Community Innovation Survey** (CIS: Eurostat), which provides data on technological and non-technological innovation as well as on innovation with environmental benefits. Since 2005, the CIS has been conducted every two years. The last available edition is 2020, but Eurostat releases micro-data up to the 2018 edition only.

For Industry 5.0 outcomes, the 2023 **EU KLEMS** release provides measures of profitability at the industry level for all EU member states. **The European Survey of Enterprises on New and Emerging Risks** (ESENER: EU-OSHA, 2019), which is an employer level survey, describes digitalisation and related potential health and safety risks at work.

Figure 2: overview of the combination of datasets for T2.2
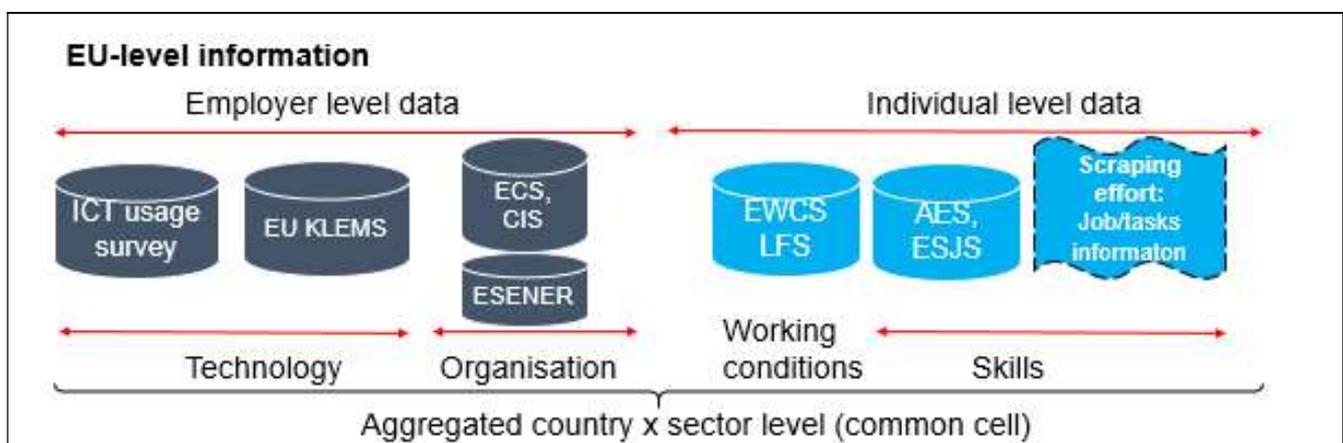
At the individual level, the **European Working Condition Survey** (EWCS: Eurofound, 2021) provides information on the quality of work and employment relationship, occupational health and safety, skills development and skills mismatches. The last available edition is 2021. However, due to the COVID-19 pandemic, face-to-face fieldwork for the 2020 EWCS was prematurely stopped. In 2021, a telephone survey was conducted. Due to the change in interviewing mode, comparison with previous editions of the survey will not be possible and the options for analysis of trends are limited. The **European Labour Force Survey** (Eurostat) provides valuable information on labour status. LFS has been conducted yearly since 1983. The last available edition is 2019. The **European Skills and Jobs Survey** (ESJS: Cedefop, 2021) cover skill requirements, skill development, skill mismatches and participation in initial and further adult education and training. The ESJS 2021 aims to inform about the impact of new digital technologies and technological change on the future of work and skills. As the EWCS, data has been collected in the context of the Covid-19 pandemic, but it is still not released. These individual level datasets are also explored to analyse job seekers' and adult students' situations, in combination with information characterising the practices of their former employers and training institutions.

Task 2.3 aims to provide an EU-wide regional overview of the transformations of jobs (see *Figure 3*). It combines the following **Eurostat's regional data** (i) Regional Economic Accounts; (ii) Regional Education Statistics; (iii) Regional Science and Technology statistics ; (iv) Regional Structural Business statistics ; (v) Regional labour markets ; (vi) Regional digital economy and society statistics. The **Regional Innovation Scoreboard** enables assessment of the innovation performance of European regions. It is a regional extension of the European innovation scoreboard covering 238 regions across 23 EU countries, Norway, Serbia, and Switzerland. In addition, Cyprus, Estonia, Latvia, Luxembourg, and Malta are included at country level. The RIS 2021 is a comparative assessment of regional innovation based on the European innovation scoreboard methodology. Using 21 indicators, it provides a more detailed breakdown of performance groups with contextual data that can be used to analyse and compare structural economic, business and socio-demographic differences between regions.

Figure 3: overview of the combination of datasets for T2.3
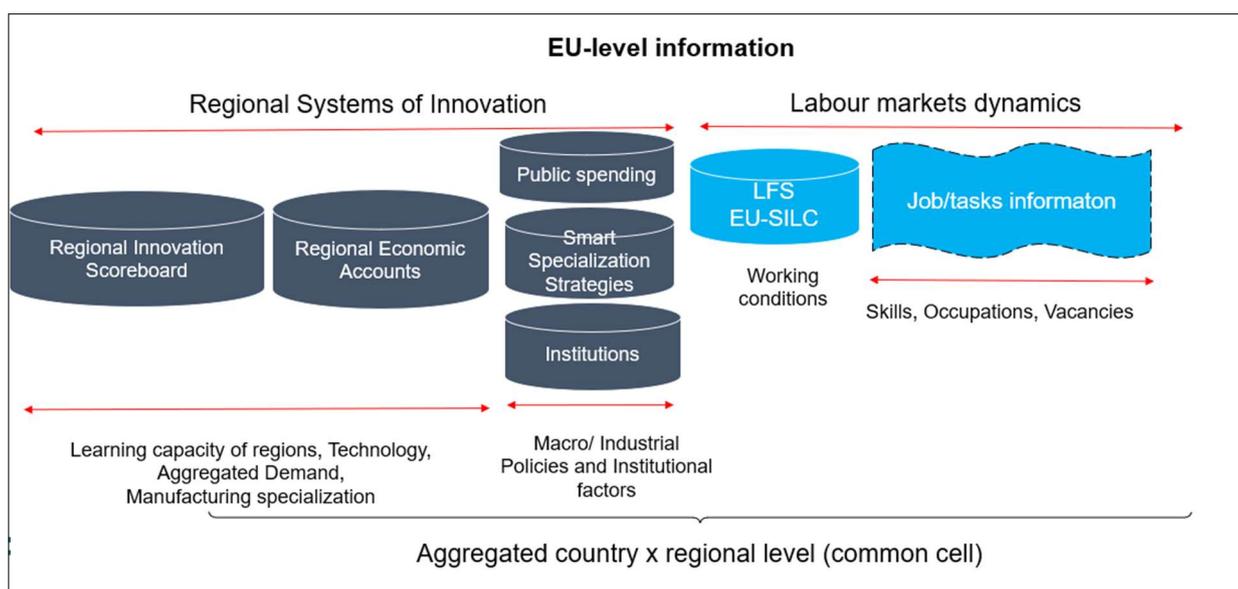
The **ETER (European Tertiary Education Register) open data portal** provides data for a reference list of Higher Education Institutions (HEIs) in Europe on activities and outputs, such as students, graduates, personnel and finances. ETER includes 41 countries in Europe and covers years from 2011 to 2019. The **R&I Territorial Economic Data Viewer** provides a comprehensive territorial data visualisation of EU R&I funding. Territorial statistical information includes macro-economic regional data, micro-level beneficiary information as well as a number of derived combined indicators from multiple data sources. This combined database is further enriched with coded information on regional policy design from automatic **lexical textual analysis of the Smart Specialisation Strategies** (S3), allowing a comparing and clustering of policy strategies in European regions and assessment of the potential impact of these regional strategies on labour markets.

The EU-wide level information is not sufficient to assess the transformations of jobs in the context of the "fourth industrial revolution". This is why we complement the research with in-depth analysis based on **individual level national data from selected countries in Europe**.

Using data at the individual level provides more fine-grained information and enables to study firm characteristics at the most immediate level, without the need for aggregation at broader sectoral or regional level. This makes it possible to study the topic at hand at the level where it occurs and where changes are decided and implemented. In addition, firm-level data enable us to create composite indices that flexibly combine multiple characteristics of the firm to one variable for further analysis. This is especially relevant in light of the growing heterogeneities between firms in the adoption of new technologies. This in turn affects asymmetrically firms' performances and widens the gap between leaders and laggards, even within narrowly defined industries (Berlingieri et al., 2020; Cirillo et al., 2023). At the same time, technological adoption and use, complementary investments and innovation strategies are not neutral with respect to employment structures and risk amplifying inequalities among workers (Domini et al., 2021; Bessen et al., 2022). Therefore, performing micro-level analyses both at the individual and firm levels is important in analysis of the effects of technological change.

Task 2.4 undertakes deep dives in five countries (see *Figure 4*). The five countries that we have selected reflect five institutional contexts as classified by Esping-Andersen (1990). Despite criticisms of Esping-Andersen's typology (Castles and Mitchell 1992), it has been validated through further research (Ferragina and Seeleib-Kaiser 2011). In our study, we include the Netherland as a liberal decentralised regime[7]; France as a corporatist regime; Norway as a social-democratic/corporatist/centralised regime; Lithuania as a statist centralised regime; and Italy as a Mediterranean Centralised regime.

We intend to process the data at the level of each country separately, but with a common measurement framework and working plan and using a core survey that is harmonised at the EU level. Indeed, the first building data source is the **Community survey on ICT usage and E-commerce in enterprises,** which is available at the individual level at the national level. This survey is combined, with no or little loss of observations, with **administrative files** giving structural social data from which we retrieve detailed breakdowns of the workforce by occupation, gender and age and with **structural business data** providing company accounts' information from which we retrieve information on job flows and productivity. The

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[7] The Netherlands is a special case. At the time of Esping-Andersen's initial study, the Netherlands was classified as a corporatist country. Many elements of corporatism are still present. However, 20 years later, the country has adopted many (neo)-liberal characteristics. Examples include: very liberalised markets, strong efforts to reduce trade union influence, hard 'labour market activation policies', pension systems relying on personal saving systems.

last data source is a **survey on working conditions** (typically collected at the employee level). A tasks and skills database is prepared from this data source to be matched with the others at the job level for a breakdown of occupations within sectors (NACE x ISCO).

Figure 4: overview of the combination of datasets for T2.4
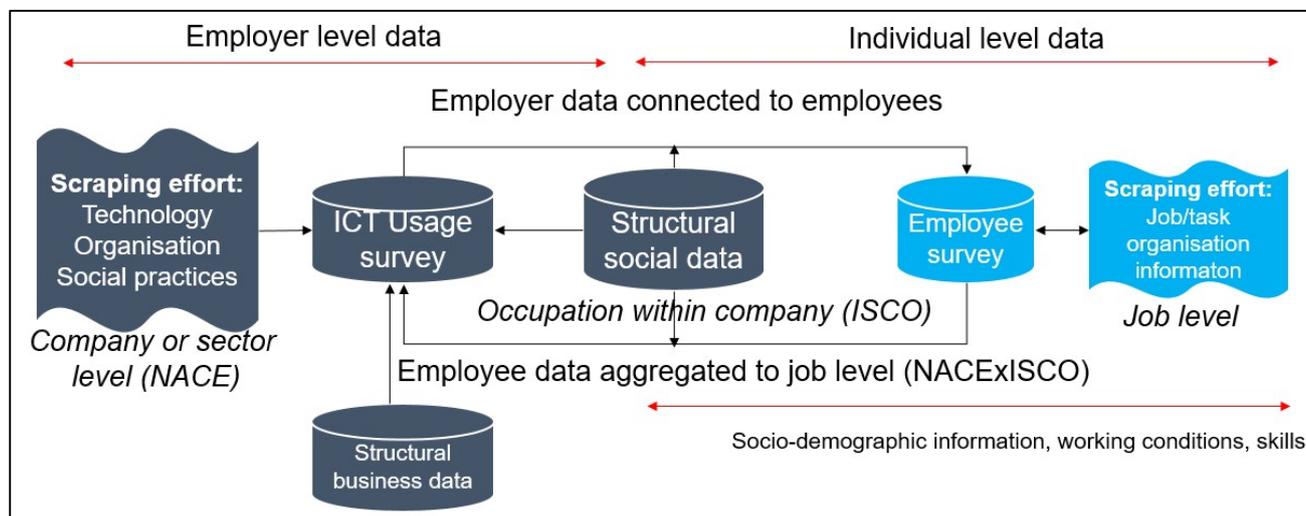
Table 5 below provides more detailed information on the data sources used in each selected country.

Table 5: Data sources for the deep-dive into five countries (T2.4)

Country (Partner)	Data sources	Unit of observation	Number of observations	Description
The Netherlands (TNO)	Dutch Netherlands Working Conditions Survey (NWCS)	Employee	50000 per year	The NWCS is a large-scale representative, yearly survey among employees with detailed information about work (e.g. technology, working conditions) and skills. The dataset is yearly, from 2005 to the current date.
	Dutch ICT usage by enterprises	Enterprises	5000 each two years	The NES is a large-scale representative, two-yearly survey among employers with detailed information about employment and other policies The dataset is two yearly, from 2008 to the current date.
France (CNAM)	French Working Condition Survey	Employee-employer	About 25000 in 2019	This is a survey conducted by the DARES every three years. It includes an "individual" section and an "establishments" section. The last available edition is 2019. It provides information on working conditions and skills utilisation
	French ICT usage by enterprises	Enterprises	About 12000 per year	This is an annual survey conducted by INSEE. It provides information on ICT equipment, Internet access and use, e-commerce, to which is added each year one or more module(s) dealing with a new theme: for example, computer security and artificial intelligence in 2019.

Country (Partner)	Data sources	Unit of observa-tion	Number of observa-tions	Description
Italy (UNIBA)	Italian Working Condition Survey	Employee-employer (Survey unit: employed persons over 18 and local units)	The survey involves 15000 employed persons and 5000 single- or multi-local units of the non-agricultural private sector	This is a survey conducted by INAPP – Istituto Nazionale per l'Analisi delle Politiche Pubbliche – every five years. It includes an "individual" section and an "establishments" section. The last available edition is 2021. It provides information on working conditions and skills utilisation. The survey is included in the National Statistical Plan (code IAP-00009) and the survey technique is CATI (Computer Assisted Telephone Interviewing).
	Italian ICT usage by enterprises	Enterprises	19915 in 2019 (annual survey)	This is an annual survey conducted by ISTAT (Italian National Statistical Office). It provides information on ICT equipment, Internet access and use, e-commerce, to which is added each year one or more module(s) dealing with a new theme: for example, computer security and artificial intelligence in 2019.

The principal aim of this survey is to supply users with indicators on information society: Internet activities (web site, social media, cloud computing) and connection used (fixed and mobile broadband), e-Business (use of software as ERP, CRM), e-Commerce, ICT skills, e-Invoice. |
| **Lithuania (KTU)** | Lithuania Working Condition Survey | Employee | 1871 in 2019 | Lithuanian working conditions survey is a survey coordinated by Eurofound. Data collected by local market research companies "RAIT" ir „Ipsos". The survey takes place every 3 years (latest in 2019 and 2022 is still unavailable). The survey measures diverse topics related with working conditions such as job characteristics, work organization, health and well-being, work-life balance, inequality and discrimination. |
| | Lithanian ICT usage by enterprises | Enterprises | About 3000 enterprises by year | This is an annual survey conducted by Lithuanian Data Agency using harmonised EUROSTAT provided questionnaire. It provides information on ICT usage and access, equipment, service, and competence. Part of the questionnaire is repeated every year. Each year includes specific questions related with various digital technologies. The data is available from year 2016 until year 2022. |

Country (Partner)	Data sources	Unit of observation	Number of observations	Description
Norway (UIA)	Norwegian Working Condition Survey	Employees	11.212 in 2019	Norwegian Working Condition Survey aims to survey different working environment conditions among employed people in Norway. The survey takes place every 3 years (latest in 2019 and 2022 is coming), and includes topics such as attachment to the workplace, physical, chemical and ergonomic work environment, psychosocial work environment, work-related health problems and sickness absence and requirements and opportunities for self-determination at work. Education level is collected from register data and combined with the survey.
	Norwegian ICT usage by enterprises	Enterprises	About 4.500 enterprises	This is an annual survey conducted by Statistics Norway. It provides information on ICT usage and access, equipment, service, and competence. The 2021 version includes artificial intelligence. Robot usage is reported annually from 2018.

Task 2.5 deep dives in value creating processes in manufacturing. The data source is the **European Manufacturing Survey** (EMS). Carried out by a network of European research institutes and managed by Fraunhofer ISI in Germany, the EMS aims to analyse the value-creating processes of production companies in the manufacturing sector (NACE C) with 20 or more employees in various European countries. It surveys the current status of the use of modern production technologies: digital exchange of scheduling data, automation and robotics (cobots), assistance systems, efficiency and closed-loop technologies, 3D printing, simulation software and AI software in production etc. In addition, data is collected on the use of innovative organisational concepts like production organisation, production management, resource and energy management and on further training and skills development for employees in production. The data is supplemented by performance indicators, company information, production parameters, as well as data on innovation activities, business models and digitalisation of products and services.

The survey is conducted about every three years. For this project, 2022 data from the Netherlands, Norway, Lithuania, Slovenia and Austria is used. However, there are doubts about the availability of data (or of data of sufficient quality) from Norway. If these doubts are confirmed, the option of using data from an alternative country such as Sweden is considered.

For preparing multinational analyses, national data needs to undergo a joint validation/harmonisation procedure. Some variables (especially when derived from the EMS non-core questionnaire) might not be available for all selected countries, so adjustments for firms from some countries or limitations to a common dataset between countries might be necessary.

The detailed firm-level data of the EMS can cover (parts of) all dimensions developed in WP2 measurement framework within a single firm. This allows us to shed light on internal processes and potential associations between those dimensions, at the firm level. Further, EMS data allows categorising firms along multiple characteristics in addition to sector and country distinctions, which enables to tease out influencing factors of Industry 5.0 outcomes or patterns between knowledge inputs/outputs and Industry 5.0 outcomes.

Since the strength of the EMS lies in the available information about firms' capacities in terms of knowledge inputs (degree of digitalisation, technological equipment, learning capacity, Big Data analytics and AI, organisational measures, training activities, planned investments, etc.), we will focus on relating these with each other to explain firm behaviour and capacities. For example, the extent of digitalisation and automation in production or product-related services may reduce the need for certain personnel while at the same time create demand for highly skilled specialists which might be hard to hire and thus require in-house training to be offered. We can provide evidence on such questions because the EMS allows the direct observation of these scenarios while at the same time taking context factors and company characteristics into account.

After that, knowledge inputs or a combination thereof might be set in relation to knowledge outputs ((green) product and process innovation). Here, we expect to find evidence supporting a beneficial influence of advanced (digital) production technologies, modern organisational concepts and the learning capacity of the organisation (among others) on knowledge outputs. What is of particular interest in this context is the identification of the potential drivers in terms of technology endowments or organisational concepts of green and digital product innovation.

Focusing mainly on the "resilience" dimension (as this is covered best in the EMS, see Section 2.d.ii), we then aim to explore barriers and drivers of Industry 5.0 outcomes by relating different knowledge inputs and their interaction as well as innovation outputs with the resilience of the firm. For example, the digital maturity of production technologies might be set in relation to employee retention or staff shortages. If data permits, multivariate regression analysis is a convenient way to disentangle the (potentially opposing) impacts of knowledge inputs/outputs and firm characteristics on Industry 5.0 outcomes.

As we anticipate that the integration of manufacturing firms into various regulatory and informal frameworks (e.g., regional innovation systems) is a substantial contributing factor that could affect every aspect of this analysis, we contrast the outcomes derived from the full sample with the conclusions drawn from country subsets in our dataset.

b. Operationalisation of key concepts in the selected data sources.

This section provides an overview of the variables and indicators available in the selected data sources, which operationalise the key concepts underlying our measurement framework.

i. Context factors

Concept:	Context factors relevant to human centricity
Operationalisation:	Construction of an indicator of investments in public infrastructures
Task	2.2
Sources of data:	See *Figure 2*
Measure:	Not applicable to the task

Task	2.3
Sources of data:	Cambridge Econometrics' European Regional Database (ERD) – ARDECO; EU-SILC; OECD-COFOG (only at the national level)
Measure:	- Real value added of the nonmarket sector which consists of the following subsectors: "Public administration and defence," "Education," "Human health and social work," "Arts, entertainment and recreation," "Other service activities," and "Activities of household and extra-territorial organizations". - Measures of social transfers aggregated at the regional level (EU-SILC). - Classification of the Functions of Government (COFOG-OECD) classifies government expenditure data from the System of National Accounts by the purpose for which the funds are used. COFOG splits expenditure data into different functional groups or sub-sectors of expenditures (such as economic affairs, education and social protection). *N.B: The indicator is a proxy for quality of life at territorial level but it does not consider the quality of the services provided. There is no regional public expenditure for EU countries. Hence, the concept in only proxied by some measures*
Task	2.4
Sources of data:	See *Figure 4* and *Table 4*
Measure:	Not applicable to the task
Task	2.5
Sources of data:	EMS
Measure:	Not available in the selected data source

Operationalisation: Construction of an indicator of social dialogue

Task	2.2
Sources of data:	European Company Survey 2019
Measure:	Involvement in joint decision making with management
Task	2.3
Sources of data:	Structure of Earnings Survey (Eurostat) 2002, 2006, 2010, 2014, 2018
Measure:	Number of employees by economic activity, collective pay agreement, sex *N.B. The indicator is a proxy for trade unions involvement in technological decisions. Main databases collect detailed information on membership to trade unions and employers' associations, collective bargaining coverage, statutory minimum wages, organisation of collective bargaining, wage coordination, social pacts and presence of works councils only at the national level (such as the ICTWSS provided by OECD/AIAS)*
Task	2.4
Sources of data:	Working Condition Survey (national)
Measure:	Presence of trade union, work council or similar committees representing employees
Task	2.5
Sources of data:	EMS
Measure:	Not applicable to the task

Operationalisation Regional Systems of Innovation

Task	2.2
Sources of data:	See *Figure 2*
Measure:	Not applicable to the task
Task	2.3
Sources of data:	Regional Innovation Scoreboard; European Tertiary Education Register database; Smart Specialisation Strategies

Measure:	Innovative SMEs collaborating with others; Public-private co-publications; Attractive research systems (international scientific co-publications, Foreign doctorate students); Direct government funding and government tax support for business R&D; Share of foreigners students ISCED 5-7; Herfindahl index students ISCED 5-7; PhD intensity; STEM orientation; Job-to-Job mobility of Human Resources in Science and Technology; Textual analysis of Smart Specialization Strategies
Task	**2.4**
Sources of data:	See *Figure 4* and *Table 4*
Measure:	Inclusion of regional dummies in the analysis
Task	**2.5**
Sources of data:	EMS
Measure:	Not available in the selected data source

Concept:	**Context factors relevant to resilience**
Operationalisation:	**Construction of a composite indicator relating to involvement in (international) value chains**
Task	**2.2**
Sources of data:	See *Figure 2*
Measure:	Not applicable to the task
Task	**2.3**
Sources of data:	See *Figure 3*
Measure:	*N.B.: the EUREGIO database provides the first time-series of global IO tables with regional detail for the entire large trading bloc of the European Union. The main problem is that the time covered is 2000-2010.*
Task	**2.4**
Sources of data:	See *Figure 4* and *Table 4*
Measure:	Not applicable to the task
Task	**2.5**
Sources of data:	EMS 2022
Measure:	Position in the value chain (producer of finished goods, supplier or contract manufacturer); Share of products exported (EU and non-EU); Inter-firm cooperation in production or R&D; Share of production or/and R&D capacity abroad (EU and non-EU); Offshored or reshored parts of production or R&D since 2020 (EMS non-core); Development time of new product (EMS non-core)
Operationalisation:	**Construction of an indicator measuring technological dependence**
Task	**2.2**
Sources of data:	See *Figure 2*
Measure:	Not applicable to the task
Task	**2.3**
Measure:	Share of imports of technological / energy goods
Sources of data:	Eurostat ARDECO; Smart Specialization Strategies
Measure:	Gross fixed capital investments per employee (Regional Economic Accounts); Change in Value Added at the regional level by types of sectors (Regional Economic Accounts) Gross Fixed Capital Formation by NACE Sector at

	constant prices (ARDECO); Textual analysis of Smart Specialization Strategies (niche and domain of specialization) *N.B. This indicator does not consider other possible channels of technological dependence.*
Task	**2.4**
Sources of data:	See *Figure 4* and *Table 4*
Measure:	Not applicable to the task
Task	**2.5**
Sources of data:	EMS
Measure:	Share of investment in machines and assets to sales (2021).

Operationalisation:	**Construction of an indicator measuring dependence on external funds and policy design**
Task	**2.2**
Sources of data:	See *Figure 2*
Measure:	Not available in the selected data sources
Task	**2.3**
Sources of data:	Eurostat and Cohesion open data platform (https://cohesiondata.ec.europa.eu/)
Measure:	Structural Funds as a percentage of GDP
Task	**2.4**
Sources of data:	See *Figure 4* and *Table 4*
Measure:	Not applicable to the task
Task	**2.5**
Sources of data:	EMS
Measure:	Not applicable to the task

Concept:	**Context factors relevant to sustainability**
Operationalisation:	**Construction of an indicator measuring "green competitiveness"**
Task	**2.2**
Sources of data:	See *Figure 2*
Measure:	Not available in the selected data sources
Task	**2.3**
Sources of data:	OECD REGPAT; Regional Innovation Scoreboard; Eurostat
Measure:	Patents in environment related technologies by regions; Regional green vulnerability index *N.B. It is a (underestimated) measure of the competitiveness of the "green sectors" (Rodríguez-Pose and Bartalucci, 2023).*
Task	**2.4**
Sources of data:	See *Figure 4* and *Table 4*
Measure:	Not available in the selected data sources
Task	**2.5**
Sources of data:	EMS
Measure:	Not applicable to the task

Operationalisation:	Proxy variables of (drivers of) environmental mitigation policies
Task	**2.2**
Sources of data:	Eurostat
Measure:	Environmental taxes by NACE Rev. 2 (ENV_AC_TAXIND2 dataset); environmental subsidies and similar transfers from general government to corporations, by environmental activity, ESA category of transfer and NACE Rev. 2 (ENV_ESST_GGCP dataset) Energy supply and use by NACE Rev. 2 (ENV_AC_PEFASU dataset); Physical energy flow accounts by NACE Rev. 2 (ENV_AC_PEFA04 dataset)
Task	**2.3**
Sources of data:	Regional Innovation Scoreboard; Eurostat
Measure:	Regional environmental and energy statistics: regional water statistics; regional energy statistics (cooling and heating degree days)
Task	**2.4**
Sources of data:	See *Figure 4* and *Table 4*
Measure:	Not available in the selected data sources
Task	**2.5**
Sources of data:	EMS
Measure:	Not applicable to the task

ii. Knowledge inputs

Domain	Industry 4.0 and Big data
Concept:	**Industry 4.0 technologies adoption and use**
Operationalisation:	**Construction of a composite indicator of Digital technologies adoption and use**
Task	**T2.2**
Sources of data:	Community ICT usage by enterprises 2016-2021
Measure:	Sum of the identified digital technologies (Access and use of the internet; E-commerce sales; Sharing information electronically within the enterprise; Internet of Things; Artificial Intelligence; Robots), with a weighting system that rewards investments in emerging technologies. Aggregation of data at the country-sector level.
Task	**2.3**
Sources of data:	EU-LFS; Patent applications to the EPO by priority year by NUTS 3 regions; Federation of Robotics (IFR)
Measure:	Digital skills and digital tasks by NUTS2; Human Resources in Science and Technology; Patent applications to the EPO by priority year by NUTS 3 regions (pat_ep_rtot); Patent applications to the EPO by priority year by NUTS 3 regions, international patent classification (IPC) sections and classes (pat_ep_ripc); High-tech patent applications to the EPO by priority year by NUTS 3 regions (pat_ep_rtec); Installations of new robots (IFR)
Task	**T2.4**
Sources of data:	ICT usage by enterprises 2016-2021 (national surveys)
Measure:	Sum of the identified digital technologies (Access and use of the internet; E-commerce sales; Sharing information electronically within the enterprise; Internet

	of Things; Artificial Intelligence; Robots), with a weighting system that rewards investments in emerging technologies.
Task	**2.5**
Sources of data:	EMS 2022
Measure:	Current use (and use planned until 2025) of (digital) automation technologies and robots such as: Industrial robots for manufacturing or handling; Cobots, mobile robots; Simulation and data analysis (e.g., 3D printing for prototyping); Mobile/wireless devices for programming and controlling machinery

Domain	Industry 4.0 and Big data
Concept:	**Big data**
Operationalisation:	**Construction of a composite indicator of big data adoption and use**
Task	**2.2**
Sources of data:	Community ICT usage by enterprises 2016-2022
Measure:	Sum of the identified digital technologies related to the use of big data (analysis of big data internally from any data source or externally). Aggregation of data at the country-sector level.
Task	**2.3**
Sources of data:	See *Figure 3*
Measure:	Not available in the selected data sources
Task	**2.4**
Sources of data:	Community ICT usage by enterprises 2016-2021 (national surveys)
Measure:	Sum of the identified digital technologies related to the use of big data (analysis of big data internally from any data source or externally).
Task	**2.5**
Sources of data:	European Manufacturing Survey 2022
Measure:	Current usage (and use planned until 2025) of production techniques such as: Software (incl. AI powered) for simulating or managing production processes, quality control, maintenance, logistics, energy management; Big Data usage with product-related services offered

Domain	Green technologies and smart materials
Concept:	**Green technologies**
Operationalisation:	**Adoption of green technologies**
Task	**2.2**
Sources of data:	Eurostat
Measure:	Environmental protection investments of corporations as ancillary producers by environmental protection activity and NACE Rev. 2 activity (ENV_AC_EPIAP1 dataset); Production of environmental protection services of corporations other than specialist producers by economic characteristics and NACE Rev. 2 activity (ENV_AC_EPIAP1 dataset)
Task	**2.3**
Sources of data:	PATSTAT database of the European Patent Office, Open-Power-System Data

Measure:	Number of green patents for 1000 inhabitants; Regional index of green technology (ratio of authorized green patent to total authorized patent)
Task	**2.4**
Sources of data:	See *Figure 4* and *Table 4*
Measure:	Not available in the selected data sources
Task	**2.5**
Sources of data:	EMS
Measure:	Not available in the selected data source
Task	**2.5**
Sources of data:	European Manufacturing Survey 2022
Measure:	Current usage (and use planned until 2025) of sustainable production techniques such as: Technologies to recuperate kinetic and process energy; Technologies for recycling and re-use of water; Technologies for remanufacturing; Technologies for recycling; Technologies for waste separation

Concept:	**Learning capacity of the organisation**
Operationalisation:	**Construction of a composite indicator of learning capacity of the organisation**
Task	**2.2**
Sources of data:	European Company Survey 2019 European Working Condition Survey 2021
Measure:	Preservation of the cognitive dimension of work; training opportunities; workers autonomy; stimulation of intrinsic motivation; autonomous team work practices; provision of direct help and support; direct worker participation; supportive supervisory style. *N.B. A composite indicator leads to a single measure of the learning capacity of the organisation, measurable from different types of surveys, both at the employee and employer level, and leads to comparable results (Greenan and Napolitano, 2023)* Possible extension with the inclusion of the dimension of workforce diversity. *N.B. the learning capacity of the organisation may be highly correlated with the education level of the workforce.* *N.B. This measure gathers information about organisational practices and it is difficult to obtain this information about former employers (of job seekers) or training institutions (for students).*
Task	**2.3**
Sources of data:	Regional innovation scoreboard 2021
Measure:	Population with tertiary education; Population involved in lifelong learning; International scientific co-publications; Public-private co-publications; Innovative SMEs collaborating with others
Task	**2.4**
Sources of data:	Working Condition Survey (national)
Measure:	Preservation of the cognitive dimension of work; training opportunities; workers autonomy in cognitive tasks; stimulation of intrinsic motivation; autonomous team work practices; provision of direct help and support; direct worker participation; supportive supervisory style. *N.B. A composite indicator leads to a single measure of the learning capacity of the organisation, measurable from different types of surveys, both at the employee and employer level, and leads to comparable results (Greenan and*

	Napolitano, 2023). Possible extension with the inclusion of the dimension of workforce diversity. *N.B. the learning capacity of the organisation may be highly correlated with the education level of the workforce.* *N.B. This measure gathers information about organisational practices and it is difficult to obtain this information about former employers (of job seekers) or training institutions (for students).*
Task	**2.5**
Sources of data:	European Manufacturing Survey 2022

Measure:	Multidimensional index capturing different aspects of learning capacity of the firm such as:
	Workforce related:
	    - Functional and educational distribution of employees
	    - Types of trainings offered
	Usage of related organisational concepts:
	    - Workforce involvement in development of products and processes
	    - Workforce involvement (bonus) in innovation activities
	    - Visual management and monitoring of work processes
	Adaptability / strategy renewal:
	    - Product innovation / share in sales of new products
	    - Market innovations / share in sales of new-to-market products
	    - Permanent product offering / share in sales
	    - Time to develop new products (EMS non-core)
	    - Modernisation / investment in new technologies, machines, equipment
	    - Reshoring of production (EMS non-core)
	    - Business model innovations / services offered

Concept:	**Environmental preservation capacity of the organisation**
Operationalisation:	**Proxy indicators of environmental preservation capacity of the organisation**
Task	**2.2**
Sources of data:	Eurostat
Measure:	Intermediate consumption of environmental protection services by institutional sector and NACE Rev. 2 activity (ENV_AC_CEPSGC1 dataset)
Task	**2.3**
Sources of data:	See *Figure 3*
Measure:	Not available in the selected data sources
Task	**2.4**
Sources of data:	Working Condition Surveys (national datasets)
Measure:	How well informed about health and safety risks are when employees are exposed to high/low temperature or breathing in smoke, fumes, powder or dust, or breathing in vapours such as solvents and thinners or handling or being in skin contact with chemical products or substances or handling or being in direct contact with materials which can be infectious
Task	**2.5**
Sources of data:	European Manufacturing Survey 2022

Measure:	Current usage (and use planned until 2025) of sustainable organisational concepts such as: Certified environmental management systems; Certified energy management systems
Operationalisation:	**Construction of a composite indicator relating to consideration of the environmental impact of ICTs**

Task	**2.2**
Sources of data:	Community ICT usage by enterprises 2016-2021
Measure:	Certified environmental management. The enterprises considered the environmental impact of ICT services, or ICT equipment, before selecting them and applying some measures, affecting the paper or energy consumption of the ICT equipment. Aggregation of data at the country-sector level.
Sources of data:	ESENER
Measure:	Routinely evaluation in the workplace of risks related to dangerous chemical or biological substances (if this risk factor is present). Aggregation of data at the country-sector level.
Task	**2.3**
Sources of data:	See *Figure 3*
Measure:	Not applicable to the task
Task	**2.4**
Sources of data:	Community ICT usage by enterprises 2016-2021 (National surveys)
Measure:	The enterprises considered the environmental impact of ICT services, or ICT equipment, before selecting them and applying some measures, affecting the paper or energy consumption of the ICT equipment
Task	**2.5**
Sources of data:	EMS
Measure:	Not applicable to the task

Concept:	**Industry 5.0 innovation capacity of the organisation**
Operationalisation:	**Firm-level composite indicator to capture multidimensional aspects of Industry 5.0 innovation capacity**

Task	**2.2**
Sources of data:	See *Figure 2*
Measure:	Not applicable to the task
Task	**2.3**
Sources of data:	See *Figure 3*
Measure:	Not applicable to the task
Task	**2.4**
Sources of data:	See *Figure 4* and *Table 4*
Measure:	Not applicable to the task
Task	**2.5**
Sources of data:	European Manufacturing Survey 2022
Measure:	Multidimensional index capturing Industry 5.0 innovation capacity of the firm. Industry 5.0 innovation capacity is understood as the combined presence of knowledge in all identified input domains such as: Industry 4.0 and Big data; Green technologies and smart materials; Learning capacity of the organisation; Environmental preservation capacity of the organisation

	Which will be measured by the aforementioned composite indices based on EMS data.

iii. Knowledge outputs

Concept:	Technological/non-technological innovation
Operationalisation:	**Organisations introducing a product innovation and/or a business process innovation**
Task	**T2.2**
Sources of data:	Community Innovation Survey 2018, 2020
Measure:	Share of enterprises at the country-sector level introducing a product innovation Share of enterprises at the country-sector level introducing a business process innovation
Task	**T2.3**
Sources of data:	Regional Innovation Scoreboard
Measure:	- SMEs introducing product innovations (Regional); - SMEs introducing business process innovations (Regional). Regional CIS data are not publicly available and have been made explicitly available for the Regional Innovation Scoreboard by national statistical offices
Task	**T2.4**
Sources of data:	Working conditions survey (national datasets)
Measure:	Changes in the last 12 months in technologies at the workplace (machines or ICT), changes in the work is executed or how manager supervise, changes in products and services, changes in contact with clients.
Sources of data:	Community Innovation Survey
Measure:	Share of enterprises at the sector and company size level introducing Technological and non-technological innovation; Share of enterprises at the sector and company size level introducing Non-technological innovation only Share of enterprises at the sector and company size level introducing Technological innovation only
Task	**2.5**
Sources of data:	European Manufacturing Survey 2022
Measure:	Introduction of products since 2019 that are: New to the firm or technically improved; Based on a digital product extension; New-to-the-market products
Measure:	Extent of digitalisation of products and product-related services such as: Usage of digital interfaces with products, sensors, VR/AR; Digital support for installation; Digital tracking of the lifecycle of products; Predictive maintenance, Chatbots, digital platforms

Concept:	Environmental innovation
Operationalisation:	**Organisations introducing an innovation with environmental benefits**
Task	**T2.2**
Sources of data:	CIS 2020
Measure:	Share of enterprises at the country-sector level introducing an innovation with environmental benefits

	N.B. The Community Innovation Survey introduce the concept only in additional modules to the core questionnaire. In the period of interest of our analysis (2016-2021), it is available only for 2020 covering the period 2018-2020 (Kemp and Pearson, 2007)
Task	**T2.3**
Sources of data:	OECD REGPAT
Measure:	Patents in environment related technologies by tl3 regions
Task	**T2.4**
Sources of data:	CIS 2020
Measure:	Enterprises introducing an innovation with environmental benefits *N.B. The Community Innovation Survey introduce the concept only in additional modules to the core questionnaire. In the period of interest of our analysis (2016-2021), it is available only for 2020 covering the period 2018-2020 (Kemp and Pearson, 2007)*
Task	**2.5**
Sources of data:	EMS 2022
Measure:	Introduction of products since 2019 that are: New to the firm or technically improved and lead to an improved environmental impact using or disposing of them

iv. Industry 5.0 outcomes

Concept:	**Human centricity**
Operationalisation:	**Indicators of quality of work and employment relationships**
Task	**2.2**
Sources of data:	Eurostat (LFS)
Measures:	Long working hours in main job (percentage of employed persons usually working 49 hours or more per week); precarious employment (percentage of employees with a short-term contract of up to 3 months) (lfsa_qoe dataset)
Sources of data:	European Working Conditions Survey 2021
Measures:	Construction of a composite indicator of cumulative adverse working conditions (Greenan and Seghir, 2022); indicators about degree of satisfaction with working conditions; composite indicators of mental wellbeing (anxiety, emotional and physical exhaustion, depression and at risk of depression)
Task	**2.3**
Sources of data:	Eurostat (LFS)
Measures:	Employment by sex, age, professional status and NUTS 2 regions (1 000) (lfst_r_lfe2estat dataset); Employment by sex, age, full-time/part-time, professional status and NUTS 2 regions (1 000) (lfst_r_lfe2eftpt dataset); Employment rates by sex, age, educational attainment level, citizenship and NUTS 2 regions (lfst_r_lfe2emprtn dataset); Average number of usual weekly hours of work in main job by sex, age and NUTS 2 regions (hours) (lfst_r_lfe2ehour dataset)
Sources of data:	Eurostat (EU-SILC)
Measures:	Wage and Salary earners; At risk of poverty by NUTS 2 regions; Persons living in households with very low work intensity by NUTS regions (population aged 0 to 59 years)
Task	**2.4**
Sources of data:	Working Condition Surveys (national datasets)
Measures:	Construction of a composite indicator of cumulative adverse working conditions (Greenan and Seghir, 2022); indicators about degree of satisfaction with working

	conditions; composite indicators of mental wellbeing (anxiety, emotional and physical exhaustion, depression and at risk of depression)
Task	**2.5**
Sources of data:	EMS
Measures:	Not available in the selected data source

Operationalisation: Indicators of occupational health and safety

Task	**2.2**
Sources of data:	European Working Condition Survey
Measures:	Occupational health & safety (e.g. vibration, noise, temperature, lifting heavy loads, repetitive work, mental health problems), (meaningful work, fair treatment, discrimination) (OSH risks perception)
Sources of data:	Eurostat (LFS ad-hoc module 2020)
Measures:	Number of accidents at work during the last 12 months; number of work-related health problems during the last 12 months; exposure to physical health risk factors; exposure to mental well-being risk factors (lfso_20 dataset)
Task	**2.3**
Sources of data:	See *Figure 3*
Measures:	Not available in the selected data sources
Task	**2.4**
Sources of data:	Working Condition Survey (national datasets)
Measures:	Occupational health & safety (e.g. vibration, noise, temperature, lifting heavy loads, repetitive work, mental health problems), (meaningful work, fair treatment, discrimination) (OSH risks perception)
Task	**2.5**
Sources of data:	EMS
Measures:	Not available in the selected data source

Operationalisation: Indicators of skills development and skills mismatches

Task	**2.2**
Sources of data:	European Working Condition Survey
Measures:	Skills mismatch perception; improved prospects of employment thank to training
Sources of data:	European Skills and Jobs Survey
Measures:	Extent to which the employee can use the current knowledge and skills in main job; need to further develop any of the following skills to do the job even better: numeracy, social, technical or job-specific skills N.*B. ESJS2 2021 microdata are not yet publicly available.*
Task	**2.3**
Sources of data:	European Labour Force Survey
Measures:	Population by educational attainment level, sex and NUTS 2 regions (%); Participation rates in selected education levels at regional level; Ratio of the proportion of tertiary students over the proportion of the population by NUTS1 and NUTS2 regions; Over-qualification rates by economic activity (NACE Rev. 2) (lfsa_eoqgan2 dataset); Regional disparities in the rate of early leavers from education and training (NUTS level 2) (lfst_r_edatd_16 dataset); Job postings of enterprises (web scraping) for selected countries
Task	**2.4**
Sources of data:	Working Condition Survey (national datasets)
Measures:	Skills mismatch perception; improved prospects of employment thank to training
Task	**2.5**
Sources of data:	EMS
Measures:	Not applicable to the task

Operationalisation:	Measuring labour market dynamics
Task	**2.2**
Sources of data:	European Labour Force Survey
Measures:	Unemployment rates by Nace Rev. 2
Sources of data:	Eurostat
Measures:	Gender pay gap in unadjusted form by Nace Rev. 2 (earn_grgpg2 dataset); Monthly minimum wage as a proportion of average monthly earnings by Nace Rev. 2 (%) (earn_minw dataset)
Task	**2.3**
Sources of data:	Eurostat (LFS); ARDECO
Measures:	Growth rate of employment at the regional level; Changes in hours worked
Task	**2.4**
Sources of data:	Administrative data
Measures:	Growth rate of employment at the firm level
Task	**2.5**
Sources of data:	EMS
Measures:	Not applicable to the task

Concept:	Resilience

Operationalisation	The share of intermediate inputs that are imported
Task	**2.2**
Sources of data:	Eurostat
Measure:	Growth rate of the trade value of intermediate goods (ext_st_27_2020msbec dataset) *N.B. Eurostat provides historical series of international trade data, but available data are usually not broken down by sector or region*
Task	**2.3**
Sources of data:	Eurostat
Measure:	Growth rate of the trade value of intermediate goods (ext_st_27_2020msbec dataset) *N.B. Eurostat provides historical series of international trade data, but available data are usually not broken down by sector or region*
Sources of data:	Eurostat (JVS)
Measure:	Job vacancy statistics by occupation, NUTS 2 regions and NACE Rev. 2/NACE Rev. 2 activity – annual data (2008-2015) (jvs_a_nace2) *N.B.: available only for few European regions*
Task	**2.4**
Sources of data:	Administrative data
Measure:	Growth rate of the trade value of intermediate goods
Task	**2.5**
Sources of data:	EMS
Measure:	Share of inputs sourced from abroad (EU and non-EU)

Operationalisation:	Firm-level composite indicator of resilience over time
Task	**2.2**
Sources of data:	EU KLEMS

Measure:	Total Factor Productivity Growth measures
Sources of data:	Eurostat
Measure:	Number of enterprise survivals up to five years/ Number of death (bd dataset)
Task	**2.3**
Sources of data:	See *Figure 3*
Measure:	Not applicable to the task
Task	**2.4**
Sources of data:	Administrative data
Measure:	Total Factor Productivity Growth measures
Task	**2.5**
Sources of data:	European Manufacturing Survey 2022
Measure:	Indication of firm resilience between 2019 and 2021 approximated by: Sales growth; Employee growth; Capacity utilisation (2021)

Operationalisation:	**Construction of a composite indicator of employee shortages**
Task	**2.2**
Sources of data:	Eurostat (JVS)
Measure:	Number of job vacancies and the number of occupied posts by NACE Rev. 2 (jvs dataset)
Task	**2.3**
Sources of data:	See *Figure 3*
Measure:	Not available in the selected datasources; *N.B. Harmonised vacancy data across regions are unavailable, however according to Eurofound (2021) the dispersion of employment rates (coefficient of variation in NUTS 2-level employment rates for the 15–64 age group) across regions can be used to approximate regional imbalances between supply of and demand for labour.*
Task:	**2.4**
Sources of data:	See *Figure 4* and *Table 4*
Measure:	Not available in the selected data sources
Task	**2.5**
Sources of data:	EMS
Measure:	Indication of staff shortages distributed along (EMS non-core): Functional employee distribution; Employee education distribution

Concept:	**Sustainability**

Operationalisation:	**Construction of an indicator measuring "green specialisation"**
Task	**2.2**
Sources of data:	See *Figure 2*
Measure:	Not applicable to the task
Task	**2.3**
Sources of data:	Eurostat
Measure:	Index of revealed comparative advantage (if in some period t the share of green product in the total exports of region I is larger than the equivalent share in all other regions, then i has a better capacity to export green products than the other regions in period t) *N.B. It is a measure of industrial transformation, but the definition of "green specialisation" is not unique*

Task	2.4
Sources of data:	See *Figure 4* and *Table 4*
Measure:	Not available in the selected data sources
Task	**2.5**
Sources of data:	EMS
Measure:	Not applicable to the task
Operationalisation:	**Proxy indicators of environmental impact**
Task	**2.2**
Sources of data:	Eurostat
Measure:	Air Emissions account by NACE Rev. 2 activity (ENV_AC_AINAH_R2 dataset)
Task	**2.3**
Sources of data:	See *Figure 3*
Measure:	Not applicable to the task
Task	**2.4**
Sources of data:	See *Figure 4* and *Table 4*
Measure:	Not available in the selected data sources
Task	**2.5**
Sources of data:	EMS
Measure:	Not applicable to the task

c. Identified data gaps.

In developing operationalisation of the proposed measurement framework, we were faced with the challenge of finding suitable measures in the selected data sources.

In doing so, we have identified some data gaps, especially concerning some concepts that we consider as key to describe the relationship between the digital and green transformations and their outcomes in terms of Industry 5.0 related human-centricity, resilience and sustainability.

First, statistical surveys still lack information about **the environmental preservation capacity of organisations.** This concept has come to the forefront only recently in the research field and is therefore largely missing in firm and worker level data collection. We will screen more sources, especially those at the employer level, as this information aligns with other indicators on organisational practices. Nonetheless, we expect that the amount of information is not substantial, especially regarding SMEs.

Second, since the last revision of the Oslo Manual, previously listed types of innovation have been reorganised in two main categories: **product innovation and business process innovation**. In the aggregated data released by Eurostat and covering Europe at large, these are the two only concepts of innovation available since the revision. It would be important to keep on providing sector level aggregated data about the sub-categories of business process innovation, namely process, marketing and organisational innovations, with indications on the measurement discontinuity.

A third identified data gap concerns **green and social innovations**. This gap is because statistical offices do not specifically consider these types of innovation in their data sources.

Green innovations are those aimed primarily at generating environmental benefits. Since the 2010 Oslo Manual, the CIS has included innovations with environmental benefits, excluding however questions about specific environmental objectives. Therefore, detailed information on different types of green innovations is only available through patent data.

Social innovations comprise new solutions focused on enhancing the welfare and wellbeing of individuals and communities. Measuring social innovation is challenging as existing social indicators, such as those from the European System of Social Indicators (Gesis), are relatively general and, within our framework, are primarily considered as outcome measures.

A fourth identified data gap concerns the measurement of **resilience.** At firm level, changes in procurement strategies can be tracked but require time series. In addition, new approaches to strategic sourcing can be used. The focus should be on the description of these sourcing strategies. In a complementary way, low resilience can also be measured and monitored using international trade data. At worker level, perceptions could be measured and actions to prevent the waste of strategic resources could be inventoried.

4.Summary.

This document outlines the development of a conceptual and measurement framework to assess the transformations of jobs in the context of the "fourth industrial revolution" and the workforce skills required for Industry 5.0. It builds on the use of available and reliable data from the European Statistical System to analyse the relationship between the digital and green transformations and their outcomes regarding human-centricity, resilience and sustainability.

The central idea of our measurement framework revolves around the role of knowledge, which we consider a collective resource transcending the confines of individual firms. Hence, we identify industry 5.0 practices as those investments that may expand firms' stock of productive knowledge to reach the industry 5.0 objectives: investments in the learning capacity of the organisation and the environmental preservation capacity and investments in digital and green technologies adoption and use. These practices generate innovations resulting from the implementation of new ideas into the production process, which we describe as knowledge outputs. We then look at **the socio-economic outcomes of the implemented Industry 5.0 practices**, which we group under the three pillars of Industry 5.0: human-centricity, resilience and sustainability. We aim to assess whether and to what extent organisations' strategic choices are effective in moving towards Industry 5.0. We also take into account the possible levers and barriers to achieving Industry 5.0 by considering context factors.

We have translated our conceptual and measurement framework into a data strategy to combine in innovative ways different data sources and analyse them from the same theoretical point of view, to be able to compare the results obtained from the various tasks and to draw conclusions from them. Hence, this document presents an overview of the data strategy to conduct EU-wide level statistical analyses at the sectoral (T2.2) and regional (T2.3) levels as well as an in-depth statistical approaches in five countries (T2.4) and in the manufacturing sector (T2.5).

On the identified data sources, we have conducted a first exploration of the available variables and indicators that would allow operationalising the key concepts underlying our measurement framework. In so doing, we have identified some data gaps. This document provides an overview of these measures and briefly highlights the data gaps.

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BRIDGES 5.0 PROJECT IDENTITY

Project name	BRIDGES 5.0 Bridging Risks to an Inclusive Digital and Green future by Enhancing workforce Skills for industry 5.0
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	Industrie 4.0 Plattform Osterreich
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