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A Conceptual Framework for Workforce Skills for Industry 5.0: Implications for Research, Policy and Practice

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Abstract

Industry 5.0 is a relatively new topic and not yet well-defined. This article's purpose is to develop understanding of Industry 5.0 by offering a new socio-centric conceptual framework. It extends prevailing perception of Industry 5.0 by integrating workforce skills, labour shortages, and eco-digital shifts. The study explores workforce skill measurement and its implementation. Three methods were combined to develop the conceptual framework: (i) review of academic and policy literature; (ii) scholarly and expert discussions; (iii) consultations with practitioners, companies and networks on Industry 5.0's relevance. Industry 5.0 expands Industry 4.0's technology-focused approach. This new paradigm emphasises human-centricity, sustainability and resilience, infusing societal values into organisational management. Our findings suggest that, while firmly rooted in EU policy, Industry 5.0 must find integration at national levels and within pertinent ecosystems. This article introduces innovative perspectives on conceptualising and evaluating workforce skills for Industry 5.0. Mitigating skills gaps is crucial in enabling companies and employees to leverage the eco-digital shift, fostering sustainability, resilience and equity across Europe. A limitation to understanding Industry 5.0 is that policy discussions run ahead of collecting empirical data. As a consequence, one must be careful in drawing firm conclusions. While prior research underscores the need for skilled workforces in Industry 5.0, it falls short of elucidating evolving job dynamics in the Industry 5.0 transition. This article addresses this gap by examining the evolving job landscape, skills, and learning trajectories.

Keywords: Industry 5.0; Sustainability; Resilience; Human-centric; Socio-centric, Workforce skills.

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1 Introduction

Against the background of the twin digital and green transitions and the Covid-19 crisis, the EU Industrial Policy (launched in March 2020 and updated in May 2021 in response to the pandemic)

renews its focus on enhancing the *competitiveness and autonomy* of EU industry and emphasises that EU industry will *lead and accelerate the transition to a sustainable and resilient economy* that achieves the *highest social, labour and environmental standards* (European Commission, 2020). The underlying fundamentals of this new industrial strategy, "Industry 5.0", are rooted in the European values and traditions, which includes setting up a common regulatory framework, fostering research and innovation, supporting efforts towards climate neutrality, among others. Importantly, (re)skilling has been flagged as a priority in the industrial policy as well.

Industry 5.0 has emerged as a key paradigm within EU industrial policy, launched by the European Commission (Breque et. al., 2021). It states (digital) innovation and its application in the form of services, products, and processes need to ensure the threefold goals of being sustainable, human-centric and resilient toward industry, the economy and society, and its citizens and members. A key issue, and elaborated below, are the workforce skills to ensure the successful implementation and adoption of Industry 5.0. Furthermore, as part of the shift to Industry 5.0 paradigm, it is recognised that industry is not influenced by global megatrends, it is itself also a major shaper of economic and societal transitions. By advancing Industry 5.0, the European Commission sets out to align its economic and social goals, firmly putting good jobs and worker well-being at the top of the policy agenda (European Commission, 2023b).

Although Industry 5.0 is gaining ground in academic and policy debates, it remains unclear how it is interpreted and applied by different stakeholders at different levels, let alone how it is implemented. A problem is that the drivers and dimensions of Industry 5.0 require further conceptualisation and measurement. These needs are the starting point for this article.

Labour and skills shortages are another factor to reckon with. Although labour shortages existed before the Covid pandemic, they have become exacerbated since reaching record highs in several EU Member States (European Commission, 2023a; Zwysen, 2023). These shortages have been attributed to several underlying drivers, such as a declining labour supply (e.g., due to population ageing, a growing economic inactivity amongst the workforce due to illness or chronic conditions). Poor working conditions and wages in some sectors also make it difficult to attract and retain workers and there are also skills mismatches (Zwysen, 2023). Digitalisation, especially, appears as a major driver of skills shortages, fuelling a demand for digital skills at all proficiency levels and which is currently not being met by education and training (European Commission, 2023a). In this context, there is an increasing focus on the role of education and training as a lever for a competitive, innovative, sustainable and inclusive labour market and economy. In fact, up- and reskilling is seen as a critical strategy, not only to absorb the effects of these global trends but also to seize their opportunities (OECD, 2023).

Our overall goal in this article is to advance the Industry 5.0 concept from a sensitising concept (closer) to an operational concept thereby grounding the debate on the workforce skills necessary for Industry 5.0. This article hence centres around three main challenges with respect to workforce skills for Industry 5.0. Firstly, we develop a *conceptual framework* that recognises the societal implications of Industry 5.0. To date, Industry 4.0, as the expression of the fourth Industrial Revolution, has mainly been driven by technological considerations (Müller, 2021). Industry 5.0 extends Industry 4.0 by emphasising technological, social, and environmental dimensions (Breque et al., 2021). This article argues that a sustainable, resilient Industry 5.0 will need to be *human-centric* as well as *socio-centric*: complementing the needs of individuals with those of society. A socio-centric approach recognises that technologies are part of systems that are organised to further societal and ecological values. Looking at Industry 5.0 through this lens makes clear the need for a holistic approach that puts technology at the service of citizens and workers, now and in the future. The conceptualisation of Industry 5.0 needs to be developed in such a

way that its importance and achievability is apparent to all stakeholders, including companies in Europe and that Industry 5.0 becomes the new 'mindset' for European industry. As such, this industrial transition resonates with the framework of socio-technical system transitions and their multi-level perspective proposed by Geels (2019).

The second goal of this article relates to specifying the skills *for a digital and green Industry 5.0*. As with any new technology, skills emerge through technological demands and organisational choices (Levy & Murnane, 2004). These skills need to be supported by training, education and other forms of learning that: (i) recognise that skills development is the responsibility of a broad set of stakeholders in society and industry; (ii) are integrated with digital technology to avoid skills gaps and ensure better skill matches between supply and demand; and (iii) tackle the polarisation between high-skill and low-skill jobs and foster job upgrading, reskilling and upskilling strategies over a lifetime. This skilling strategy must be premised on companies (large companies as well as small- and medium-sized enterprises) better empowering their workforces because workers: have the expertise, knowledge and the most direct link to technology; and are best placed to identify what skills are needed to be developed, which in turn requires companies to offer participative training opportunities. Companies should use workers' talents and innovative capacity and create environments that support workers' innovative work behaviours and reward workers' skills and knowledge (Dosi, 1988). The second challenge is thus to find out the 'what' and 'how' of this new skilling for a green and digital Industry 5.0.

We consider this article as a contribution to the necessary *policy support for a green and digital Industry 5.0*. Industry 5.0 foresees an alternative future in which industries focus more on the interests of a wider set of stakeholders, within and outside the organisation. A productive, sustainable and resilient future is possible if companies adopt a human- and socio-centric approach. This article will look at different stakeholders across different levels and discuss how to best connect them around Industry 5.0. This includes companies, industrial networks, social partners and policymakers among others. In this way, the article signals how Industry 5.0 policy can be transferred from the EU level to Member States and, vice versa, how current national Industry 4.0 platforms can be integrated into an overarching Industry 5.0 platform. The effectiveness of Industry 4.0 in terms of innovation and inclusiveness is not yet clear-cut (Grond et al., 2021). As a result, for many policymakers, thinking about Industry 4.0 is still largely experimental. Industry 5.0 is an attempt at policy correction for these Industry 4.0 policies, but the question remains what policies are effective.

Given these three considerations, the research question is: What can be a conceptual framework of Industry 5.0 that is useful for stakeholders from business and policy and that can be applied as a building block for skilling for companies that require greening and digital transformation and provides enough practical direction for policymakers?

The remainder of this article is structured as follows. In the following section, the transition from Industry 4.0 to Industry 5.0 is described and positioned in current academic and policy debates. The next section then outlines the research design. The following section then proposes a new conceptual framework for Industry 5.0, which is further elaborated in the subsequent section focused on workforce skills. The following section then focuses on the measurement and implementation of Industry 5.0, followed by conclusions and a discussion of possible avenues for further research. In the final section we draw conclusions, offer recommendations and discuss possible avenues for further research.

2 The transition from Industry 4.0 to Industry 5.0 and its implications

Industry 4.0 was developed in Germany as a new way of doing industrialisation in the context of wider technological transformation (Kagermann, 2013). It was a national industrial strategy (Kagermann, 2011) to ensure that German high-tech manufacturing was 'fit for the future'. It rested on the combined use of new digital technology such as artificial intelligence (AI), advanced automation and robotics, and big data (Davies, 2015). The outcome is the creation of what is sometimes called 'smart factories' that use the new digital technologies to integrate the whole production system(European Commission, 2017). Moreover, the same digital technology enables the linking of this production to upstream, how goods are conceived, and downstream, how goods are consumed (Davies, 2015). The Journal of Innovation Management was one of the first journals publishing a Letter about Industry 4.0 in its early days. Centralized and monolithic production monitoring and control applications will eventually cease to exist, giving way to solutions capable of supporting this radically different vision of connected yet decentralized production and supply chain processes (Almada-Lobo, 2015).

Industry 4.0 is seen as a technological leap forward, with a whole new context for manufacturing companies. Perez and Murray-Leach (2021) show that how we look at the past determines our policy responses. Technological advance is not continuous but happens in major transitions and periods of economic decline and growth. Academic literature identifies different numbers of "industrial" or "technological" revolutions and provides diverging interpretations of their nature and consequences. In the digital age, some authors see a role for the state to intervene and manage the financial situation, prevent monopolies from arising, and guide innovation and investment through mission-driven policies. Considering social and environmental goals, they argue that there is certainly a role for policymakers to 'tilt' the market forces in a "positive-sum game between business, society and the planet" (Perez and Murray-Leach, 2021; Mazzucato et al., 2020).

There are two main views on how to see Industry 5.0 in relation with Industry 4.0. On the one hand, it is suggested that it is a deepening of Industry 4.0 (European Commission, 2021b). The objective is to continue with the digital transformation of industry. This redefinition is also meant to bring Industry 4.0 within the broad European strategy of greening and sustainability, adding human- and socio-centeredness (Müller, 2021). The European Commission proposes Industry 5.0 as a solution to make Industry 4.0 more successful. On the other hand, its treatment of the technology within the digital transformation is different. As a response to accusations that Industry 4.0 was technologically deterministic, technology is now recognised to be socially constructed and must serve, not substitute or subordinate human labour. As Acemoglu and Johnson (2023) ascertain, most digital technologies can be qualified as 'so-so' technologies. They automate jobs, but do not lead to higher productivity. Industry 5.0 also adds two new elements of the industrial strategy – sustainability and resilience as responses to the climate crisis and recent economic shocks, respectively. Therefore, Industry 5.0 offers a twist to and an extension of Industry 4.0.

Whilst the conceptualisation of Industry 5.0 addresses the techno-centrism of Industry 4.0, three other problems with Industry 4.0 have carried over to Industry 5.0, which must be addressed (Warhurst & Dhondt, 2023). The first issue is that, unlike there is a broad definition of Industry 5.0 (Breque et al., 2021), it operates at a high level – the industry level, in a way even societal level – and is abstract, thus lacking operationalisable detail. The practices of Industry 5.0 now need to be developed and agreed upon, and set at the organisational level so that companies, employees and policymakers know what it looks like within workplaces. The second issue is that, once knowing what Industry 5.0 ought to look like within workplaces, there need to be actionable policy and practice for organisations to encourage and support them in its adoption. The third

issue is to develop the means by which to measure the progress of organisations in adopting Industry 5.0. This requires the development of an appropriate dataset that captures organisational adoption within the European Union.

Importantly, the realisation of Industry 5.0 has far reaching implications for workforce competencies and skills. This is already subject to communications and activities on various EU and international levels:

First, in its Communication on the new EU industrial strategy, the European Commission underlines that "*A competitive industry depends on recruiting and retaining a qualified workforce. As the twin transitions gathers speed, Europe will need to ensure that education and training keep pace. Making lifelong learning a reality for all will become all the more important: in the next five years alone, 120 million Europeans will have to upskill or reskill.*" (European Commission, 2020, p. 11). To bring the topic of up- and reskilling to the foreground, 2023 marked the European Year of Skills. This was announced in the 2022 State of the Union address and echoed the 2019 Political Guidelines of Commission President von der Leyen. Key building blocks to make progress in up- and reskilling are found in the European Pillar of Social Rights (EPSR), of which the first principle is that *'everyone has the right to quality and inclusive education, training and life-long learning in order to maintain and acquire skills that enable them to participate fully in society and manage the transitions in the labour market'*.

Second, the European Pillar of Social Rights (EPSR) Action Plan translates this principle into concrete actions in the form of the European Skills Agenda. The European Skills Agenda serves as a guide to develop more and better skills and includes 12 actions organised into four blocks: (i) a call to join forces in a collective action (Pact for Skills); (ii) actions to ensure that people have the right skills for jobs (strengthening skills intelligence, support for strategic national upskilling action, a proposed Council recommendation on vocational education and training, rolling out the European Universities initiative and the upskilling of scientists, skills to support the twin transitions, raising STEM graduates and fostering entrepreneurial and transversal skills, skills for life); (iii) tools and initiatives to support people in their lifelong learning pathways (initiative on individual learning accounts, approach to micro-credentials and a new Europass platform); (iv) a framework to unlock investments in skills. Especially this call for collective action – from the EU Member States, social partners, industry, the education system and training providers, (. . .) runs through most of these programmes and initiatives.

Nevertheless, when it comes to up- and re-skilling, there is still a long way to go. A recent OECD report on up- and reskilling in the context of the green and digital transition, for example, shows that only a minority of adults in OECD countries participated in training, and there are major differences between sociodemographic groups – especially those groups who would benefit most, appear to participate least (OECD, 2023). This points to significant barriers to up- and re-skilling, for both companies and individuals, which must be addressed (Baiocco et al., 2020). Similarly, in the context of Industry 4.0 (which was increasingly put forward as a vision of industrial transformation aimed at achieving the twin transition, see European Commission, 2023b), the impact of new technologies, digitalisation, computerisation and robotisation on jobs and skill needs has been discussed extensively, while skills development has been identified as a main determinant of the successful adoption and implementation of specific technologies and of Industry 4.0 overall (Pereira & Romero, 2017; Fareri et al., 2020; Saniuk et al., 2023). Although the literature seems to have reached a consensus on the importance of skills development for Industry 4.0, there is still a long road ahead in practice, with challenges such as a mismatch between formal education and companies' skills needs, a lack of lifelong learning, etc. (Maresova et al., 2018; Saniuk et al., 2023).

3 Research design

3.1 The BRIDGES 5.0 project

This article draws on work from the BRIDGES 5.0 project, which focuses on workforce skills for Industry 5.0 (Oeij et al., 2023). More specifically, the BRIDGES 5.0 project pursues four main objectives. A first objective is to map how jobs are transforming and what new green and digital jobs are emerging in the fourth Industrial Revolution, and to understand the Industry 5.0 requirements for these jobs and company practices. A second objective is to map Industry 5.0 skills and skill gaps at the EU-level and across various national contexts for emerging green and digital jobs and enable monitoring of skill gaps using skills taxonomies/standards. A third objective is to set up learning trajectories and training pathways, using the enriched Teaching and Learning Factories concepts (see below), and experiment with these interventions to reduce skill gaps for four target groups, i.e. managers, employees, job seekers and students. Finally, BRIDGES 5.0 aims to engage with a range of industry and related stakeholders (policymakers, large companies, SMEs, social partners, vocational education and training providers at the regional, national and EU levels. With their support, a collaborative (web) platform 'Bridges 5.0' will be established to facilitate social innovation in the learning field. The platform will also provide these stakeholders and the target groups with recommendations and instruments for new learning and training systems. In this article we only report on the conceptualisation of Industry 5.0.

3.2 Methodology and data

In this study, we use a mixed-method approach to develop the conceptual framework on (workforce skills for) Industry 5.0. Three methodological approaches were combined and carried out in the period November 2022 – November 2023. We started with an extensive review of the available academic and grey literature and a review of the available data sources at EU level and in the EU Member States. However, as the literature on Industry 5.0 was still scarce in the period and scattered across scientific disciplines. insights from this review were further enriched and triangulated through consultations with academics and experts and with practitioners, companies and networks.

First, a literature search and review were performed that focused on scientific and policy literature. Some 500 publications were found in SCOPUS that discuss Industry 5.0 as a concept (up to 2022). We used search terms like "Industry 5.0", and the search terms reflecting the three pillars of Industry 5.0 (human-centricity, sustainability and resilience). We included overview articles on the topics, an exclusion criterion was however if articles only offered opinions and concepts of desired states, and not empirical evidence for Industry 4.0 and 5.0 practices. We preferred review articles over single case studies or small-scale empirical research. For the concept of Industry 5.0 itself, our starting point are the main documents developed by the European Commission (European Commission, 2021b; Müller, 2021). Core results of our analysis are included in sections 4 and 5. The main function of this literature review was however, to serve as inputs to and to trigger discussions and debates with stakeholders.

Second, building on the literature review, a conceptual discussion on Industry 5.0 was managed within the multidisciplinary project team of academics and experts. The expertise present in this team helped to develop a plausible understanding of Industry 5.0, its elements and their relationships. More specifically, over the course of twelve months, there has been regular exchange (in person and online).

Third, practitioners, companies and networks were engaged to discuss how they perceive the relevance of Industry 5.0 and its key elements, human-centricity, resilience and sustainability.

Several of the companies and networks that were part of the project team. Companies consulted are involved in digital interventions and could thus inform us on how they enhanced the feasibility to implement Industry 5.0's key elements. In total, nine major companies from various European countries were consulted over the period of several months. Additionally, a large number of social partner organisations, networks of companies and practitioners working around Industry 4.0 and Industry 5.0, and similar organisations were engaged in the debates in parallel over the same time period. The following table summarises the mixed method approach.

Table 1. Research information)

	Sources	Type of data	Method of analysis
Literature search	Scopus database followed by Internet search and snowballing on keywords 'Industry 4.0', 'Industry 5.0', 'human-centric*', 'resilien*', 'sustainability', 'skill*', 'explainable technology'.	Circa 500 publications of scientific and policy literature (mainly articles and book chapters) reviewed. 50 selected after checking titles on face value. Further selection on the basis of abstract. Publications that were not based on research were excluded (i.e., if they were position papers, they were excluded).	Analysis of abstracts and selective reading of circa 50 publications
Expert discussions	Team members of the Bridges 5.0 consortium with academic expertise in workforce skills, technology, education & training; members of the scientific advisory board	Expert views, expert opinions provided by circa 30 experts	Exploring discussions / search conferences based on short notes and written documents
Practitioner discussions	Representatives of companies, networks, social partners comprised in the Company Board and Stakeholder Boards of the BRIDGES 5.0 project	Practitioner views, practitioner opinions provided by circa 20 practitioners, information about planned digital inventions in participating companies*	Discussions and qualitative (group) interviews about the practicalities of Industry 4.0 and 5.0

Overall, we chose a discursive approach, where literature served as entry point for expert discussions and industry experts recommended reports and articles that reflected important lines of arguments. Hence, the mixed methods were used in an iterative manner, snowballing between experts and scientific and grey literature, and subsequently sense-making within the project team, complemented by discussions around topical events with high-profile participants. This empirical approach seems appropriate if the topic is as recent as the present one around Industry 5.0 and hence insufficiently covered by academic literature alone.

4 A conceptual framework of Industry 5.0

4.1 Three goals of Industry 5.0: human-centrism, resilience and sustainability

One of the key distinguishing features of Industry 5.0 compared to Industry 4.0 is the inclusion of societal, not just technological or economic, goals and which put people central, enable businesses to anticipate and respond to disruptions, and ensure a society's durable well-being and welfare. These three pillars are the core values of Industry 5.0 (Xu et al., 2021). By contrast, Industry 4.0 was techno-centric and primarily focused on organisational efficiency and productivity. Industry 5.0, instead, clearly rests on a 'humanised philosophy' (Oeij et al., 2019), adopting inclusive growth (Warhurst & Dhondt, 2023) and has a normative guiding principle.

Human-centricity covers two core ideas in our view: technology itself can be 1) human-centred or introduced in a human-centred way. Unlike Industry 4.0 in which machines were anticipated to substitute many tasks, Industrie 5.0 wants to see technology as complementary to humans; besides that, technology users have to 2) be socio-centric, i.e., consider the social context. This last addition is needed because many technical specialists interpret human-centric in an individualist way. The work environment goes beyond an individualistic approach. Not just individuals need to adapt to new surroundings, as the decision makers in organisations make organisational choices (e.g., Resende et al., 2021). A human-centred approach to technology requires (a) technology to be developed in such a way that it helps humans. For example, Welfare et al. (2019) identified several ways in which robots could help reduce negative work attributes and enhance positive ones, such as reducing work interruptions and cultivating physical and psychological well-being. In this respect, , engineering sciences are tasked with adapting technology. To do so, Welfare et al. see the solution as being a re-orientation of Industry 4.0 in terms of investments and technology development. Other researchers discuss the conditions under which Industry 5.0 can succeed, namely that the modern customisation and technological upgrading challenges can only be met through human involvement and empowerment (Kumar et al., 2021).

Nonaka and Takeuchi (2021) further stress the need for a "humanising" company strategy. Humans should be at the centre of company strategies, driving future-making with the help of digital-led automation. The reward to the company is resilience, longevity, and sustainability, in line with all three Industry 5.0 goals. Human-centricity requires not only the technology perspective, but also the organisation of work as to make Industry 5.0 successful. Because organisations are social entities, comprising different types of actors with different interests, experiences and expectations, there is a socio-centric approach needed, one that goes beyond human-centric workplaces, as it stresses the social function of cooperation, collaboration, and as it links workplace, organisational, industry and societal levels. Industry 5.0 therefore requires new organisational policies that connect the human-centric and socio-centric viewpoint. Approaches such as workplace innovation (Oeij, Dhondt & McMurray, 2023) and high-performance work systems (Eurofound & Cedefop, 2020) pay attention to these aspects.

Resilience is needed to be better prepared to withstand major disruptions, such as the global financial crashes, energy crises, the Covid-19 pandemic, and the Ukraine-Russia war. Disruptions can reveal vulnerabilities on the organisational level, the industry level, and the value chain and supply chain level. Businesses need to handle these disruptions. And as some industries more than others play a key role in providing critical infrastructure, such as for healthcare and security, business failure in these industries has repercussions on the societal level. Increasing resilience in instances of crises may call for different strategies than while operating under stable circumstances. Breque et al. (2021) point out that under stable circumstances the focus on efficiency often leads to outsourcing, or geo-political shifting of business activities and hence to cost reductions. These

business-level strategic decisions happen often at the expense of creating vulnerabilities in the supply network and production thus compromising industrial supply and leading to shortages of products.

Acknowledging that industrial resilience is key, Breque et al. (2021) stress the "robustness of industrial production" anchoring resilience in resilient value chains and resilient production capacity. This implies that the concept of resilience is seen from a systemic perspective – beyond the business boundaries - on the level of industries and global value chains. The target is then the resilient (sub-) system (firm, sector, industry), which has repercussions on resilience skills of the workforce. Resilience as a strategy requires better anticipation of what will happen, quick response after a disruption has occurred, and strategic intervention to support the changes. As in the case of 'high reliability organisations' (like nuclear power plants, aircraft carrier vessels, first responder organisations), resilient organisations and industries must internalise the capability to anticipate, respond and recover in the case of disruptive events (Dwyer et al., 2023). Relevant actors must successfully deal with weak signals, future risks, possible futures, and actual mishaps in a complex world to address rapidly changing environments (Teece et al., 1997, p. 516). Apart from skills that have a definitorial closeness to specific tasks, resilience needs capabilities that are increasingly dynamic, and co-evolve with organisational phenomena like firm governance structures, open innovation, ecosystems and a view on the central role of stakeholders (Vogel & Güttel, 2012).

The *sustainability* notion rests on the idea that the EU aims for competitiveness that is not only oriented at economic criteria but also reflecting how the output is generated, taking in account life-cycle perspectives that means doing better with less by optimising the relationship between product output and resource input. In the context of the climate crisis, the European Commission initiated the green deal with the goal to be the first climate neutral continent. To achieve this goal, a massive reduction in energy consumption and use of natural resources is required, which requires heavy involvement of the European industry. Additionally, the EU encourages a circular economy where industry re-uses, re-purposes and recycles products and resources. The importance of this topic has increased steadily in the manufacturing sector for many different reasons (environmental concerns, diminishing non-renewable resources, stricter legislation and inflated energy costs, consumer preferences). Sustainability has strong ties with Industry 4.0 technologies, such as AI and additive manufacturing. There are also intrinsic benefits for the industry as moving to more sustainable production might save resources, reduce costs, and help build a better corporate image (Breque et al., 2021, p14 & 27). The sustainability efforts from EU regarding to manufacturing are strongly connected with the approach of Industry 5.0 that also should be embedded in activities like smart specialisation (European Commission, 2020c).

4.2 Target groups: Building the workforce for Industry 5.0

The specific features of Industry 5.0 require new skill sets of people. These new skill sets will not be evenly distributed across the population and they cannot be uniformly rolled in the education system. Instead, the types of skills and the channels to implement them in the businesses and industries will have to be carefully devised. Building on the literature review and the expert and stakeholder consultations, *four target groups* have been identified as key for an investigation into workforce skills required for Industry 5.0. These groups form the future workforce (students and job seekers), current workforce (workers) as well as those playing an important role in creating and managing Industry 5.0 (managers and engineers). Each group can be linked to different workforce skills and to different skilling approaches. In our research, we will be exploring the presented conceptual framework with respect to these four groups.

Students are those following vocational training and those in less specific education such as scientific training at universities. Industrial firms in the stakeholder consultations for this study voiced considerable concern that students as the future workforce with high potential for creativity and innovation may reject jobs in industry because they find working in a highly automated and artificial intelligence populated environment unattractive. Here, industry themselves are responsible for creating attractive jobs that leave room for manoeuvre. But also educational institutes play a large role in preparing potentials who can fulfil an ambassador's role on themes such as sustainability and inclusiveness. As Industry 5.0 is a new vision, educational and vocational institutions and agents must consider what the three goals mean for the curricula of their studies.

A second target group for (re-) skilling efforts are clearly workers. Technologies like cyber-physical systems that take over tasks with high levels of repetition and biomechanical overload transform labour to activities with high demand for cognitive and manual skills. Skills can be complements or substitutes of digitalisation, with e.g., social coordination and negotiation skills as complements versus physically intense labour as substitutes (Worldbank, 2024) The major reskilling effort for *workers* will be at the company with on-the-job training and other forms of non-formal training. Individual workers may further invest themselves in training. Additionally, the workers might have unique knowledge that needs to be transferred to a new generation of workers.

Job seekers include short- and long-term unemployed, and lateral entrants. In discussions with stakeholders for this study the effects of new technological opportunities like increasing digital remote worker exoskeletons allow inclusion of people previously excluded from large parts of the job market and alleviate skill gaps and pressing labour demand. However, views are contested and certainly, skilling efforts require mobility measures on the labour market. It will also require understanding from labour market institutions of what companies will be needing in the future.

Managers and engineers are responsible for the decisions that lead to Industry 5.0. Traditionally, managers at different levels were responsible for the decisions that were made in an organisation. To make Industry 5.0 happen, managers have to be entrepreneurial, as well as cognitively and socially highly skilled. (Heubeck, 2023) Design decisions need new skills from engineers (de Souza and Debs, 2024) and have to be moderated and complemented by other stakeholders and managers. Managers and engineers are both key decision-makers and differently impacted by industrial transformation than other employees. (Cirillo et al., 2023) Both groups play a leading role in the adoption of Industry 5.0. The key challenge for these groups is to adopt a wider perspective that comprises not only the economic factors but also human, resilience, and sustainability factors. Engineers need to adopt new criteria in their design process. Aiming for human- and socio-centrism will also require a more direct input from different stakeholders by using design methods such as co-creation and ethics for innovation.

4.3 Ecosystem levels

Industry 5.0 implementation has consequences for several levels. Industry 5.0 differs from Industry 4.0 in its explicit attention to the worker and the workplace, *the workplace level*. Human-centricity is about improving labour market access, employment security within the labour market and the quality of jobs in that labour market. It is also about creating opportunities for job seekers and students. As a result of the improved conditions, workers can do their jobs better, which benefits the organisation and the industry. Additionally, those without work could benefit from easier access to work. Resilience and sustainability are about behavioural change and the need to understand how workers can make their organisation more sustainable, the company practices more circular, and help companies become more robust and resilient. Concepts at the individual

level and the job level, such as the resilient worker, sustainable employability and job quality, are included in the concept of human-centricity.

The *organisational level* reflects the responsibilities of management and the collective of workers. Organisations should incorporate human-centricity, resilience, and sustainability into their values and business models and expand their conventional economic indexes (such as capitalisation, market penetration, revenue, and profit) with additional Industry 5.0 indicators (European Commission, 2021b). As a result, new business models might be adopted that, for example, aim for circularity in goods and services. Human-centricity is a concept that should be adopted across the whole organisation. It requires acknowledging the socio-centric role a company (i.e., its organisational members) has in its surroundings – human society, instead of viewing society as a resource for workers to achieve isolated company goals. A human-centric approach views workers as assets in which the company should invest, for example, training and education. Workers, in return, share larger responsibility with respect to participating in the company's Industry 5.0 objectives. It is important to mention that 'organisations' are not a fixed concept. With hybrid work, platformisation, networks, projectification, and self-steering teams, organisational boundaries are evolving.

At *industry level,* agents must make agreements about sustainability and resilience. With regard to sustainability, it is imperative to establish a level playing field between competitors within sectors and industries. As regards resilience, agents must ensure that organisations in their industry are supported and facilitated in how to deal with disruptions. Agents must support the transition to green and digital technologies. Resilience and sustainability primarily benefit the society in the long term by decoupling economic prosperity from the use of energy and resources. Companies cannot do this own their own. Instead, industrial standards are needed. This will further strengthen companies in their endeavours to implement human centricity for its employees.

At *society level* a '5.0 Society' should be established, with human-centricity, resilience and sustainability as core values, and which would build institutions to support this. Democratic institutions, broad education, inclusive growth and access to social security would be among the most salient ones. These institutions and their values and norms would nurture a culture of welfare combined with well-being for all life on the planet now and in the future.

4.4 Industry 5.0 as a multidimensional concept

All the above considerations and inputs from various empirical methods applied lead us to an Industry 5.0 conceptual frameworks as depicted in Figure 1.

Importantly, we see Industry 5.0 is an open and evolving concept, and as a *'sensitizing concept'*, (. . .) *"it gives the user a general sense of reference and guidance in approaching empirical instances"* (Blumer, 1954, p. 7). Industry 5.0 to date is a sociotechnical imaginary. As a sensitizing concept outlining a desired state, that has not yet been attained, a possible future pathway to provide orientation, Industry 5.0 is different from an analytical concept framing technological and sustainability transitions in a multi-level perspective for example in Geels (2019). Both, the analytical as well as the guiding lens are complementary to achieve transitions.

Industry 5.0, as a sensitizing concept, helps to identify the main features of what companies and other actors should do in practice. Although this article limits the scope of Industry 5.0 to the development of workforce skills, Industry 5.0 remains a multidimensional concept with different pillars that touches the very different realities of the individual worker and workplace, organisational policies and actions, and the societal level. Therefore, Industry 5.0 is regarded as a multidimensional concept, as is shown in Figure 1, with three dimensions and three main connections.

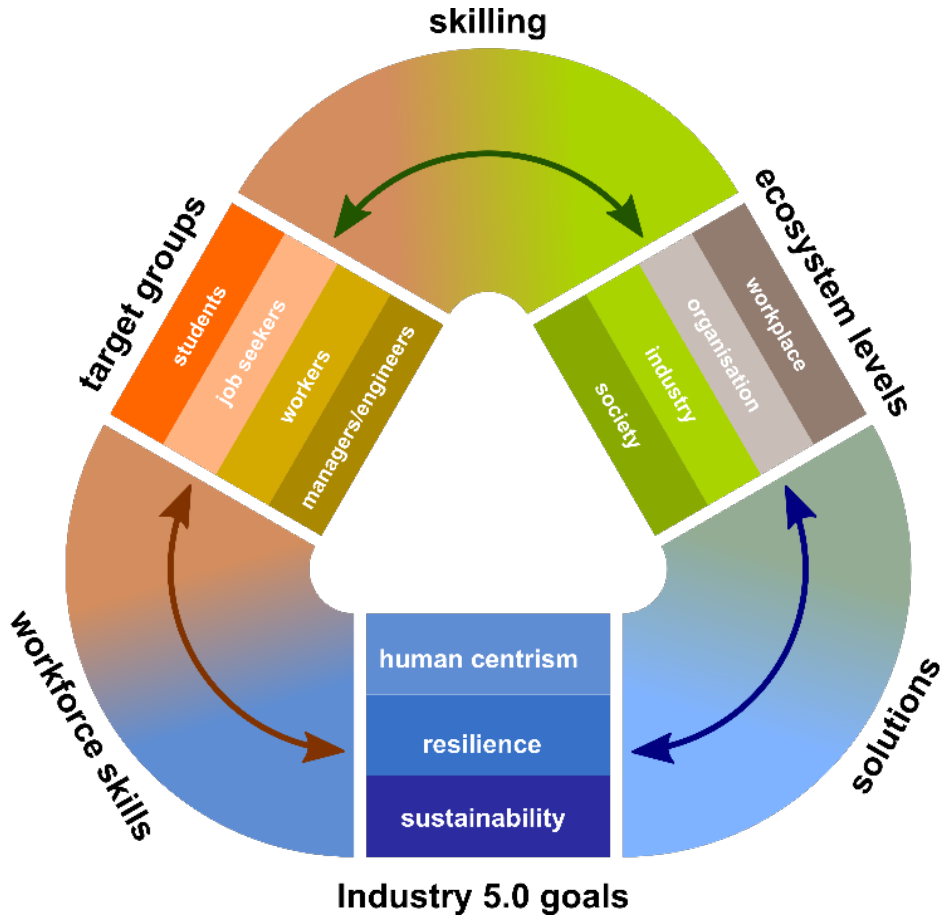

Figure 1. Framework model for workforce skills in Industry 5.0 Source: Authors' own elaboration, based on literature search and review and consultations.

The three dimensions are, first of all the *Industry 5.0's pillars or societal goals*: human-centrism, sustainability, and resilience. It should be mentioned that these dimensions are not just social goals. Rather, Industry 5.0 is primarily focused on having a system or organisation of production that is intended to have socio-economic outcomes. In the second place, the model distinguishes an *ecosystem* with four different levels: workplace, organisation, industry, society. As a third dimension, *four different target groups* are identified: students, job seekers, workers, managers / engineers. If Industry 5.0 is about 'behavioural change' at the company level, this touches on decisions and behaviours made by workers, managers, job seekers and students.

Then, there are important connections between the dimensions. First, *solutions* form the connection between Industry 5.0's pillars and the different ecosystem levels. To give an example: the connection between organisational level and sustainability is the solution for how an organisation does adopt a circular production process. Second, *workforce skills* i.e., the skills that are needed for Industry 5.0, form the connection between the Industry 5.0 pillars and the target groups: e.g. the workforce skills that managers need for improving the sustainability of an organisation and society. *Skilling* (the process of acquiring skills) forms the third and last connection: between the target groups and the ecosystem levels.

The skilling of the different target groups will not occur in one place, instead, each level of the ecosystem and its agents will have its own responsibility of skilling the (future) workforce for Industry 5.0. At societal level, e.g., one could place educational and vocational systems, and at

organisational level the company's own training activities. Figure 1 further displays that certain 'solutions' to achieve Industry 5.0 require certain 'workforce skills' (for the different target groups) and that the task of 'skilling' is shared among the target groups to acquire them and the ecosystem level agents to deliver the appropriate training and work experience. In what follows, these three dimensions are further elaborated on. [1]

5 Workforce skills for Industry 5.0

5.1 Knowledge, skills and attitudes required for Industry 5.0

"An essential step in the definition of the future systemic transformation pathways that are aligned with an Industry 5.0 paradigm is the mainstreaming of jobs quantity and quality, as well as related skills. This requires an analysis of the job-creating potential of different industry pathways, including existing jobs that will remain relevant in most or all future scenarios; jobs that could be created by securing adequate skills through ad hoc up- or re-skilling policies; jobs that may emerge in the future as a result of technology developments and/or megatrends." (European Commission, 2023b, p 15.). Whereas the earlier research on Industry 4.0 focused largely on STEM skills, the most recent research is highlighting a much wider skills set that is a mix of hard, soft and IT skills (European Commission, 2023b).

Building on the methodology of the European Qualifications Framework (EQF) and e-Competence Framework (eCF) which highlights both individual and organisational competences (i.e. supply and demand) and the literature on Industry 4.0, it is clear that Industry 5.0 requires not only changes in knowledge and skills but also in the attitudes of the workforce (CEN et al., 2013). Knowledge is defined as the *"set of know-what"*, skill refers to the *"ability to carry out managerial or technical tasks"* (know how), and attitude is the "*cognitive and relational capacity"* (CEN et al., 2013, p. 13). In terms of skills, in the context of Industry 5.0, a further distinction can be made between foundational skills (e.g., literacy), job-specific skills (e.g., social skills required to deal with clients), and Industry 5.0 skills related to acting human-centric, resilient and sustainable. The advantage of using the EQF is that within the same occupation, different skills profiles are possible. There is a need to understand which organisational approaches are used.

The *human-centric* aspect of Industry 5.0 places workers' well-being at the core of the production process and uses new technologies to provide prosperity beyond jobs (Breque et al., 2021). The basis of this concept is thus a change in the strategic orientation of manufacturing companies and the mindset of industrial companies, mainly from profit maximisation towards increased responsibility for society and the people within the organisation (Breque et al., 2021). In this context, the following demands are put on the workforce: (i) dealing with human-centred technologies, and (ii) dealing with empowerment and participation.

Technology that is human-centric needs to factor in that human-centredness in its design, introduction, use and outcomes (Warhurst et al. 2020). Technology, if it does not replace or controls humans, can also augment their capabilities. Such augmenting technologies are also known as assistance technologies. Their purpose is to support people in their work and to make work easier. Assistance technologies enable individual need-based support directly at the workplace (Sorko & Brunnhofer, 2019), whether due to physical limitations, different levels of education, or other language skills. Such technologies offer a means to address shortages of skilled workers

1. Figures 1 suggests that there are many relationships, but these are not all part of the project. Since the BRIDGES 5.0 project is focused on workforce skills, this contribution stresses the three main dimensions (human-centricity, sustainability, and resilience) and the second (workforce skills) and third connection (skilling 4).

by an increasing number of potential workers (Sorko, 2022). Especially in industry, collaborative robots (Wallhoff et al., 2019) or augmented and mixed reality (AR/MR) solutions (McKinsey, 2022) are increasingly implemented. The latter especially in the context of individual information provision and on-demand training. It requires that the workforce can work with these technologies and support the development technologies in the workplace. Adding the socio-centric perspective, even these augmenting technologies require a perspective in which the perspective of the user in included in designing, developing and implementing these technologies (Acemoglu & Johnson, 2023; Belloc et al., 2020; Bal et al., 2021).

Instead of technology merely to replace the human being in manufacturing areas, today's trend is tending towards a collaboration between people and technology. The influence of technology on the work design depends, for example, on the technology itself, the organisational framework in the company, and the intended areas of application of the technology. In addition, the adoption of technology by the worker further depends on the usage of the technology and the quality of work results. Optimal use of technology requires the decentralisation of decision-making and empowers workers to have more autonomy in decision-making (Parker & Grote, 2020). The workforce not only needs to understand technology in all its forms, it also needs to understand how to co-decide in the shaping of the Industry 5.0 workplace. Participation is core to human-centric technology and work.. These workforce skills require management to understand what helps organisations to become more human-centric. Thus, Industry 5.0 indirectly supports the autonomy and needs of workers.

Resilience points to anticipation skills and how to manage resilience. Resilience is, partly, the capability to anticipate to (external) shocks and/or crises (Fougère & Meriläinen, 2021). Resilience seems to have an invariably positive connotation (Patel et al., 2017), seen as a collective resource and capacity, social support in a system, a coping mechanism, a collective systemic reduction of vulnerability. However, there is an inherent trade-off in the strive towards resilience between efficiency and redundancy. Efficiency in the form outsourcing, downgrading, saving resources, saving costs, streamlining structures etc., may lead to lock-ins and rigidities, and in the face of a shock, lead to vulnerability and disruption. On the contrary, redundancies are perceived as inefficient in periods of non-crisis and in a short-term perspective. In the long run, acceptance of redundancies may be an enabler of long-term flexibility and long-term efficiency. Resilience is the skill to deal with disruption, manage disruption, and bounce back to stable functioning, and on top of that bounce forward, i.e. learn from the past, conceptualise shocks as opportunity to evaluate options, and embrace (radical) change (creative destruction) (Hynes et al., 2020; Roth et al., 2021). Workforce skills are how to understand and anticipate shocks, and how to develop strategies to deal with these shocks, in the longer term, understanding the need for redundancy.

Sustainability skills of the workforce are perhaps the less concrete and tangible of the three workforce skills. To develop sustainable manufacturing systems, it needs coordinated efforts in many areas (product, process, technology, organisation, skills, mindset, leadership approach etc.) and along the whole value chain (Giret, Trentesaux & Prabhu, 2015). To reach the sustainability goals there are green tasks, jobs and skills demands for the European workforce. In addition, the workforce must adopt sustainable behaviours that allows them to make the right judgements in their work. Green jobs are two of a kind: (1) jobs in businesses that produce goods or provide services that benefit the environment or conserve resources; (2) jobs in which workers' tasks involve making their establishment's production processes more environmentally friendly or use fewer natural resources. The green transition requires major changes in (general) behaviours of the workforce. Reaching net-zero emission targets, requires a fundamental change in attitudes and behaviours at the workplace, and in companies, industry and society. The input of everyone is

needed to avoid unnecessary emission and support to change personal behaviours (also outside the workplace, for example, travel behaviour, consumption patterns) and deal with the complicated trade-offs that will arise.

5.2 Developing Industry 5.0 workforce skills

Following this logic of knowledge, skills, attitudes, it is clear that current understanding is limited of what is necessary to develop the competences that workers need to work in an Industry 5.0 work environment. At present, it is generally understood that what is needed in terms of knowledge, that is, the "know-what". Similarly, there is a general understanding about what kind of behaviour is needed and expected in this environment. What is not yet understood are the workforce skills needed to carry out managerial or technical tasks (know how), and the appropriate attitude, namely the "cognitive and relational capacity" to .... Table 2 provides an overview of directions for skill development with regard to general, human-centric, resilient and sustainable abilities, divided into what is needed to create an Industry 5.0 work environment and what is the knowledge needed to work in this environment. We stress that the abilities in Table 2 are general, and that specific skills still need to be identified for employees and managers, and for technical and non-technical tasks. This is part of the upcoming research in the BRIDGES 5.0 project.

Table 2. An overview of directions in which to develop Industry 5.0 workforce skills)

Ability	Create Industry 5.0	Work in Industry 5.0
General	▪ Design and use digital technologies and AI systems in a way that meets industry 5.0's three objectives ▪ Include human-centric, resilient and sustainable values in business models and KPI's.	▪ Learn to, and work with existing, new and complex digital technologies and AI systems.
Human-centric	▪ Understand human centricity ▪ Include basic humanised values, e.g., freedom, autonomy, self-steering, self-fulfilment (based on evidence-based criteria of job / work design) ▪ Support and implement worker participation in decision making processes aimed at change and daily operations ▪ Support and implement worker participation in decision making processes aimed at change and daily operations ▪ Apply a human in command-principle with respect to human-technology interaction (where machines remain machines and people retain control over these machines at all times). ▪ Use human centred design methods ▪ Use assistive / supporting / augmenting technologies	▪ Show responsibility, intrapeneurship and make use of being empowered ▪ Make use of offered learning opportunities (see also Resilience) ▪ Participate in processes related to (re)design / change ▪ Participate in processes related to (re)design / change ▪ Be able to communicate in participation processes (Internal & external interaction) ▪ Working with assistive technologies

Ability	Create Industry 5.0	Work in Industry 5.0
Resilient	▪ Assess the company's dependencies through planning for different scenarios and risk assessments ▪ Develop a resilient production process ▪ Develop a resilient network of suppliers, partners, and customers (systemic thinking) / supply chain / value chain ▪ Encourage self-organisation, creativity, innovation, and flexibility, e.g. by providing learning opportunities for them ▪ Implement training and education systems that guarantee the availability of knowledge and skills ▪ Develop strong risk management policies and financial resilience	▪ Understand/integrate resilience in company policies ▪ Engage in lifelong learning and develop ability to adapt and to creativity ▪ Reflect on and respond to the resilience of the work process, and analyse and solve problems at systems level ▪ Be self-organising (e.g. as a team), manage yourself
Sustainable	▪ Care for the environment ▪ Provide the knowledge for workers to do so ▪ Carry out environmental impact and lifecycle assessments ▪ Make and promote 'green choices, use green technologies, develop green tasks and design and implement circular processes	▪ Care for the environment and act sustainably ▪ Understand circularity and carry out lifecycle and environmental impact assessments ▪ Evaluate green technologies ▪ Elaborate resources efficiency

Source: Authors' own elaboration.

To guide the further discussion on working definitions around workforce skills in Industry 5.0, Annexe 1 contains narratives that were developed at three levels: the company level, the employee level and the industry level. These narratives logically overlap. Their aim is to provide a general storyline, without too many details. Each narrative can be tailor-made for a specific situation or case, and can thus guide future working definitions of the central constructs and concepts.

6 Measurement and implementation of Industry 5.0: What will make Industry 5.0 work?

6.1 Measurement of (workforce skills for) Industry 5.0

The basis for shaping policy and strategies on Industry 5.0 is sufficient high-quality data that allows both looking back and look forward. On the one hand, traditional statistical surveys do not always provide the required information; on the other hand, there is a surge in data possibilities from web scraping and unstructured data sources. To assess what the current situation with technology and skills is for the four target groups (managers, employed, students, job seekers) defined above, information from several data sources that cover the topics of emerging technologies, forms of work organisation, workplace and social innovation, skill utilisation and development, labour market outcomes, etc., need to be used. As no single data source provides all the needed information

to approach Industry 5.0 challenges, several surveys and administrative data would need to be combined. Examples include employer and employee level data at the sector level within countries, or regional data sources at the detailed NUTS-2 level. Eurostat provides relevant EU-wide data on digital technologies and the labour market. Yet, information about the dynamics of organisations and work is limited in most EU-wide data sources, and data sources on adult learning and training cannot be easily linked with other sources. Because the linkage of data sources at the company level is easier in their national context, it is worthwhile to look for high-quality data at the country level (e.g. surveys, register data). Another interesting source is web-scraped data, which provide 'real-time' information of emerging work profiles, tasks, skills, and occupations within sectors, that is typically unavailable from traditional statistical sources (Cardenas Rubio & Warhurst, 2022). One downside, however, is that representativeness is not built into the raw data and further elaboration must be undertaken to establish it. More information than what is usually processed could be extracted from such unstructured web-based data sources. In particular, company policies and practices, organisational context and technology uses that are key aspects of Industry 5.0 could be analysed. To dig deeper into vacancy analysis, web-scraped data can be further enriched with other data sources such as company data from websites, public reports, official registers, and company information databases and collective agreements. Finally, using different types of data to develop future scenarios can also be helpful to anticipate changing skill needs.

6.2 Implementation of Industry 5.0: Teaching and learning factories

The changing demands for knowledge, skills and attitudes in the context of Industry 5.0 also come with new requirements in terms of education and lifelong learning (EASME, 2020; European Commission, 2023b). Already in the context of Industry 4.0, several efforts have been made to better connect teaching and learning with industry, experimenting with new approaches and initiatives such as living labs, field labs and other combined public-private learning ecosystems. Importantly, these approaches and initiatives not only innovate the learning environment and format and the institutional context, but also pilot novel pedagogical approaches in companies and at the regional and national levels. Educational specialists contend that new competencies only succeed if action-based learning and comprehension-based learning are combined (Pittich et al., 2013). Therefore, attention has focused on creating more practice-based learning environments.

Against this background, especially the *teaching factories* and *learning factories* are often considered as very promising, in particular in manufacturing settings (EASME, 2020). Educational interventions with practice-based learning at the company level are classified as teaching factories. The teaching factory approach is seen as an alternative in which education, research and innovation activities are integrated (Chryssolouris et al., 2016), and learning takes place in a real-life environment. The interventions that require broader public-private engagement in learning ecosystems are classified as learning factories (EASME, 2020). Examples include the academic education of students in a physical or virtual 'factory' environment. However, the assessment of outcomes and evidence of teaching factories and learning factories remains limited (Nick et al., 2019; Pittich et al., 2020), mainly because of the inaccessibility of these interventions (Lensing, 2016). A key area for future progress is, therefore, the redevelopment and enhancement of teaching and learning factories in the framework of Industry 5.0 and the twin transition, and to support their implementation in different institutional contexts. Further evaluations of their impact would also be valuable. To do so, the next steps in the BRIDGES 5.0 project involve the updating of these concepts and their testing and development with the companies participating in the Company Board. In particular, Industry 5.0 requirements are discussed with companies and translated into a training system that will be managed over two years. The companies will select settings in which

technologies will be introduced according to the training concept with the project team. The interventions allow comparing different training methodologies between technologies and between target groups.

To upgrade the governance of skills systems from the current Industry 4.0-approach to Industry 5.0, an evaluation of the current performance of the skills systems in industry is also required. This calls for an assessment of the current state of these skills systems in terms of strengthening governance, developing relevant (green and digital) skills and effectively using the skills. In addition, the interaction with the institutional context in which these systems are embedded and the impact on related policies should be examined.

6.3 A conducive policy framework and ecosystem around Industry 5.0

To make progress towards Industry 5.0, a conducive policy framework must be created, in which both the government as well as the wider ecosystem of actors play an important role (European Commission, 2021b; 2023b). The logic of Industry 5.0 should be mainstreamed across all policy areas, policy processes, funding sources, etc. to ensure all are aligned towards meeting the same goal. With its focus on Industry 5.0, the Commission touches on several of its key priorities and initiatives, including the Pact for Skills, the European Green Deal, the Proposal for AI Regulation, and others. To enhance *human-centeredness*, key points of attention for policymakers are making technologies trustworthy and aligned with human rights, enhancing the understanding of the determinants of wellbeing at work and investing in the development of those skills that are meet the demand by companies and allow workers to grow professionally and personally (European Commission, 2023b). With regard to resilience, policymakers should empower companies and workers to better manage unexpected shocks, in different areas (European Commission, 2023b), for example by investing in foresight and anticipation tools, improving the human capital stock, etc. Concerning sustainability, the focus should be on ensuring that economic, social and environmental goals are aligned (European Commission, 2023b), e.g., by promoting green jobs providing good working and employment conditions.

As part of the EU industrial strategy, the need for a well-established industrial ecosystem and alliances is highlighted (2020). In order to accelerate the transition to Industry 5.0, policy support and the take-up of the concepts and its core principles by key stakeholders, networks and companies (e.g., the social partners, training providers, labour market actors, industrial networks) at the EU, national and regional levels is required. Within the BRIDGES 5.0 project, these actors will be brought together in the framework of a collaborative (web) platform: the Industry 5.0 Platform. This platform facilitates social innovation in the learning field. It also provides these stakeholders and the four target groups with recommendations and instruments for new learning and training systems. The main functions of the Industry 5.0 Platform are to (1) inform the debate and the main stakeholders, (2) capturing and analysing outputs throughout the life of the project, and creating related opportunities for stakeholders to discuss and develop consensus on a wide set of digital skilling issues, (3) innovate through exchanges at a European scale, and (4) influence skills policies at the EU-level by helping to generate a Strategic Research Innovation Agenda for Europe, for transition to Industry 5.0 skilling policies.

7 Conclusion, discussion and recommendations

European industries must undergo a transformative shift, prioritising sustainability, human-centred approaches, and resilience, as outlined by the EU. The Industry 5.0 policy by the European Commission is not merely another phase of industrial development but a strategic initiative

encouraging companies to alter their business practices. This transformation requires collaboration among managers, employees, and customers to promote environmentally friendly production processes, services, and products. Companies should adopt material reuse strategies to reduce their reliance on scarce resources and minimise waste and pollution. Central to making this shift successful is the acknowledgement that the most precious and limited resource is the human worker. By harnessing the intellect and skills of the human workforce, Industry 5.0 can effectively leverage the latest technologies to address not only the pressing technological challenges of our time, but also contribute to social challenges like the energy transition, environmental pollution and climate related issues Europe's Industry 4.0 and 5.0 initiatives are not created in a void but in competition with what happens elsewhere on the globe. Japan started developing 'Society 5.0', which resembles Industry 5.0, in the sense that it also aims at human-centric goals. It is route is different, namely by creating a new science, technology and innovation ecosystem that addresses both economic and social issues (Fukuda, 2022; Huang et al., 2022). The United States developed a somewhat different strategy to improve the national innovation capacity through initiatives such as the National Network for Manufacturing Innovation program. Its goal was to reinvigorate 'advanced manufacturing', which should bring greater income, higher quality jobs, and improved health and quality of life to all nation's citizens (Fukuda, 2022). What these EU, Japanese and US initiatives share is their strive to make use of digital technologies that both benefit economic and social goals. Perhaps the main difference is that the EU want to put humans in the production process more central instead of technology, while Japan wishes to stress customer-centricity instead of a production-fucus; and the US emphasises the role of skilling the workforce. Apart from that, the EU approach strongly weighs sustainability, whereas Japan and the US underline the resilience of their ecosystems. But overall, the tendencies are in a similar direction (Adel, 2022; Fukuda, 2022; Huang et al., 2022).

Contrary to profit-centric approaches, Industry 5.0 places priority on the essential social change achievable through optimal resource utilisation encompassing technology, circularity, and skills within companies. Realising the goals of Industry 5.0 necessitates a redevelopment of employee skills.

The article's main contribution to the literature on Industry 4.0 and 5.0 is to offer a conceptual framework that intends to link the three pillars of human-centricity, resilience and sustainability to relevant ecosystem levels (workplace, organisation, industry, and society). Its guiding principle is that choices about Industry 5.0 are most often made at the company level, which means that the future of workforce skills is mainly an organisational-level issue and not, for instance, a matter of training for which individual workers and educational institutes are mainly responsible. This enables a more open discussion about the roles of the target groups (students, job seekers, workers, managers and engineers) and the responsibilities of target groups and management in shaping Industry 5.0 conditions within companies. The contribution should be understood as firmly shifting away from technological determinism in developing and implementing digital technologies

This article offers a comprehensive theoretical and conceptual framework to devise solutions for workforce skills in Industry 5.0. It operationalises the required research to shape various workforce skills essential for Industry 5.0. The project emphasises a participatory approach, engaging a diverse set of stakeholders in decision-making at every research stage.

Regarding the methodology, the aim was to ensure a holistic approach to the topic. This included the integration of polyvalent experts from different disciplines such as psychology, history, human resources, technology, etc. as well as from different countries. This holistic, iterative approach also represents a degree of novelty compared to existing I5.0 approaches.

At this stage, we are about to start collecting data and creating research outputs. The project BRIDGES 5.0 has considered several avenues for delivering scientific results to answer the main research questions. A first possibility was to create a survey to map practices in companies. Our assessment was that such a survey would surely be needed, but first an assessment was needed of existing database. The work by Greenan and Napolitano (2024) has shown that the combination of datasources offers an important understanding of Industry 5.0 and that this venue needed to be inspected first. We combine EU and national level data with the European Manufacturing Survey. Many datasources are therefore inspected. In the future, specific surveys can be designed to investigate residual questions. Also, specific case studies could be designed to find out what the Industry 5.0 requirements mean in practice. This approach can be endeavoured in the future. In the project, we have a set of intervention studies linked to the Teaching and Learning Factory. Other machine learning approaches could also be considered. For the moment, we are trying to understand what the innovative approach delivers. More research is needed, but first, several steps are taken in this project

The research explores the latest technologies and endeavours to identify optimal implementation strategies. It's important to note a limitation in the focus on specific learning interventions like training and learning factories, not fully encompass lifelong learning. The study's strength lies in examining skill requirements both in educational settings and workplaces, drawing insights from managers, employees, and educators across different European countries. While these insights are intended feeding back into company policies on workforce skills, the project as a whole will also inform practice on the consequences for business models, responsible innovation and contributing to human-centric, resilient and sustainable business ecosystems in general. Additionally, the project kickstarts a policy development process from scratch, involving social partners, education institutions, and industry authorities to formulate strategies conducive to a more inclusive and sustainable future. Collaborations with other European and national research projects enrich the study, potentially yielding a more supported future perspective through shared data and insights.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this article.

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Annexe 1: Narratives of Industry 5.0 as a guide for future working definitions

"Industry 5.0 companies are in terms of technology and digitalisation up-to-date and future-proof. The deployment of new technology and digitalisation is to support the work of employees, not to control them. The management philosophy and strategy of the company is to align economic goals, ***sustainability*** goals and social goals simultaneously. Management behaviours combine the strive for successful business performance with ways to support employees. Their workforce has the necessary skills and the opportunity to continuously upskills their competencies. Their jobs are characterised by a balance of job demands and job control opportunities. Their labour contract and renumerations are aligned with fundamental rights and a fair day's pay. The relationship between workers and management is constructive and cooperative due to these ***human-centric*** factors. Employees have decision power with regard to changes in the organisation that affect them directly. In this safe, healthy and productive environment, employees are motivated to do their best, contribute to the innovativeness of the company, and adopt renewal. Such companies, with the appropriate style of management, level of digitalisation, human centred / supporting technology and quality of the skilled workforce, are ***resilient*** to adopt changes in the environment and to adapt to changing circumstances in their business and entrepreneurial networks. Companies in Industry 5.0-proof environments benefit from the relative strengths of technologies and workers, because they invest in both."

"Industry 5.0 employees are persons with the right level of skills to function in the current digital working environment. They function well because their jobs are characterised by a balance of job demands and job control opportunities. Their labour contract and renumerations are aligned with fundamental rights and a fair day's pay. The relationship with other workers, other disciplines (e.g. engineering and technology design) and management is constructive and cooperative due to these ***human-centric*** factors. Employees have decision power with regard to changes in the organisation that affect them directly. In this safe, healthy and productive environment, employees are motivated to do their best, contribute to the innovativeness of the company, and adopt renewal. These employees are motivated to upskill their competencies continuously. As a consequence they are ***resilient*** and able to deal adequately with changes and setbacks within their company or on the labour market. Due to their employability employees can develop ***sustainable*** careers for their life course."

"An industry, sector or branch is 'Industry 5.0'-proof when it is, apart from being profitable and competitive, respecting workers' needs and interests as well as ensuring environmental ***sustainability***. Such sustainability refers to resource efficiency, which is about doing "better with less", about optimising the relationship between product output and resource input. This means taking into account a life-cycle perspective and end-of-life considerations. Companies have incorporated sustainability into their circular business models. Such industries apply technologies like AI and additive manufacturing to optimise their resource-efficiency and minimising waste. Innovation reversed the trend of more energy and increases carbon emissions by smarter production planning and the use of more energy-efficient technologies. These industries are ***resilient*** because they have the ability to cope flexibly with (disruptive) change in their markets, (global) value chains, and (geo-)political environments. They are equipped to adapt quickly to changing circumstances for key value chains, and to secure its role as a sustainable engine for prosperity. These industries can deal with vulnerabilities that can occur on many levels, including the factory floor, supply network and industrial system levels. Such industrial contexts are applying a ***human-centric*** approach when they ensure that both companies and workers benefit from the digital transition, adapt business models accordingly, and involve employees in every step of this transition process. Companies in Industry 5.0-proof environments benefit from the relative strengths of technologies and workers, because they invest in both. There is a strong cooperation between enterprises on the one hand, and education and training institutions on the other, as companies are well placed to determine the skills gaps and forecast the skills needs for the near future. Education, training, re-skilling and up-skilling are successfully addressed in accommodating the digital transition in their industries, because qualified human capital is seen as basic to realise the digital and green transition. Successful reforms and investing in the green, digital and social resilience priorities enable these industries to create jobs and sustainable growth, and allow resilient recovery in a balanced, forward-looking and sustained manner. Such Industry 5.0-proof performance secured the transition to a more resilient, sustainable and human-centric society."

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