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# Industrial Technologies Roadmap on Human-Centric Research and Innovation

## for the manufacturing sector

Research and Innovation

**ERA Industrial Technologies Roadmap on Human-Centric Research and Innovation for the manufacturing sector**

European Commission
Directorate-General for Research and Innovation
Directorate E— PROSPERITY
Unit E4 — Industry 5.0 and AI in Science

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# ERA

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## for the manufacturing sector

2024 Directorate-General for Research and Innovation

# FOREWORD BY COMMISSIONER IVANOVA

Mastering the digital transformation is critical for Europe’s industrial competitiveness and wellbeing. The current wave of emerging digital technologies, in particular artificial intelligence, machine learning, virtual reality and industrial wearables, presents an opportunity to optimise interactions between individuals and machines for the benefit of all. By focusing on people-powered solutions, Europe can ensure that technological advancements contribute both to economic success and address key concerns for society. Putting people first ensures that new technologies are developed and adopted in line with sound ethical standards.

The notion of human centricity puts core values and principles such as trust, security, openness and inclusiveness at the heart of technology development. Digital technologies themselves can facilitate human centricity in ways that have not previously been possible, in particular by allowing the joint design of processes, systems and work environments. They are instrumental in developing work environments that enhance employee engagement, safety, well-being and productivity, while also strengthening the role of human learning.

Currently, international players are more advanced than European ones in patenting complex technologies related to human-centricity. While the recently adopted European Artificial Intelligence Act will provide a supportive regulatory environment for the development of trustworthy AI, we also need to better equip the European innovation ecosystems to be able to adapt to a fast-changing scientific, technological and geopolitical environment. This means fostering the development and uptake of relevant technologies for human-centric technological transformation as well as of new skills and capacities suited to new working methods, processes and organisational changes.

This ERA Industrial Technologies Roadmap for Human-Centric Research and Innovation has been developed in cooperation with stakeholders and representatives from EU Member States and countries associated to our research and innovation programme Horizon Europe to accelerate the green and digital transition of key EU industrial systems. It builds on a study that supported the identification of the key features and enabling factors for the design and use of human-centric approaches to technologies and organisational models in industry. Human-centric technology development and deployment is still an emerging industry in the EU and requires further policy attention amidst intense global competition. Our work on the roadmap helps uncover hitherto untapped potential across the EU and identifies avenues for further research and innovation efforts and ecosystem development, which can guide actions at all levels of government and industry.

I encourage all stakeholders to draw inspiration from this Roadmap to support a human-centric digital transition in Europe for the benefit of our economy and society.

The European Community of Practice on Industry 5.0, to be established in 2024 with industry, investors, public authorities, academia and civil society, will provide an ideal forum for discussing concrete implementation initiatives to advance in the direction set out in this Roadmap until 2030.

**Iliana Ivanova**
European Commissioner for Innovation, Research, Culture, Education and Youth

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The roadmap relies on the research work performed as part of a specific contract under the European Commission framework contract ‘Foresight on Demand’ by a consortium led by Technopolis Group, Austrian Institute of Technologies and Insight Foresight Institute, including the following team: Orestas Strauka, Carmen Moreno, Izabella Martins Grapengiesser, Krystel Montpetit, Viola Peter (Technopolis Group), Karl-Heinz Leitner, Huu-Quynh-Huong Nyuyen, Nico Pintar, Wolfram Rhomberg, Manfred Tscheligi, Setareh Zafari (AIT), Totti Könnölä (Insight Foresight).

We are also grateful for the stakeholder contributions received as part of the three workshops organised with researchers, industry and civil society. The Roadmap was also discussed and validated with representatives of Member States and Associated Countries in the context of European Research Area (ERA) Action 12 and with members of the Community of Practice on Industry 5.0 during a validation workshop in December 2023.

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# EXECUTIVE SUMMARY

In recent decades, we have witnessed a remarkable surge in technological advancements, catalysing transformative shifts across various industries. The journey from steam-powered machinery (Industry 1.0) to the seamless integration of digital technologies (Industry 4.0) has been nothing short of awe-inspiring. However, recent developments mapped in this study point to significant challenges of the rapid implementation of advanced technologies in industry, as well as uncertainties with regard to technological trajectories and effects on workers and society at large, global competitiveness, technology sovereignty, and the climate change pressures. This calls for a more sophisticated approach to such a transformation, in order to make sure that we harness the technologies‘ real potential for driving industrial leadership and competitiveness, as well as enhance industry’s positive societal and environmental impact.

In the context of the twin green and digital transition, climate change pressures and societal challenges, Industry 5.0 (I5.0)[1] provides a transformative vision for industry as a driver of sustainability, resilience, and human-centricity. It supports the shift of industry towards a new paradigm as a powerful lever to help the planet (industry that respects the environmental boundaries of the planet), leaves no one behind and actively contributes to wellbeing and planetary regeneration. Human centricity is one of the three pillars of the Industry 5.0 concept, in line with the European Commission’s priorities for an Economy that works for People, in addition to those for a Europe Fit for the Digital Age, and the EU Green Deal.

This industrial technology roadmap also comes at a time when the industry awareness of the transformative potential of ground-breaking technologies like artificial intelligence and virtual worlds has been rising. Global competitiveness pressures and media hype create the sensation that the global industrial landscape entered a more accelerated stage of adoption of such technologies. However, data collected in this study points to remaining bottlenecks in industry absorption of such technologies in the EU, and ethical considerations that need to be tackled for a human-centric approach in developing and adopting such technologies

This Roadmap is published in the context of the EU’s efforts to ensure an industrial policy grounded in EU values, promoting skills and innovation in industry, as well as the achievement of environmental goals, as prioritised in the EU Industrial Strategy[2]. The adoption of the EU’s Artificial Intelligene Act[3] is a significant milestone in ensuring a values-based and human-centric approach in the development and adoption of artificial intelligence technologies that can be expected to have an impact on the workforce and society at large.

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[1] European Commission, Directorate-General for Research and Innovation, Renda, A., Schwaag Serger, S., Tataj, D. et al., Industry 5.0, A transformative vision for Europe – Governing systemic transformations towards a sustainable industry, Publications Office of the European Union, 2021, https://data.europa.eu/doi/10.2777/17322

[2] European Commission, 2020: Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic And Social Committee and the Committee of the Regions. A New Industrial Strategy For Europe, COM/2020/102 final, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52020DC0102

[3] European Parliament legislative resolution of 13 March 2024 on the proposal for a regulation of the European Parliament and of the Council on laying down harmonised rules on Artificial Intelligence (Artificial Intelligence Act) and amending certain Union Legislative Acts (COM(2021)0206 – C9-0146/2021 – 2021/0106(COD))

This technology roadmap has been developed under the European Research Area (ERA) Action 12, which aims to accelerate the green and digital transition of key EU industrial ecosystems[4], and following the Industry 5.0 policy approach to foster human-centricity, resilience and sustainability in industry. The concept of human centricity in the context of Industry 5.0 is still evolving and is thus explored in this study. Human centricity is a multidimensional framework that places human needs, characteristics, motivation and experiences at the centre of design, development, and implementation of technological solutions and organisational practices that not only meet functional requirements, but also enhance human well-being, capabilities, skills, and working conditions. Thus, we use the term human-centric enabling technologies specifically to denote technologies with the potential to contribute to human centricity.

The human dimension of technology development and adoption needs further investigation, as a harmonious collaboration between humans and machines is prioritised, harnessing the human cognitive and emotional capacities, augmenting human skills and learning processes with technologies, while recognising the interdependence of technology, industry, society and environment. The pressing question arises: in a rapidly evolving economic, technological, environmental and geopolitical context, as well as in light of the high potential for positive impact on the industry, society and environment of the use of digital technologies, when appropriately designed and used, how can we best harness the potential of a digitally-driven work landscape and extend its benefits across the European Union (EU) and beyond, ultimately benefiting workers, companies, and society at large?

First, this roadmap delves into the configuration of the human-centric manufacturing ecosystem within which businesses and various actors operate, aiming to foster a direct, human-centric approach. However, it is important to note that **this effort represents just an initial step**, as there remains an undeniable need for further research, particularly in terms of defining and refining conceptual boundaries. Nevertheless, **this systemic approach to defining human-centricity aims to ensure that technological advancements not only enhance individual performance and well-being, but also contributes to a more equitable, sustainable, and humane society.**

The roadmap builds on a study that supported the identification of key features of the design and use of human-centric approaches to technologies and organisational models in industry, with a focus on the manufacturing sector, particularly the shop-floor level, in the context of Industry 5.0 challenges. Importantly, the results of the study show that technology development and deployment with human-centric approaches is a nascent industry in EU, which needs further policy attention, in the context of intense global competition. In the face of significant societal challenges of demographic ageing, skills and education challenges given fast technological pace geopolitical and environmental pressures, **policy-makers will need to focus on technology as a means to achieve societal goals beyond efficiency, such as sustainability and worker wellbeing.**

As of 2023, the majority of companies actively developing human-centred technologies (patents) for the European market are non-European companies, with more concentration among Chinese and US. While some German, Swiss, and French companies also rank amongst the top patenting firms, the rest of the European countries are running behind. Substantial technological innovation predominantly occurs within well-established companies in Europe, equipped with the necessary resources for experimentation. The

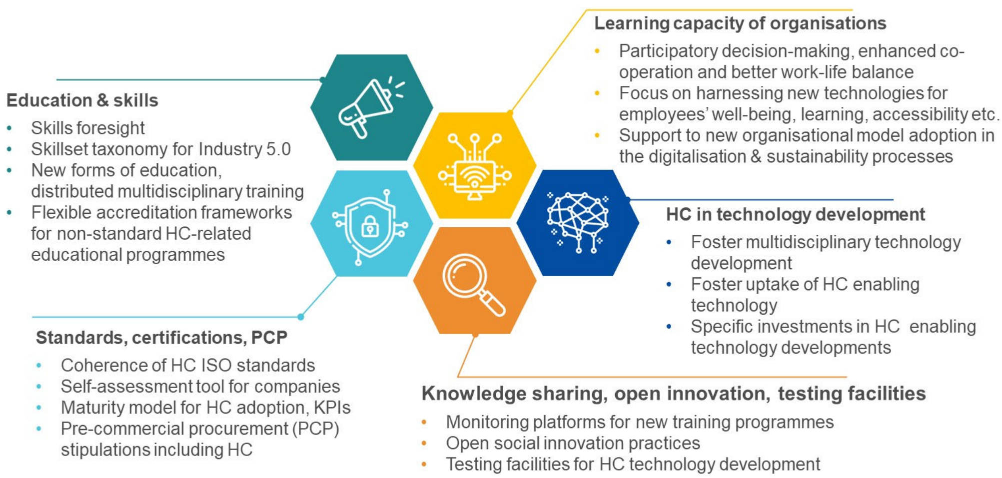
[4] European Commission, European Research Area Policy Agenda – Overview of actions for the period 2022-2024, Brussels, 2021. Internet source: https://commission.europa.eu/system/files/2021-11/ec_rtd_era-policy-agenda-2021.pdf

majority of startups in this sector are concentrated in Italy and Germany, with other countries less prolific in the start-up scene, considering the high costs associated with developing equipment such as robots. At the same time, the rising venture capital investment in start-ups related to human-centric enabling technologies shows encouraging trends for this budding field for startups, which need to be matched with more public funding efforts.

Second, this roadmap uncovers **untapped potential and significant gaps within the ecosystems of EU Member States**. An important element is the needed shift in perspective related to a more holistic, outcomes-oriented practice in technology development and adoption, focused on ensuring such innovations are considering a wider approach to human-centricity, and especially looking at the effects of technology on workers, customers, people and planet.

Third, this roadmap outlines possible **steps for further research and innovation efforts and human-centric R&I ecosystem development**, which can guide the actions of EU, Member States and industrial stakeholders. It recommends that policymakers take on a role that goes far beyond the mere facilitation of Human-Centred (HC) design approaches to technology development, but towards a more holistic, outcomes-oriented approach. There is a resounding call from the ecosystem stakeholders for policymakers to lead a comprehensive initiative aimed at enhancing promotional, implementation, and support mechanisms at the organisational level. Likewise, the **pro-active approach of industrial players is crucial**, as this holistic approach delves into the very essence of organisational effectiveness, championing the development of essential skills, nurturing a forward-thinking mindset, and advocating for the active involvement of employees in high-level decision-making. The figure below provides a snapshot of the policy actions recommended in this roadmap, to be further discussed with stakeholders until 2030 and implemented by 2035.

**Figure 1 Policy recommendations**



# 1. Introduction

This technology roadmap under the European Research Area provides a first exploratory analysis on the state-of-the art in human-centric approaches to technology development in Europe and beyond, and the enabling factors for their adoption in the manufacturing sector, to achieve human-centric goals in Industry 5.0 (I5.0).[5] Industry 5.0 provides a transformative vision for industry as a driver of sustainability, resilience, and human-centricity. It supports the shift of industry towards a new paradigm as a powerful lever to help the planet (industry that remains within the planetary boundaries), leaves no one behind and actively contributes to wellbeing and planetary regeneration. Human centricity is one of the three pillars of the Industry 5.0 concept, in line with the European Commission's priorities for an Economy that works for People, in addition to those for a Europe Fit for the Digital Age, and the EU Green Deal.

**What do we mean by human centricity?**

Human centricity is a multidimensional framework that places human needs, characteristics, motivation and experiences at the centre of design, development, and implementation of technological solutions and organisational practices that not only meet functional requirements but also enhance human well-being, capabilities, skills, and working conditions. Thus, we use the term human-centric enabling technologies specifically to denote technologies with the potential to contribute to human centricity. In the scope of this report, the concept of human centricity pertains specifically to the context of Industry 5.0.

As organisations increasingly digitise and automate, a human-centric approach considers human-centred factors in both the development and adoption of technology at the organisational level.

On a technological level, human centricity aims to optimise interactions between individuals and machines. This encompasses the joint design of processes, systems, and work environments aimed at enhancing employee engagement, safety, well-being, and productivity, while strengthening the human role through technology integration. The objective is to ensure the ethical development and adoption of technologies, preserving individuals' autonomy and control, while respecting human values.

At an organisational level, the human-centric approach places a particular emphasis on the well-being and satisfaction of workers, taking into account their specific needs, skills, and perspectives. This approach highly values the contribution and expertise of employees, thus fostering a culture of collaboration and inclusivity. It also actively encourages skill development and continuous learning among employees, ensuring they have the necessary abilities to adapt to the constantly evolving technology. Additionally, it ensures a healthy balance between work and personal life. By prioritising individuals, a human-centric approach leads to improved employee motivation, efficiency, and overall organisational success. Furthermore, it ensures that the company has the capabilities needed to adapt to the rapidly advancing pace of technology.

[5] European Commission, Directorate-General for Research and Innovation, Renda, A., Schwaag Serger, S., Tataj, D. et al., Industry 5.0, A transformative vision for Europe – Governing systemic transformations towards a sustainable industry, Publications Office of the European Union, 2021, https://data.europa.eu/doi/10.2777/17322

We can begin this report by posing the question: What is required to ensure that the development and use of technologies are human-centric?

A number of suggestions are provided in the literature. Historically, human-centricity in technology development has been often approached through human-centred design (HCD)[6], an approach to systems design and development that originally aims to render interactive systems more usable as formally encoded in the relevant ISO standard on Ergonomics of human-system interaction (ISO 9241-210:2019). A recent interpretation of the concept extends it to "life-centred" design, which considers not only the interaction with users, workers, customers, but also ethical and environmental aspects.[7] Technologies centred around humans, often referred to as "labour-friendly", aim to support and enhance the workforce. Examples within this category encompass advanced IT and digital technologies, robots, artificial intelligence (AI), human-machine interaction, extended reality technologies, bio-inspired technologies and materials, nature-based solutions, digital twins, simulation, and technologies for data transmission, storage, and analysis. Additionally, automation and robotics, wearable technologies (such as smart glasses and exoskeletons), collaborative platforms, blockchain, 3D printing, Internet of Things (IoT), augmented reality (AR) for training, and biometric technologies all contribute to a more labour-friendly and efficient working environment across various industries.

Starting from the technological aspect of the human-centric concept, which essentially revolves around the technological supply side, it is also essential to scrutinise the demand side represented by companies. What are the industry's needs, motivations, and benefits in transitioning to this concept, adopting technological changes, transforming organisational processes, and developing new business models? Numerous company surveys and case studies analyse the requirements or effects of introducing innovation on productivity, employees, or organisational change.

The integration of human attributes with advanced technologies holds the potential to unlock unprecedented levels of innovation, productivity, and empowerment. This symbiotic relationship aligns seamlessly with the broader trend of digitalisation within industries, marking the initial push toward human-centricity. Simultaneously, there are notable barriers and challenges in the design, deployment, and adoption of human-centric technology. Challenges in technology design encompass the absence of practical guidelines and standards, the complexity arising from required high customisation, and the difficulty in adopting a multidisciplinary approach involving ergonomics, behavioural science, cognitive processes, and socio-cultural dimensions within the manufacturing workforce.

Adoption and implementation of human-centric approaches to technology need further evidence of a favourable return on investment and are faced with complications due to the multidisciplinary requirements in deployment, attracting a skilled workforce, ensuring harmonious integration with existing infrastructure, budget constraints and increased workloads during scale-up. Such approaches also require a robust IT infrastructure, addressing GDPR and data privacy concerns. Despite potentially positive returns at company level in diverse potential areas (e.g. human resources' well-being, health and safety, organisational agility, reputation and talent attraction which may indirectly translate in economic returns), study findings point to organisational level bottlenecks in adoption: such approaches may face cultural resistance, assessing organisational readiness for

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[6] ISO 9241-210:2019

[7] Borthwick, M., Tomitsch, M., & Gaughwin, M. (2022). From human-centred to life-centred design: Considering environmental and ethical concerns in the design of interactive products. *Journal of Responsible Technology*, 100032. https://miro.com/app/board/uXjVMKPkR6w=/?share_link_id=425545623356

change, addressing managerial skills gaps, adapting workflows to technological innovations and translating them into new skills, and the absence of standardised accreditations tailored for blue-collar workers.

In line with research and innovation (R&I) policy directions in Europe and the U.S., which revolve around the ethical, legal, societal aspects/impacts8 approaches, and the EU-based triple-helix[9] approach to Responsible Research and Innovation, the imperative of human-centricity has become increasingly explicit in the policies, research, and industry practices associated with recent developments in (digital) technology.

This roadmap outlines possible steps for further research and innovation efforts and human-centric R&I ecosystem development where the EU, Member States and industrial stakeholders can act. Key dimensions analysed in the following chapters are described in the box below.

**The dimensions of the roadmap**

**Technologies and their potential to support human-centricity**: Technologies are applications of knowledge (e.g. computer science), techniques (e.g. machine learning), and tools (e.g. wheel) to adapt and control physical environments and material resources to satisfy human needs. The identified technologies and their associated benefits can leverage the creativity of human experts in collaboration with intelligent machines, to obtain resource-efficient and user-centred manufacturing solutions.

**Organisational environment (processes and methods):** Organisational contexts and managerial practices. Organisational environment refers to the factors that influence and shape the organisation's overall functioning (incl. culture, processes, etc.), such as organisational structure, resources, management style, and procedure. Processes (shop floor business processes, workflow management, etc.). Methods (i.e., tools, activities, and procedures to human-centredness in design and deployment) refer to those specifically related to enhancing human-centricity, e.g., a human-centred design process.

**R&I investments** from the public and private sector, directly targeting the development of technologies with human-centric approaches or the fostering of start-ups providing such technologies or services.

**Framework conditions** that can contribute to more human-centric approaches to technology development, deployment and adoption:

- **R&I ecosystem enablers**: Skills and competencies, support services and infrastructure. Learning capacities, training needs as well as support services and infrastructure for experimentation and testing required to enhance human-centricity in organisations and technology and innovation processes required in human-centricity.

- **Society, workforce, and governance**: Societal changes, demographics and

[8] Chadwick, R., & Zwart, H. (2013). From ELSA to responsible research and Promisomics. *Life Sciences, Society and Policy*, *9*(1), 1-3.
[9] See Lee, et al, 2020: Effect of efficient triple-helix collaboration on organizations based on their stage of growth, Journal of Engineering and Technology Management,Volume 58, 2020, https://doi.org/10.1016/j.jengtecman.2020.101604.

workforce, governance, regulations and ecosystem actors and other stakeholders that are participating. Here we deal with the necessary framework conditions and enablers which are crucial to successfully realise Industry 5.0 and covers both, the meso and macro level. In that sense, the society and governance dimension also deal with the entire ecosystem.

The remainder of the report is structured as follows:

Section 2 outlines a range of **objectives and impacts that may be captured under the concept of human centricity** at the individual, organisational, and societal levels.

Section 3 reviews **key technologies, methods and organisational practices enabling human-centricity**. It sketches the steps to achieve human-centricity related goals in technology development, analyses the technological development and adoption landscape and highlights the role of organisational innovation in fostering the achievement of human-centric goals and technology adoption in companies.

Section 4 provides an overview of **R&I investments** from the private and public sector in Europe.

Section 5 focuses on **framework conditions** for fostering human-centric approaches to technology development and adoption. It takes into account  societal, demographic and governance drivers and barriers of Industry 5.0 and human-centric enabling technologies in manufacturing, and provides an overview of the existing European policy framework and standardisation efforts relevant to human-centricity in companies. It then goes on to identify policy gaps related to fostering human-centricoutcomes.

Section 6 draws from stakeholder input, data analysis, and literature review and provides the **policy recommendations**.

## 2. Human-centric goals of Industry 5.0

The concept of human centricity in the context of Industry 5.0 is still evolving and is thus explored in this study. In this chapter we describe in more detail the goals of Industry 5.0 related to human-centricity, based on the results of the stakeholder discussions performed in the context of this study.

The concept of human-centricity encompasses a broad spectrum. It can pertain to the design of human-(digital) technology interfaces, addressing concerns such as ergonomics, safety, and task completion at one end of the spectrum. Alternatively, it can refer to the relationships within the system of human-technology-society, as well as the long-term secondary effects of human-technology interaction. These broader aspects include the ethics of technology, human-machine collaboration, organisational transformation, the interplay between the economy and ecology, and more. Human centricity aims to empower humans in collaboration with emerging technologies in the industrial context[10]. It involves organisational innovation, social innovation, co-creation, and the adoption of new industrial practices and business models that prioritise social and environmental considerations.[11]

Industry 5.0 is not a technology-driven but value-driven initiative that leads technological transformation with a purpose of maintaining a synergy between humans and machines)[12]. By realisation of human centricity, values at micro (e.g., worker empowerment, satisfaction), meso- (e.g., employee retention, profitability) and macro level (e.g., Improved quality of life, sustainable growth) can emerge. These interconnected values are in line with Value Sensitive Design[13] that put human principles and standards into design of artefacts and technologies. Longo and colleagues (2020) evaluate the applicability of value sensitive design approach to guide designers and engineers in the development of industry 5.0 solutions.[14] By focusing on empowering the human workers and optimising the holistic performance of the human machine system, synergistic relationships between technological and social systems can be created that lead to positive impact such as employee satisfaction, skills as well as employee growth in the long term. **This systemic approach to human-centricity therefore aims to ensure that technological advancements not only enhance individual performance and well-being, but also contributes to a more equitable, sustainable, and humane society.**

Table 1 summarises the objectives and impacts of human centricity at the individual, organisational, and societal levels. The goals and effects presented in the table below are derived from a comprehensive literature review. It is important to highlight that none of the examined documents offer a precise definition or metrics for evaluating the various potential effects of human centricity.

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[10] Alves J, Lima TM, Gaspar PD. Is Industry 5.0 a Human-Centred Approach? A Systematic Review. *Processes*. 2023; 11(1):193. https://doi.org/10.3390/pr11010193 https://miro.com/app/board/uXjVMKPkR6w=/?share_link_id=425545623356

[11] See Reiman, A., Kaivo-oja, J., Parviainen, E., Takala, E. P., & Lauraeus, T. (2021). Human factors and ergonomics in manufacturing in the industry 4.0 context–A scoping review. *Technology in Society*, *65*, 101572.

[12] Xu, X., Lu, Y., Vogel-Heuser, B., & Wang, L. (2021). Industry 4.0 and Industry 5.0—Inception, conception and perception. *Journal of Manufacturing Systems*, *61*, 530-535.

[13] Friedman, B. (1996). Value-sensitive design. *Interactions*, 3(6), 16-23.

[14] Longo, F., Padovano, A., & Umbrello, S. (2020). Value-oriented and ethical technology engineering in industry 5.0: A human-centric perspective for the design of the factory of the future. *Applied Sciences*, *10*(12), 4182.

**Table 1 Human-centric goals and effects**

| Level | Goals/Effects |
|---|---|
| Individual/Micro | • Worker empowerment<br>• Higher workers' satisfaction<br>• Fostering creativity<br>• Better work-life balance and well-being<br>• Better security<br>• Life-long learning<br>• Ethical approaches to business |
| Organisational/Meso | • Growth & productivity<br>• Employee retention & attraction<br>• Enhanced innovation & learning capacities of organisations<br>• Aligning the core beliefs and values of the organisation with behaviours that prioritise people as well as planet<br>• Flexibility & agility, future-preparedness at organisational level |
| Economic and societal/Macro | • Long-term competitiveness through enhanced innovation and learning capacity of companies<br>• More labour market resilience, in particular less unemployment and less occupational downgrading due to technological shifts<br>• Emergence of industry 5.0 related learning ecosystems<br>• Improved quality of work and health for workers<br>• Sustainable development |

### Individual/Micro level

Some authors highlight the aspect of human-machine interaction and the corresponding goals. Maddikunta et al. (2022) define: "Industry 5.0 is a human-centric design solution where the ideal human companion and cobots collaborate with human resources to enable customisable autonomous manufacturing through enterprise social networks." In this respect, Alves et al. (2023) argue that robots leverage individual and technological capabilities together, making it possible to overcome limitations in the execution of awkward, repetitive, and potentially harmful tasks and operations, improving the workplace, as well as the repeatability and reliability of processes.[15]

The Expert group on the economic and societal impact of research and innovation (ESIR), a high-level expert group that provides evidence-based policy advice to the Commission on how to develop a forward-looking and transformative research and innovation policy, claims that human centricity allows: i) the development of trustworthy technologies that are compatible with fundamental rights and the rights of workers in the workplace, ii) to enhance the well-being of the workplace, and (iii) enables workers to enhance their productivity, liberate themselves from repetitive tasks and focus on the more intellectually stimulating tasks.[16] The expert group tries also to define what is a "good job". Good jobs aim to go beyond the static observation of the individual condition of the worker by focusing on human flourishing and gradual upgrade of human capital, as well as the upgrade of the tasks themselves, requiring more complex skills.

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[15] Alves et al.

[16] European Commission, Renda, A., Schwaag Serger, S., Tataj, D. et al. (2022): Industry 5.0, a transformative vision for Europe – Governing systemic transformations towards a sustainable industry, Publications Office of the European Union, https://research-and-innovation.ec.europa.eu/knowledge-publications-tools-and-data/publications/all-publications/industry-50-transformative-vision-europe_en

The Strategic Research and Innovation Agenda (SRIA) of the European Factories of the Future Research Association (EFFRA) also stresses the importance of a human-centred approach considering the well-being, attractiveness, health and safety of the people at work at any level of all manufacturing phases as key goal. Research activities aim to improve the awareness, preparedness, communication, resilience and safety of the worker, having both a positive impact on workers' wellbeing as well as on the performance of the manufacturing operations.[17]

Standardisation organisations have also described and defined the goals and purpose for the adoption of a human-centric approach. The main aims of HCD ISO 9241-210:2019 (Ergonomics of human-system interaction. Part 220: Processes for enabling, executing and assessing human-centred design within organisations) presents process models for human-centricity at different levels within an organisation for human-centred quality. Furthermore, interpretations of what 'human-centricity' (should) mean are adapting to consider new aspects. For example, Professor Don Norman, Founding Director of the Design Lab at the University of California, has proposed to extend HCD towards 'humanity-centred' design which emphasises the rights of all of humanity and expands intentionality towards the entire ecosystem which encompasses all living creatures and earth's environment.[18] Similarly, "life-centred" design considers not only the inter-action with users, workers, customers, but ethical and environmental concerns. This approach takes into account the natural environment and the human connection to nature.

**Organisational/Meso level**

The development of skills in the manufacturing sector is an integral part of human-centred innovation. The focus on skills inherently places people at the core, emphasising the importance of investing in human capital and enabling individuals to upskill and retrain. This approach also aims to enhance access to skills for companies and organisations, ultimately benefiting individuals in the labour market. However, human-centred development extends beyond the realm of skills alone. It signifies a paradigm shift in mindset, prioritising the human perspective and leveraging technology and organisational structures as enablers. While the skills perspective is an integral part of human-centred development, human centricity serves as a broader framework and specific umbrella. The significance of human centricity and skills development mutually reinforce each other, potentially moving them to the forefront of programme priority lists.

The Beyond 4.0 project stands as another valuable resource, offering a framework concerning Industry 5.0. It addresses potential negative or unforeseen societal outcomes and impacts, such as increased workplace surveillance, skill-to-labour mismatches, and potential workforce de-skilling. In a recent paper, the Beyond 4.0 project outlines key differences between Industry 4.0 and 5.0, highlighting elements that focus on human-centric approaches. The concept may contribute to promoting further the "learning capacities of organisations" and foster a discussion about ethical management of technology.[19] Emphasising the importance of human-centricity, the paper stresses the need to place worker needs and interests at the core of the production process.

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[17] EFFRA (2021): Made in Europe. The manufacturing partnership in Horizon Europe - Strategic Research and Innovation Agenda (SRIA), Version October 2021, Brussels, https://www.effra.eu/sites/default/files/made_in_europe-sria.pdf

[18] Norman, D. A. (2023). Design for a better world: Meaningful, sustainable, humanity centered. MIT Press.

[19] Dhondt, S., Greenan, N., Hulsegge, G., Kirov, V. (2023). Working futures: a forecasting exercise, BEYOND 4.0 deliverable D5.2,
Leiden, https://beyond4-0.eu/publications

**Economic and societal/macro**

Socio-economic development and pressures (demographic change, technological change, productivity, environmental) deliver a rationale for promoting a human-centric development approach (see section 3). Companies and organisations in Europe are grappling with an increasingly ageing workforce. This presents a demand for the adoption of more intelligent and efficient working methods to address this challenge. It entails the need for re-skilling and upskilling the current workforce, as well as the utilisation of innovative digital technologies to attract a younger audience,[20] including those just entering the workforce, whether from within the EU or internationally.[21]

There is a need for policies that bolster the future readiness of companies and encourage the adoption of human-centric approaches to technology development. This necessitates a heightened focus on enhancing the framework conditions within industrial ecosystems, fostering co-evolution and organisational learning across companies, education systems, the public sector, research and innovation, and financial entities. The goal is to facilitate collaboration with new technologies to accomplish societal and environmental objectives.

The research community, standardisation organisations, industry groups, and policy advocate a human-centric approach in technology development. This entails designing technologies with a focus on human values and integrating principles like safety, reliability, trustworthiness, and human control from the outset. Historically, human-centricity has been pursued through human-centred design (HCD), emphasising usability through human factors and ergonomics.

In the industrial context, the need for a human-centred approach arises from concerns that conventional methods neglect user skills, impacting work quality.[22] For instance, Hanke et al. (1990) proposed 'human-centred technology' as an alternative for manufacturing systems, treating the operator as an "asset" and leveraging their abilities.[23] ACE Factories projects[24] under H2020 makers and flexible problem solvers.

It showed the importance and potential of envisioning intelligent and skilled human operators supported and empowered by technical devices and tools that reduce physical and mental strain and foster creativity and innovation without compromising production goals. Romero et al. (2016) introduced various Operator 4.0 types, including Super-strength, Augmented, Virtual, Healthy, Smarter, Collaborative, Social, and Analytical Operators. Emerging technologies such as virtual reality, augmented reality, robotics, and wearables offer promising avenues to realize these concepts.

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[20] This point is echoed by a recent Finnish industry position paper in which they state "the brand of industry for millennials is old-fashioned, a rebranding is need to 1) have enough future professionals and 2) to have a flourishing startup scene." https://www.alliedict.fi/wp-content/uploads/2021/08/Industry-X-White-Paper-3.5.2021_Final.pdf

[21] Symons, Angela. Germany's new immigration law is making it easier for foreign workers to move there. Euronews. 2023. Access at: https://www.euronews.com/travel/2023/06/21/skilled-workers-are-in-demand-as-germany-tackles-labour-shortage-with-new-points-based-vis

[22] Gasson, S. (2003). Human-centred vs. user-centred approaches to information system design. *Journal of Information Technology Theory and Application (JITTA)*, *5*(2), 5.

[23] Hancke, T., Besant, C. B., Ristic, M., & Husband, T. M. (1990). Human-centred technology. *IFAC Proceedings Volumes*, *23*(7), 59-66.

[24] ACE Factories White paper: http://www.fofdation-project.eu/wp-content/uploads/ACE-Factories-White-Paper.pdf

# 3. Key technologies, methods and organisational practices enabling human-centricity

## 3.1. Technology development

In this chapter and in the overall context of this report, it is worth noting that we use the term human-centric technology specifically to denote **technology with the potential to contribute to human centricity** and when positive effects are evident.

A first exercise identified six categories of Industry 5.0 enabling technologies discussed with European technology leaders in 2020:[25]

- Multi-lingual **speech** and **gesture recognition** and human intention prediction.
- **Tracking technologies** for mental and physical strain and stress of employees.
- **Robotics**: Collaborative robots ('cobots'), which work together with humans and assist humans.
- **Augmented, virtual or mixed reality technologies**, especially for training and inclusiveness.
- **Enhancing physical human capabilities**: Exoskeletons, bio-inspired working gear and safety equipment.
- **Enhancing cognitive human capabilities**: Technologies for matching the strengths of Artificial Intelligence and the human brain (e.g., combining creativity with analytical skills), decision support systems.

Based on the discussions undertaken for this study, the key technologies with potential to enable human-centricity in work-related contexts, especially when applied in the manufacturing sector, were categorised into the following groups.

**Table 2 Key technologies with impacts on human-centricity**

| Category | Short description | Technologies |
|---|---|---|
| Automation | When designed and/or implemented with a human-centric lens these technologies support the interplay of machine and human autonomy in automated and augmented socio-technical systems (consisting of human and artificial agents) for an effective collaborative task performance. | Adaptive automation |
| | | Automation control and monitoring (control centres) |
| | | Prediction-based forecasting interaction |
| | | Reliability indication and trust calibration |
| Computation | These technologies support the interplay with multimodal communication for seamless interaction. | Affective computing for experience optimisation |
| | | Natural language processing |

[25] European Commission, Directorate-General for Research and Innovation, Müller, J., Enabling Technologies for Industry 5.0 – Results of a workshop with Europe's technology leaders, Publications Office, 2020, https://data.europa.eu/doi/10.2777/082634

| Category | Short description | Technologies |
|---|---|---|
| AI & Machine learning | These technologies facilitate the implication of big data and AI for data driven experience optimisation and improved analytical capabilities. | XAI for interactive support<br>XAI for model transparency<br>XAI for feature importance analysis<br>Human intention and support need recognition<br>User modelling for behaviour prediction |
| Simulation & immersion | These technologies facilitate remote presence and create new capabilities for operating, maintaining, training, guidance and co-design of workplaces. | Digital Twin for real-time data integration and synchronisation<br>Digital Twin for human machine interaction simulation<br>Human Digital Twin<br>Extended Reality (AR, VR, MR) & Holography |
| Robotics | These technologies support the interplay of machine and human agency for an improved physical and psychological safety in collaborative task performance. | Cobots/collaborative robotics for (safe) collaboration<br>Robot learning by demonstration, learning by interaction<br>Intuitive robot programming<br>Human Robot teaming |
| Industrial wearables & smart artefacts | These technologies can increase individual competences and usability of manufacturing equipment, give feedback on well-being and achievements, leading to higher work satisfaction and well-being of workers. | Exoskeleton for physical support<br>Smart glasses for remote assistance<br>Tangible interfaces for industrial application<br>Dedicated interaction devices (e.g., smart pens)<br>Smart gloves for enhanced interaction<br>Wearable UI for seamless interaction |
| Knowledge management | These technologies support the contextual training, skill development and personal development of workers | Data visualisation for decision support/data analysis and insights<br>Process visualisation for compliance/motivation/understanding<br>Contextual training, skill development and personal development |
| User interface | These adaptive interaction technologies support new forms of human machine interaction by providing real-time feedback on personal performance and holistic intuitive workplace interfaces | Multimodal HMI for seamless interaction<br>Persuasive interfaces towards optimisation on the shopfloor<br>Holistic intuitive workplace interfaces<br>Situation aware assistance systems<br>Adaptive dialogue/conversational systems<br>Flying HMI for support in long distance locations |
| Connectivity | These technologies can upskill and motivate worker, make skills and qualifications more visible, and facilitate knowledge sharing for a learning organisation | Internet of Everything (IOE) |
| Personalised systems | Personalisation systems are proactive navigation structures, which are designed in accordance with user expectations, and which as a result offer the labels and | Adaptive Interaction technologies<br>Realtime feedback on personal performance |

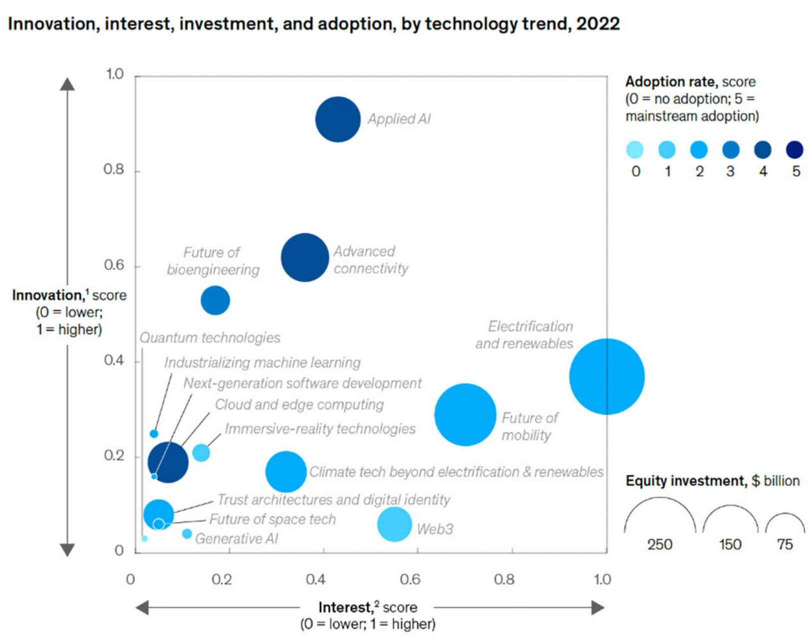
| Category | Short description | Technologies |
|---|---|---|
| | links a user of a given profile will use | |
| Miscellaneous HC enabling technologies | This category groups together other human-centricity enabling technologies. | 6G and beyond |
| | | Additive manufacturing |
| | | Cloud computing |
| | | Edge computing |
| | | Blockchain |

Source: Authors

The main trends in HCT technology development and adoption were assessed by carrying out patent, start-up and European Framework Programme funded project analysis. In addition, the key trends in terms of identified technologies are assessed in the context of EU Industrial R&D Investment Trends, work carried out by European Commission Joint Research Centre and the European Innovation Council (EIC) to anticipate and monitor emerging technologies and disruptive innovation.

The McKinsey Technology Outlook 2023 list trends of 15 key technologies-based interest in them and received equity investments. Out of 15 technologies, the following are related to Industry 5.0: Industrialising machine learning, immersive-reality technologies, advanced connectivity and advanced AI. According to McKinsey, advanced AI is leading among other 14 technologies in terms of related patents and publications.  The figure below provides and overview of all identified technologies.

**Figure 2 Technology trends by innovation, interest, investment and adoption.**




Source: McKinsey Technology Outlook 2023

A more thorough overview of key trends and emerging technologies is provided in the JRC-EIC study that reports on 106 signals and trends on emerging technologies and disruptive innovations across several areas of application.[26] The report distinguishes three EU-level macro areas: 1) digital & industry; 2) green; 3) health. Table 3**Error! Reference source not found.** summarises the relevant signals and technologies for the digital & industry macro area.

**Table 3 Relevant signals and technology for digital and industry macro area**

| Technologies/innovation | Signals |
|---|---|
| Ambient computing | Convergence of IoT, IoB, AR and 5G leading to ambient computing |
| Exponential Intelligence | Emotion AI to support decision-making |
| 5G | Human-machine networks for human perception and cognitive capabilities |
| Computer-human interfaces | |
| Magnetic levitation | Magnetic levitation technology enhances industrial production |
| Metacloud | Metacloud centralises and secures multiple cloud instances |
| Autonomous systems | Miniaturisation, satellite constellations and swarms |
| 3D printing | Rapid prototyping for cost efficiency |
| Additive manufacturing | Rapid prototyping for cost efficiency |
| Soft Robotics | Soft robots to revolutionise the relation humans-robots |
| Advanced manufacturing | Transformative impact of industry 4.0 in space and industry |
| Cyberphysical systems | |
| Industry 4.0 | |
| Haptic Devices | |
| Industrial Digital Tools | |
| AI | Use of AI-driven cybersecurity against AI-cyber attacks, Ethical use of digital technologies for trust, Miniaturisation, satellite constellations and swarms, AI trust programmes based on social and ethical requirements |
| Augmented reality | AR, VR and metaverse converge for enterprises and healthcare, Human-machine networks for human perception and cognitive capabilities, Convergence of IoT, IoB, AR and 5G leading to ambient computing, Fostering social acceptability of the metaverse |
| Digital twin | Digital twins for optimisation of product/service design |
| Industrial IoT | Transformative impact of industry 4.0 in space and industry, Advanced connectivity: IoT for automotive and assembly |
| Internet of the Body | Human-machine networks for human perception and cognitive capabilities, Convergence of IoT, IoB, AR and 5G leading to ambient computing |
| Metaverse | AR, VR and metaverse converge for enterprises and healthcare, Services and data transactions impacted by metaverse and Web3 convergence, Fostering social acceptability of the metaverse |
| Robotics | Miniaturisation, satellite constellations and swarms |
| Virtual Reality | AR, VR and metaverse converge for enterprises and healthcare, Fostering social acceptability of the metaverse |

Source: Authors

Overall, the technologies identified in the table above are aligned with the technologies identified in the JRC-EIC report. It should be noted however, that the JRC-EIC report does not mention Industry 5.0, only transformative impact of industry 4.0 in industry and human-machine networks for human perception and cognitive capabilities are identified as important signals for emerging technologies. More specifically:

[26]Everybody is looking into Future, 2023

The industry 4.0 signal includes transformative innovations in advanced manufacturing, industrial digital tools (IDTs) and industry 4.0 (i4.0) technologies and techniques. Advances associated with i4.0 have the potential to drive sweeping changes in industrial design, production and through-life support. Though many of the underlying technologies may already be in varying stages of adoption across the industry, they are projected to have a collective transformative impact in industry if used in combination with novel manufacturing models.[27]

Regarding the human-machine networks, they expand the range and depth of human perception and cognitive capabilities, also expanding current uses on medical treatments (to overcome neurological conditions) to include leisure and entertainment applications. These developments include sensory expansion (which would evolve to include experiences beyond visual and auditory stimulation, such as smell and taste experiences in virtual reality (VR) headsets and haptic gloves to deliver a sense of touch), thought-based control (brain-computer interfaces are starting to find their way into augmented reality (AR) and VR headsets), all in one devices (that serve as a way to connect users to the metaverse without additional headsets and handheld devices), and spatial interaction (smart glasses and motion sensors can enable spatial interaction, allowing users to interact directly with physical data without creating a digital copy).[28]

The EU Survey on Industrial R&D Investment Trends complements the roadmap report, McKinsey technology outlook and JRC-EIC report findings. In particular, the table below displays the importance of specific technologies for the future competitiveness of companies categorised into four size classes.

**Figure 3 Capital investment (highly relevant + relevant) – by technology and size classes**

| | Technology classes | | | Size classes | | | |
|---|---|---|---|---|---|---|---|
| | High | Medium | Low | up to 2 500 | 2 501 to 10 000 | 10 001 to 50 000 | more than 50 000 |
| ICT hardware | 50.0% | 42.4% | 24.0% | 44.0% | 15.8% | 48.1% | 47.4% |
| Software and ICT services | 59.4% | 69.7% | 57.7% | 64.0% | 57.9% | 63.0% | 65.0% |
| Adaptation to Industry 4.0 | 60.0% | 71.4% | 80.8% | 62.5% | 63.2% | 74.1% | 81.0% |
| Low-emission technologies | 32.3% | 82.9% | 92.6% | 32.0% | 75.0% | 88.9% | 81.0% |
| Circular technologies | 23.3% | 74.3% | 85.2% | 20.8% | 75.0% | 85.2% | 61.9% |
| Other environmentally sustainable technology | 33.3% | 80.0% | 77.8% | 36.0% | 68.4% | 81.5% | 71.4% |

Source: Nindl, E., The 2022 EU Survey on Industrial R&D Investment Trends

We conducted a search for specific keywords in the title or abstract of patent applications to identify patents that may contribute to the advancement of human-centricity in technology and industry. Our search encompassed patents published in all major patent offices, including the US Patent Office (USPTO), historically the most prolific publisher of patent applications worldwide. Additionally, we considered patents from the European Patent Office (EPO) and those undergoing WIPO's (WO) Patent Cooperation Treaty (PCT) procedure, which expedites the process of applying for global patent protection. We also included patent offices in Eastern and emerging markets, such as Japan (JP), Korea (KR), and China (CN). These patent applications were sourced from the European Patent Office database via their online access tool Espacenet which covers data of all mentioned patent office since the mid-1980s and is updated weekly. We did not limit the search strategy to a subset of years as we want to map and analyse the full history of human-centred related patenting activities.

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[27]Everybody is looking into Future, 2023
[28]Everybody is looking into Future, 2023

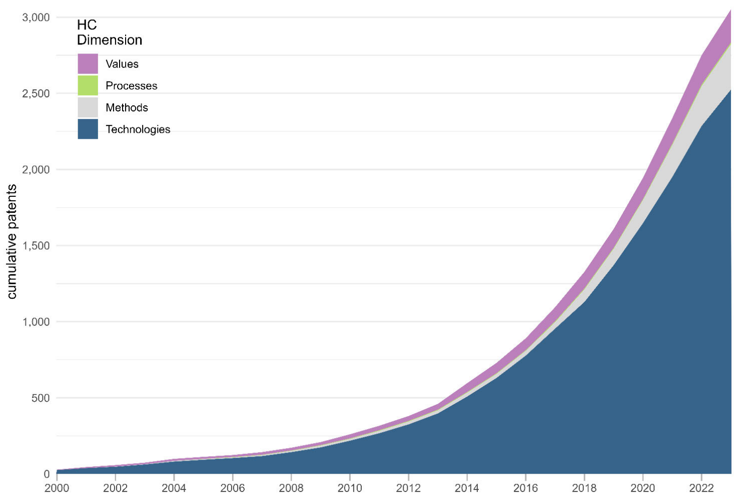
In total, we identified 36,995 patent documents that are potentially related to human-centric technologies, belonging to 24,630 distinct patent families, as of October 6th, 2023. Amongst these, only 3,043 patent documents from 2,472 patent families were published by the EPO and WO.

It is worth highlighting the significant increase reported by the Chinese patent office since 2009. Before that time, the US patent office consistently issued a similar number of patent applications with a notion of human-centredness. However, from 2009 onwards, the Chinese market has surpassed in generating patents that could drive advancements with a focus on human-centric goals.

This impressive rise in patenting is however subject to a widespread debate, namely if a patent application submitted to the Chinese patent office is equivalent to a similar application at the USPTO. This debate is fuelled by the perception that, on average, the quality of patent applications considered suitable for publication is lower at the Chinese patent office compared to the more established patent office.[29]

Furthermore, the implementation of politically motivated patent subsidy programmes in China might have played a role in the exceptionally high number of patent applications, although this could potentially come at the expense of quality.[30]. It is important to note that the location of patent applicants and the chosen patent offices do not necessarily correspond, since companies apply for IP protection in their business markets.

**Figure 4 Patents that potentially affect human-centricity, EPO and WO, distinguishing the four HC dimensions**




Data: EPO, Analysis: AIT.

[29] Santacreu, A.M. and Zhu, H. (2018) *What Does China's Rise in Patents Mean? A Look at Quality vs. Quantity*. Economic Synopses, Federal Reserve Bank of St Louis, No. 14. Available at: https://doi.org/10.20955/es.2018.14

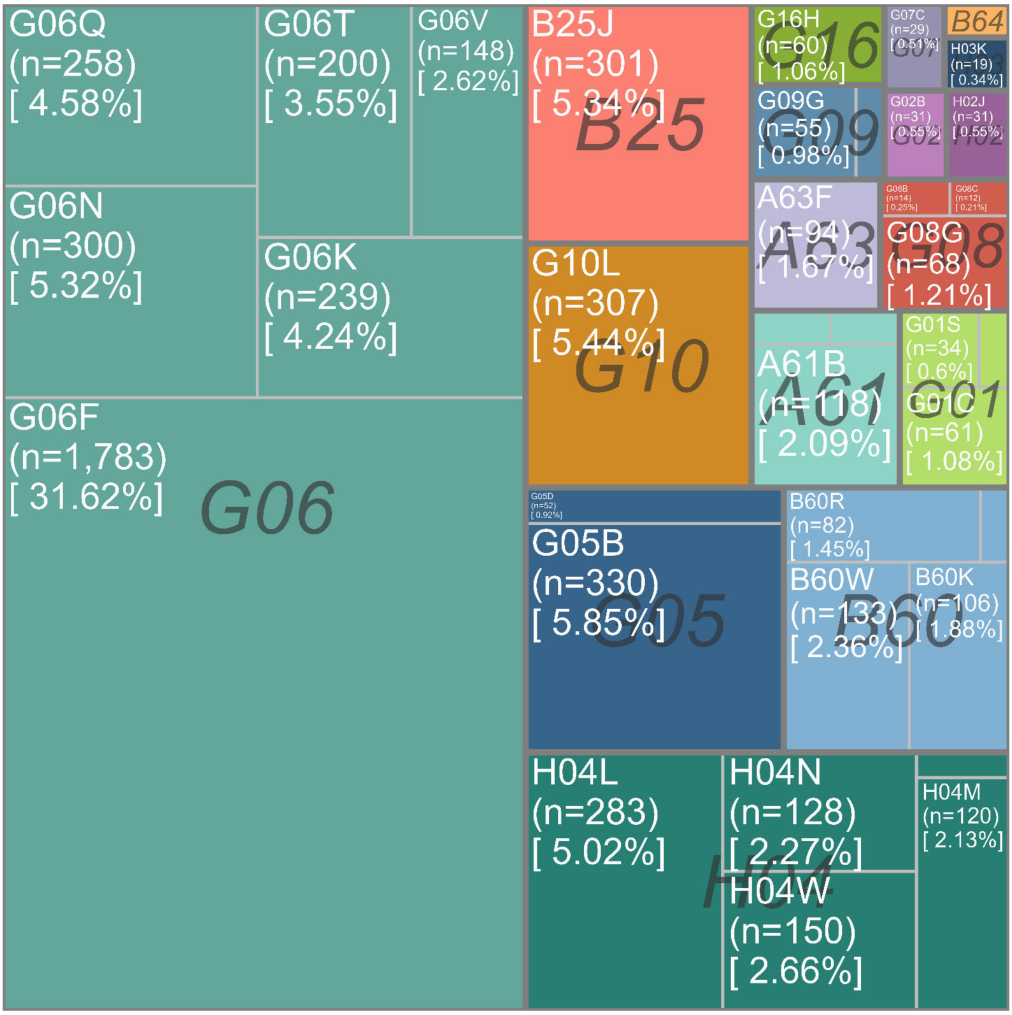
[30] Dang, J. and Motohashi, K. (2015) 'Patent statistics: A good indicator for innovation in China? Patent subsidy program impacts on patent quality', *China Economic Review*, 35, pp. 137–155. Available at: https://doi.org/10.1016/j.chieco.2015.03.012

Note: Patents filed either through the WIPO's (WO) Patent Cooperation Treaty (PCT) procedure or to the European patent office (EPO) are shown here. These patent applications are most relevant for the European market as applicants will receive patent protection in at least some European countries in case the patent is granted. Patents are distinguished according to the human-centricity dimension they are associated with.

The figure above illustrates the **development of patenting since 2000 of patents relevant for the European market**. Patent applications filed either to the European patent office (EPO) or through the WIPO's Patent Cooperation Treaty (PCT) can be considered highly relevant for the European market as patents filed there – if granted – entitle the applicant with corresponding rights in at least some European countries. Patents in the figure above are delineated based on four keyword searches reflecting the four dimensions of human-centricity identified for the roadmap. While the overwhelming majority of patent applications were identified using technology-related keywords, it is noteworthy that process-related keywords are nearly absent in patent documents. Interestingly, there is an observable increase in patents that may be linked to the dimension of human-centred values, and to an even greater extent, to methods.

The technology class distribution of families of patents filed to the EPO and WO reveal that **patents that might proxy human-centric enabling technology development predominantly focus on a specific technology category, namely "Computing: Calculating or Counting" (G06)**, with one subclass being particularly common (G06F). This popular subclass pertains to technologies falling under "Electric Digital Data Processing (Computer Systems Based on Specific Computational Models G06N)" which covers – for example – input arrangements used for transferring data to be processed by a computer, technologies for pattern recognition or the handling of natural language data. The frequent appearance of this subclass underscores the significance of digital technologies required for enabling human-computer interaction.

**Figure 5 Technology class distribution of families of patents; EPO and WO**




Data: EPO, Analysis: AIT. Note: See the current IPC technology classification online. Here, the frequency of appearance of detailed technology Main Groups (5 digit), aggregated to Subclass level (4 digit) (double counting) is shown by the area of squares (and n in parenthesis). The relative share of aggregated Subclass technology classes is shown in brackets. Squares are coloured according to the higher-level technology Class (3 digit). Only patents relevant for the European market (EP and WO) are sourced here.

Other noteworthy technology classes within G06 include G06Q, G06N, G06K, and G06T. G06Q pertains to ICT technologies tailored for administrative, commercial, managerial, or supervisory purposes. The subclass G06N includes developments in quantum computing, machine learning and the like. The latter two technology classes, G06K and G06T, deal with image and video information processing and analysis, which have experienced substantial growth in recent years, significantly influenced by the emergence of AI and machine learning technologies.

The second largest class among patents that may contribute to enhancing human-centricity addresses techniques essential for digitally transmitting information processed by technologies within G06. Within this realm, we find the relatively broad subclass H04L ("Transmission of Digital Information"), as well as notable areas such as wireless communication networks (H04W) and telephonic communication (H04M). Additionally, noteworthy technology classes include G05 and B25, which are more mechanically oriented and likely involve technologies required for modern machinery involved in human-interaction manufacturing processes, such as collaborative robots. In these general categories, there are subclasses such as G05B, which pertains to the control and regulation of systems in a broad sense (e.g., arrangements for electrical safety, adaptive control systems), and B25J, which covers technologies vital for the operation of manipulation devices like hand tools (including those utilised by robots) and portable power-driven tools. Additionally, the domain of speech analysis, recognition, or processing (G10L), which has been notably impacted by the rise of AI, holds substantial importance in the realm of human-centred enabling technology, as expected.

It is noteworthy that a significant share of patent applications proxying human-centred enabling technology developments are filed by non-European applicants. Chinese and US applicants hold the largest shares, accounting for approximately 40% and 20%, respectively. In Table 41 Top 10 applicants of patents that potentially enhance human-centricity, main patent offices you can find the top 10 patent applicants across all patent offices, while lists the top 25 patent applicants for EPO and WIPO.

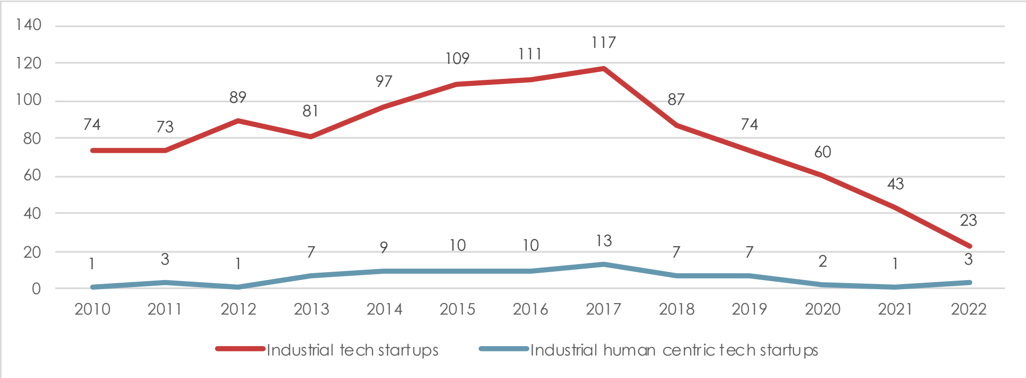
Amongst European entities, German applicants lead the way with a share of about 10% of the total patents that we linked with human-centricity. The most prolific German technology producer in the field of technologies that might improve human-centricity is Siemens AG which ranks fourth in terms of patent applications, putting it ahead of US and other notable competitors (e.g., Microsoft, Rockwell, Bosch, Intel, Qualcomm and others). Core EU countries like Germany and France, and to a lesser extent (Northern) Italy, exhibit relatively high levels of potentially human-centred patent production, while the rest of Europe lags behind. Despite the United Kingdom and Switzerland having substantial production of patents that might enhance human-centricity compared to other non-EU countries, they are still not as active in this area as Germany and France. Overall, the European development of potentially human-centred technologies is concentrated on a few innovation powerhouses among core countries.

**Trends in start-ups related to human-centric enabling technologies**

The start-up analysis on the other hand indicates that Innovative start-ups developing HC enabling technologies offer a range of solutions. This includes human centred robotics aimed at enhancing collaboration between robots and humans, as well as wearables designed to improve the operator's safety. The keywords search analysis for technologies can lead to fostering "learning", "collaborative learning", "learning companies", and "learning ecosystems" in the context of HCT did not result in any start-ups.

When looking at the number of created start-up by year, results point out to an increasing trend until 2017, that later leads to a downtrend in the last year. This downtrend can be partially explained due to the time lag that it takes for a company to be visible and therefore included within the database. To further benchmark, we looked into the proportion of human centric technologies within industrial technology startups. The analysis shows that while the absolute number of total industrial tech startups has fluctuated over the years, the share of those focusing on human-centric solutions has remained relatively steady.

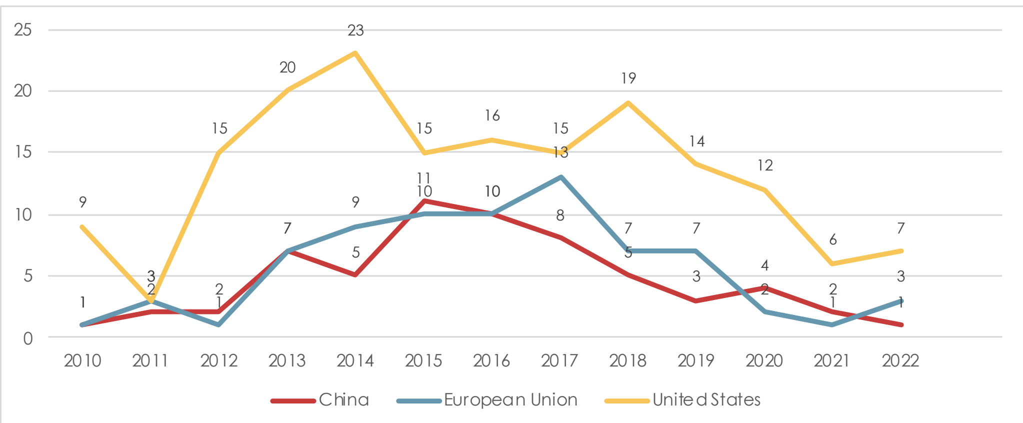
**Figure 6 Evolution of yearly created startups**




Data: Crunchbase, Analysis: Technopolis Group

When examining the number of startups established in China and the United States, it becomes evident that the United States outperforms the market in comparison to both China and European Union countries. Furthermore, a comparable pattern arises when observing China and the EU member states, as both regions undergo fluctuations in the number of startups over the years. While the United States has consistently held a prominent position in the startup ecosystem, both China and the European Union have witnessed periods of growth but have struggled to sustain momentum consistently over the years.

**Figure 7 Global comparison on year creation of startups relevant to human-centricity in technology development**




Data: Crunchbase, Analysis: Technopolis Group

A relevant number of the identified start-ups (28) are developing applications that enhance human centred robotics. These often involve collaborative robots. For instance, the company AIRSKIN[31], has created a pressure sensitive skin that can transform an industrial robot application into a collaborative one, making robots safe for human interaction and

[31]Airskin. Access at: https://www.airskin.io/airskin

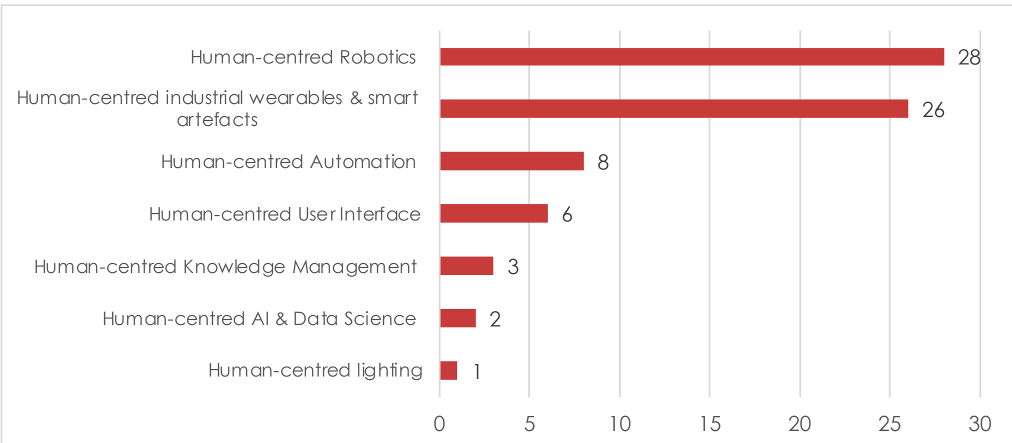
more efficient for enterprises. Another noteworthy example is the Danish company OnRobot[32], which focuses on developing and distributing end-of-arm tools and software, such as grippers, sensors, and other collaborative cobot equipment that can be integrated into manufacturing processes. These tools facilitate the use of technology in various applications like packaging, quality testing, material handling, machine tending, assembly, and welding.

We also identified 25 start-ups focusing on industrial wearables and smart artefacts. Notably, some companies are developing exoskeletons. For instance, AGADE[33] has created an exoskeleton that significantly reduces muscle fatigue and the risk of injury associated with repetitive and dynamic activities. Their technology provides variable support, negating the effects of gravity on human limbs and enabling movements comparable to those possible in a zero-gravity environment.

Furthermore, there are start-ups working on smart wearables like smart gloves and glasses. An example is the Oculavis[34], a company producing data glasses that offer hands-free functionalities.

Additionally, we found start-ups offering tools to streamline data management tasks derived from the implementation of other technologies, primarily focused on data analysis and generating valuable insights. An example of this is the Polish company Kogena[35], which provides an industrial IoT Platform automating machine data collection and production analytics, delivering actionable information to integrators and factory workers.

**Figure 8 Number of created start-ups since 2010 with a human-centric focus in EU**



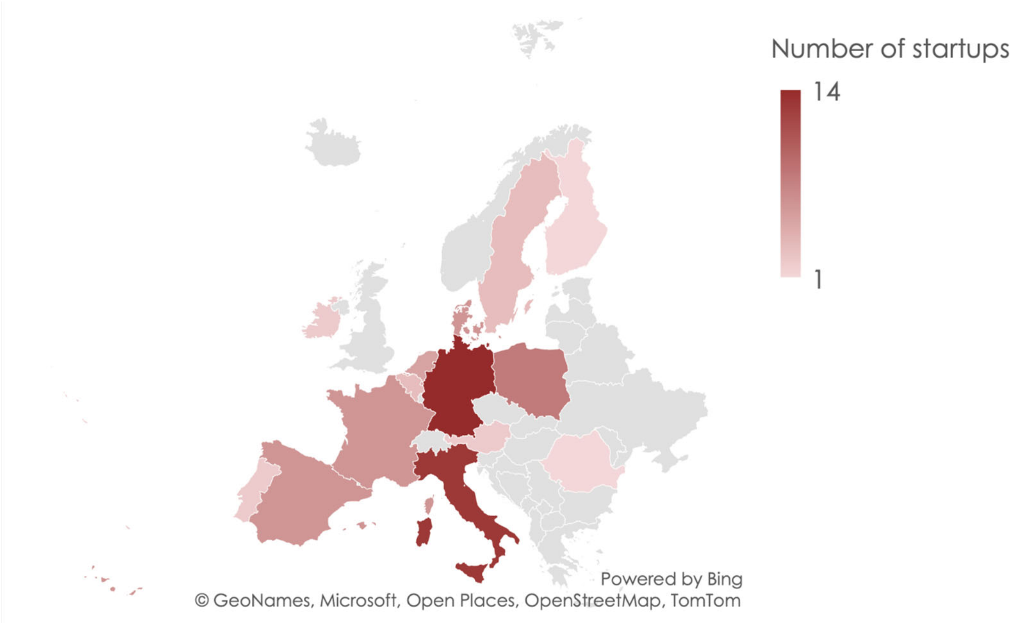

Data: Crunchbase, Analysis: Technopolis Group

It is not unexpected that the majority of start-ups are clustered in the top two countries, Italy and Germany (as depicted in the figure below). While Italian start-ups cover a broad

[32]On Robot. Collaborative Applications. 2023. Access at: https://onrobot.com/en/applications
[33]Agade. 2023. Access at: https://agade-exoskeletons.com
[34]Oculavis. 2023. Access at: https://oculavis.de/de/start/
[35]Optimatik. *El futuro del comercio online: 3 tendencias a tener en cuenta.* 2023. Access at: https://optimatik.co/

spectrum of human-centric interests, it is noteworthy that half of the German start-ups are primarily focused on the advancement of smart wearables and exoskeletons.

**Figure 9 Geographical distribution of HC start-ups**




Data: Crunchbase, Analysis: Technopolis Group

## 3.2. Technology adoption as an opportunity for a more human-centric industry

Findings from the 2022 EU Survey on Industrial R&D Investment Trends show that companies in high-tech sectors prioritise the significance of ICT software, services, hardware, and adaptation to Industry 4.0 for their future competitiveness. Medium- and low-tech companies emphasise the critical importance of environmental sustainability, particularly when considered alongside Industry 4.0, as highlighted above. The differences in the relevance of certain forms of capital investment appear to be determined by technology classes rather than company size.[36]

The EU Survey on Industrial R&D Investment Trends also captured the opinion of companies on whether they produced new goods or provided new services in 2021 using one or more of a list of technologies. The table provides and overview of technologies related to Industry 5.0 that are already used and are being tested, thus potentially adopted in future.

[36] Nindl, E., The 2022 EU Survey on Industrial R&D Investment Trends, Publications Office of the European Union, Luxembourg, 2022, doi:10.2760/579174, JRC131984

**Table 4 Share of companies that have already adopted advanced technologies or are testing their application in goods and services**

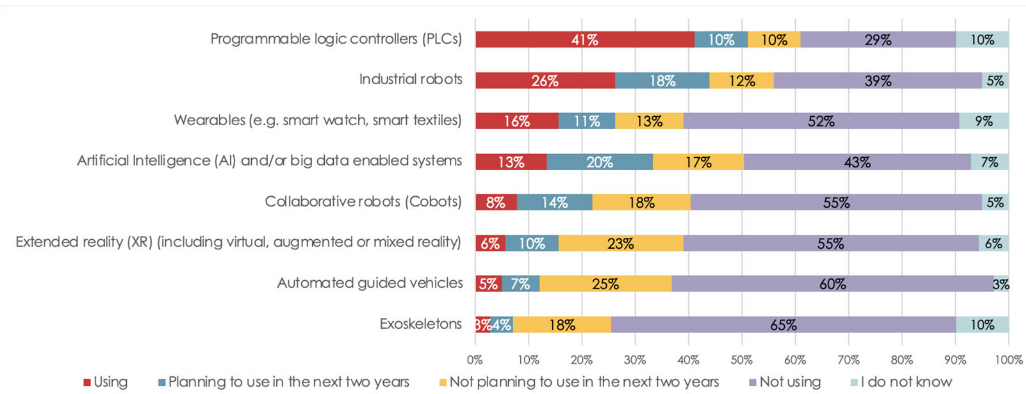
| Technologies related to I 5.0 | Already implemented | Tested |
|---|---|---|
| Augmented reality | 34.8% | 22.8% |
| Additive manufacturing, including prototyping | 40.2% | 21.7% |
| Machine learning | 66.7% | 20.4% |
| Machine vision | 41.3% | 18.5% |
| Robotics | 65.2% | 12% |
| Touchscreens/kiosks for customer interface | 46.2% | 3.3% |

Source: Nindl, E., The 2022 EU Survey on Industrial R&D Investment Trends. Note: table sorted by share of companies that are testing technologies

Machine learning and robotics are already used by two thirds of the responding companies, and they are in testing in another 20% and 12% respectively. The most widely tested technologies for producing goods and services include augmented reality, additive manufacturing and machine learning.

The study team further investigated technological uptake within surveyed companies. Results show that programmable logic controllers (PLCs) lead with 41% of surveyed companies currently using them. Industrial robots follow, with a current usage of 26% and an additional 18% of surveyed companies that are planning to implement them within two years. The use of wearable devices is also notable as 31% of organisations have adopted these technologies. According to the surveyed companies, Artificial intelligence (AI), big data, collaborative robots (Cobots) likely will be adopted in the near future. Exoskeletons and automated guided vehicles are the least utilised technologies among the respondents.

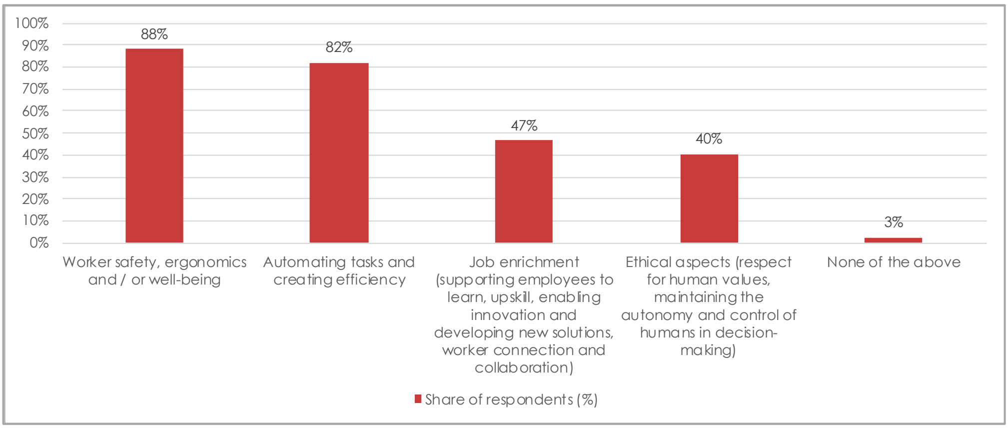
**Figure 10 Uptake of technologies among surveyed manufacturing companies**




Source: Authors based on survey question 19: Which technologies are you using or are you planning to use in your manufacturing processes?

Given that these technologies can be acquired with or without a human-centricity purpose, we surveyed manufacturing companies whether they considered human-centric aspects when investing in new technology or software. Results show that there is a relevant number of companies with a strong focus on human-centric factors, such as 88% of companies considered the worker safety, ergonomics and / or well- being as part of their purchase decision and 82% prioritised automating tasks and creating efficiency. Job enrichment and ethical aspects were also considered, albeit to a lesser extent, by 47% and 40% of companies respectively.

**Figure 11 Human centric aspects considered when purchasing manufacturing technologies**




Source: Authors based on survey question 21: When you invested in new machinery/technology/software did you consider any of the following human-centric aspects in the purchase decision? (N=77)

The acceptance and, consequently, adoption of these technologies is often a complex multidimensional process that requires careful consideration and preparation. Foremost, it is necessary to assess the alignment of the technology with the needs of the organisations. The technological solutions need to improve efficiency and performance but also optimise the experience and well-being of the workers. Therefore, it is important to have a thorough understanding of the technology and its characteristic by clearly communicating and demonstrating the benefits and potential risks.[37] This would help to gain insight into the capabilities and prospective applications of the technologies to comprehend how it can be integrated into the existing processes. Organisations are thus recommended to engage in proactive exploration with the technologies and interact with them rather than a static utilisation (for instance by participation in a co-design process). This approach can facilitate identification of how the technology can best support their work. A pilot testing could therefore help to identify potential challenges and benefits before its full-scale adoption.

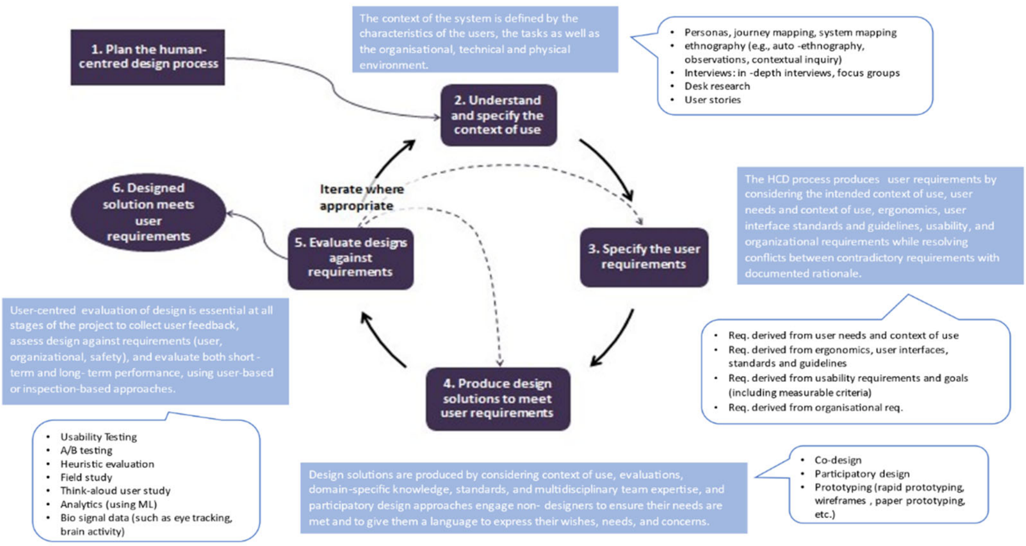
[37] Jandl, C., Zafari, S., Taurer, F., Hartner-Tiefenthaler, M., & Schlund, S. (2023). *Location-based monitoring in production environments: does transparency help to increase the acceptance of monitoring?.* Production & Manufacturing Research, 11(1), 2160387.

## 3.3. The role of fostering organisational innovations and new business models in promoting human-centric approaches in industry

The shift towards increasingly human-centred organisations needs the incorporation of human-centric design processes and methods that facilitate such transition. The following sections outline the key processes and methods of human-centred design and highlight prominent human-centric organisational models.

The process aimed at establishing human-centricity as a standard practice within organisations through the application of human-centred design (HCD). Human-centred design follows an iterative process consisting of four primary phases. These phases are revisited in design cycles until the resulting solution aligns with user requirements. Error! Reference source not found. provides a summary of these HCD phases, along with illustrative methods associated with each phase for clarity.

**Figure 12 Overview of exemplary methods for each human-centred design phase**




Source: International Organisation for Standardisation. (2016). Ergonomics of human-system interaction. Part 210: Human-centred design for interactive systems (EN ISO 9241-210:2019).

To ensure the integration of human-centricity in interactive systems, the HCD process should be applied across various organisational levels:[38]

- **Top Management**: The highest levels of an organisation bear the responsibility of setting the vision and strategy for incorporating human-centred design to achieve human-centric quality (Category 1).

[38] International Organisation for Standardisation. (2016). *Ergonomics of human-system interaction. Part 220: Processes for enabling, executing and assessing human-centred design within organisations (*EN ISO 9241-220:2019). Retrieved https://shop.austrian-standards.at/action/de/public/details/664103/OENORM_EN_ISO_9241-220_2019_10_15

- **Project and Programme Managers**, **System Operators**: Those in charge of managing projects, programmes, or system operations play a crucial role in facilitating the adoption of human-centred design principles across these initiatives and systems (Category 2).

- **Project Teams and Experts**: Within each project, individuals possessing the necessary expertise are tasked with the implementation of human-centred design practices (Category 3).

- **Support and Context Adaptation**: These experts support the introduction, operation, and end-of-life phases of systems. This includes tasks such as identifying changes in the context of use (Category 4) to ensure ongoing human-centred quality.

By delineating these responsibilities across different organisational levels, the HCD process can be effectively embedded in the organisations of to enhance their human-centricity. The specific phases of the HCD process are described in the following. More details about each step of the process are provided in Annex 5.

The increasing focus on human-centricity also reflects a broader shift toward more responsible and sustainable organisational practices that prioritise human well-being, ethical technology, and social impact. In addition, to achieve successful human-centricity integration, the organisation must make appropriate strategic and operational decisions for its business environment.

In the industrial context, the demand for a more human-centred approach has arisen due to concerns that traditional methods of technology design often disregard the skills of users, resulting in a diminished overall quality of the work experience[39]. It is important to note, however, that the industry must consider several conditions and needs before developing, upgrading, or adopting human-centred technology. Specifically, these industry needs include:

- Replacing existing tools and machines with advanced manufacturing technologies such as robotics and IoT.

- Seeking consultation and advice on the development and adoption of human-centred technology.

- Ensuring access to a skilled workforce capable of effectively using human-centred technology.

- Allocating investments dedicated to the purchase, development, or upgrade of human-centred technologies.

- Complying with regulations, addressing ethical issues associated with new technologies, and leveraging the opportunities presented by human-centred technology to address societal challenges.

[39] Gasson, S. (2003). Human-centred vs. user-centred approaches to information system design. *Journal of Information Technology Theory and Application (JITTA)*, *5*(2), 5.

The aforementioned needs are not comprehensive, nor presented in a prioritised order, and are derived from workshops and interviews with HC relevant ecosystem key stakeholders.[40] They also point to the need to better understand how organisational processes can be improved to ensure positive outcomes of technology adoption among employees, customers and / or community. Innovations in organisational and business models could be considered as solutions for this, as well as more standardised ways of institutionalising human-centricity related practices in organisations and collaborations with relevant supporting actors.

There are emerging organisational models that focus on human centricity. For example, many organisations are shifting towards a purpose-driven model. Purpose – the common goal that provides social good and goes beyond only making a profit towards which all stakeholders in the organisation strive – is a principle that guides the organisation's strategies, policies, operations, and initiatives.[41] Other important concepts also applied in practice are Holacracy and Agile Organisations. Such models emphasise greater employee empowerment, flexibility, and customer-centricity. Moreover, the models promote human-centric values, such as employee well-being, user satisfaction, and in some applications, also social impact.

Several tools and models have been proposed in the field of smart manufacturing. For instance, the Toolbox Workforce Management 4.0 measures the readiness of human factors and work environments towards digital manufacturing.[42] The Augmented Workforce Canvas is another example. Developed through Procedural Action Research (PAR), the Canvas is a strategic technology management tool aimed at systematically guiding users through the complex transformation towards human-centricity on the shop floor.[43] The Canvas takes a value-driven, technology-neutral approach. The tool begins with an assessment by key stakeholder groups of the set of underlying problems and the required added value of new technology that could enable human centricity. It can be used as a methodological framework for industrial researchers to identify their respective contributions to the overall context of human-centricity in industrial contexts.

Further, the model of Schumacher et al (2016) assesses the readiness and maturity of organisations based on the nine dimensions of products, customer, operation, technology, strategy, leadership, governance, culture and people.[44] Velasco et al (2022) propose a methodology for a human-centred workstation framework that allows identification of industrial requirements and ergonomic considerations.[45] Overall, only a few models have

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[40] More elaborated overview of industry opportunities in a resource-constrained and geopolitically complex global environment is provided in annex.

[41] Basu, S. (2018). Corporate purpose: Why it matters more than strategy. Garland Publishing, Inc.

[42] Galaske, N., Arndt, A., Friedrich, H., Bettenhausen, K. D., & Anderl, R. (2018). Workforce management 4.0-assessment of human factors readiness towards digital manufacturing. In Advances in Ergonomics of Manufacturing: Managing the Enterprise of the Future: Proceedings of the AHFE 2017 International Conference on Human Aspects of Advanced Manufacturing, July 17-21, 2017, The Westin Bonaventure Hotel, Los Angeles, California, USA 8 (pp. 106-115). Springer International Publishing.

[43] Moencks, M., Roth, E., Bohné, T., Romero, D., & Stahre, J. (2022). Augmented Workforce Canvas: a management tool for guiding human-centric, value-driven human-technology integration in industry. Computers & Industrial Engineering, 163, 107803.

[71] Schumacher, Andreas & Erol, Selim & Sihn, Wilfried. (2016). *A Maturity Model for Assessing Industry 4.0 Readiness and Maturity of Manufacturing Enterprises*. Procedia CIRP. 52. 161-166. 10.1016/j.procir.2016.07.040.

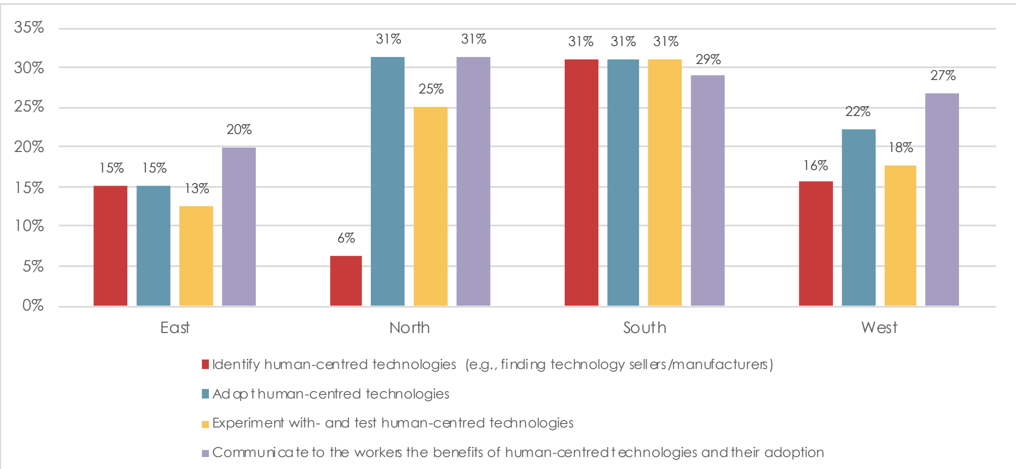
[72] Laura[7246]Laura[46] Laura Stefannia Forero Velasco, Pablo Emilio Rodríguez Revilla, Laura Valentina Ruiz Rodríguez, María Paz Santa Hincapié, Luis A. Saavedra-Robinson, Jose-Fernando Jiménez, *A human-centred workstation in industry 4.0 for balancing the industrial productivity and human well-being*, International Journal of Industrial Ergonomics, Volume 91, 2022, 103355, ISSN 0169-8141, https://doi.org/10.1016/j.ergon.2022.103355.

been proposed to assess the extent of human centredness of the organisations and guide them to become truly human-centred.

More importantly, the key element of the new organisational models is the realisation that human-centricity requires a comprehensive organisational change that encompasses both social and technical aspects. **In line, the capability of organisations to learn and adapt themselves to innovate is necessary to drive long term growth**. Learning organisations develop greater agility and the ability to react to unexpected events and embrace innovation.[46] The importance of this organisational change was also highlighted by the interviewees. Companies that are already open to innovation and have a worker empowerment culture in place are better positioned to have a successful HCT implementation.[47]

Within the survey we investigated the significance of various human-centred aspects within manufacturing companies. We observed that the perceived importance of these aspects varies across geographical areas. Overall, organisations based in Southern European countries demonstrate a higher involvement in all HCT-related activities, including identification, experimentation, adoption, and communication to workers. Companies from Northern countries also seem to be prioritising communicating the benefits of human-centred technologies and their adoption, with 31% of respondents highlighting this as the most crucial aspect. On the other hand, companies in Western and Eastern Europe seem to have primarily concentrated on communicating the benefits of integrating human-centred enabling technologies to their workforce.

**Figure 13 Organisational actions related to human centric aspects**




Source: Authors based on survey question 18: Please indicate how relevant it is for your company to identify human-centred technologies (e.g. finding technology sellers/manufacturers, to adopt human-centred technologies, experiment with and test human centred technologies and communicate to the workers the benefits of human-centred technologies and their adoption. (N=146)

Another approach that sheds light on company performance in terms of human-centricity includes the **learning capacity of organisations**, as defined by the BEYOND 4.0 Horizon

[46] Ibid.
[47] Interviews conducted between 16-10-2023 and 3-11-2023

2020 project.[48] The learning capacity of an organisation is understood as its ability to adapt and compete through learning. It is related to the following organisational mindsets, actions and investments that companies can promote:

- Preservation of the cognitive dimension of work
- Training opportunities
- Autonomy in cognitive tasks
- Stimulation of intrinsic motivation
- Autonomous teamwork practices
- Social support
- Supportive supervisory style
- Direct participation

The **organisation's learning capacity is a vital component of the innovation process**, facilitating adaptation and cost-effective competition through continuous learning. In addition, the economic and management literature emphasises that learning occurs when organisations can assess and adjust the norms and values guiding their strategies and modify them accordingly. **Learning organisations exhibit the managerial prowess to evolve their strategies dynamically without disrupting their structure, successfully balancing exploration and exploitation goals.**[49] Results from the Beyond 4.0 project showed the following:[50]

- The investment into the learning capacity of the organisation is a win-win strategy leading to more innovativeness and a high road of improved socio-economics outcomes.
  - Higher learning capacity favours all forms of innovation.
  - In terms of combination of innovations within firms, a higher learning capacity favours non-technological innovations only and combinations of technological and non-technological innovations, but not technological innovations only.

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[48] Greenan, N., et.al (2023), *Analysing the socio-economic consequences of the technological transformation.* Deliverable 5.1. Beyond 4.0 Project

[49] Greenan, N., Napolitano, S. (2021). Why Do Employees Participate in Innovations? Skills and Organizational Design Issues and the Ongoing Technological Transformation. In: Zimmermann, K.F. (eds) *Handbook of Labor, Human Resources and Population Economics*. Springer, Cham. https://doi.org/10.1007/978-3-319-57365-6_233-1 and Teece, D. J. (2018). *Business models and dynamic capabilities*. Long range planning, 51(1), 40-49. https://doi.org/10.1016/j.lrp.2017.06.007

[50] Greenan, N., et.al (2023), *Analysing the socio-economic consequences of the technological transformation.* Deliverable 5.1. Beyond 4.0 Project

  - Higher **learning capacity is also related with more labour market resilience**, in particular less unemployment and less occupational downgrading.

  - **In sectors with higher learning capacity employees have higher quality of working life.** They are less exposed to the platformisation of work, to low working time autonomy and to involuntary part time work.

- Combined with high levels of digital technologies use, **a high learning capacity of the organisation accelerates innovation** and tends to curb negative outcomes of technology uses.

  - It allows for a more parsimonious use of skills

  - It reduces occupational restructuring

  - In terms of job strain and adverse physical environment, discussions on health and safety issues promote lower psychological job demands and environmental risks in highly digitalised work environments, while having self-managed teams promotes greater autonomy.

  - In addition, to strengthen the learning capacity of organisations, enabling forms of organisations allowing for experimentations and failures are needed.[51]

In general, a learning organisation also poses a management challenge in ensuring that diversity enhances innovation and performance without hindering productivity.[52] Although it is crucial for innovation, in most sectors the level of the learning capacity of the organisation has been stagnating over the last decade.[53] Barriers to the development of the learning capacity of organisations and adoption of human-centricity approaches include:

- Lack of trust between employers and employees. Trust is an important ingredient for the sharing of knowledge, giving a strong role to social dialogue.

- Lack of enabling forms of organisations allowing for experimentations and failures

- Unclear responsibility for implementation

- and limited understanding of the benefits of human-centric solutions were raised during the interviews for ACE cluster case study (see Annex 8).

- Conflicting interests and differing mental models among stakeholders that can lead to resistance, often due to a lack of awareness or understanding of how human-centric design can improve processes and services.

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[51] Greenan, N., et.al (2023), *Analysing the socio-economic consequences of the technological transformation*. Deliverable 5.1. Beyond 4.0 Project

[52] Greenan N., Napolitano S. (2021), *Why do employees participate in innovation? Skills and organisational design issues and the ongoing technological transformation,* in Klaus F. Zimmermann (ed.) Handbook of Labor, Human Resources and Population Economics, Springer Nature. https://doi.org/10.1007/978-3-319-57365-6_233-1

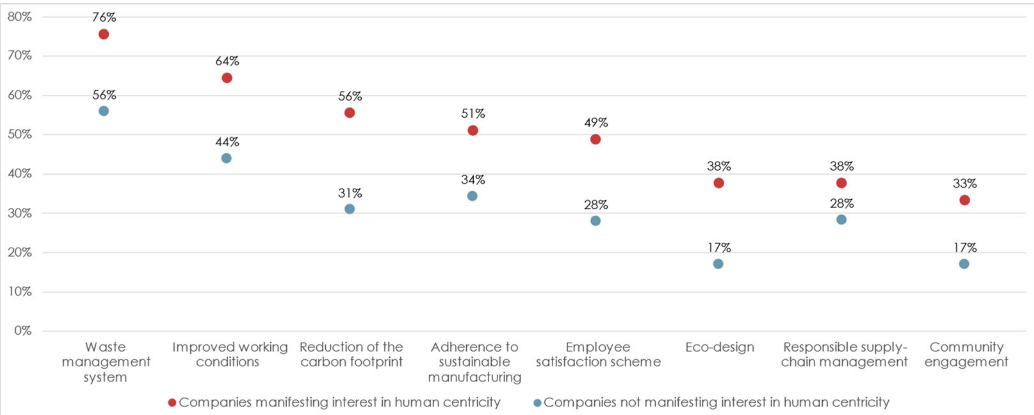
[53] Greenan, N., et.al (2023), *Analysing the socio-economic consequences of the technological transformation*. Deliverable 5.1. Beyond 4.0 Project

- Quantifying the return on investment in human-centred design efforts can be challenging, as the benefits may not be immediately measurable.

- Prioritising short-term goals over the longer-term efforts required to establish human-centric principles can also undermine commitment to these principles and goals.

Survey results indicate that the companies which are closer to human centricity[54] also consider the social and environmental aspects to a larger extent. For the surveyed companies, the most prioritised aspects are the waste management systems (62% of respondents addressed it to a large extent). Improved working conditions also received significant attention with 51.4% of organisations focusing on this aspect. On the one hand, the sustainable manufacturing and carbon footprint reduction are considered as very important by nearly 40% of respondents. This indicates a moderate engagement with environmental sustainability. On the other hand, eco-design and community engagement are the least selected options, with only 23.9% and 22.5% of respondents dedicating efforts to these areas respectively.

**Figure 14 Level of engagement with social and environmental aspects based on companies' interest in human centricity**




Source: Authors based on survey question 13, "To what extent does your organisation take into consideration the following social and environmental aspects?" (N=147), and question 18, "Please indicate how relevant it is for your company to identify human-centred technologies (e.g. finding technology sellers/manufacturers, to adopt human-centred technologies, experiment with and test human centred technologies and communicate to the workers the benefits of human-centred technologies and their adoption" (N=146)

Moreover, the survey results did not reveal a correlation between a company's turnover in 2022 and various reported social and environmental performance indicators, such as having a waste management system and reduced carbon footprint.

As mentioned in the ESIR report on Industry 5.0 and the Future of Work, the Industry 5.0 approach has to include the future of work as an essential dimension of future sustainable

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[54] In this specific case, by "closer to human centricity" we refer to those companies who responded to consider as largely relevant any of the options within question 18: identify human-centred technologies (e.g., finding technology sellers/manufacturers, to adopt human-centred technologies, experiment with and test human centred technologies and communicate to the workers the benefits of human-centred technologies and their adoption"

development, at the same level as other essential goals such as protecting climate and biodiversity and, more broadly, ensuring long-term resilience.[55] During the interviews, it was emphasised that human centricity should be considered in the same manner as companies have incorporated goals such as climate protection. The interviewees experienced that there was an existing knowledge and recognition of the importance of for instance climate related approaches within the companies in the manufacturing industry in Europe through sustainability programmes, but that human centricity was not at the moment included in such programmes.[56]

Adopting a human-centric approach within an organisation often **necessitates substantial organisational changes** to prioritise the needs and experiences of employees, customers, and other stakeholders. These changes can manifest in both the informal and formal structures of the organisation. For instance, this might involve **revamping work processes to align them with human needs** and **incorporating human-centric metrics, rather than (only) traditional financial ones, into incentive systems.**

Addressing the informal aspects of organisations is equally important. This entails nurturing a culture that places value on well-being, employee engagement, and self-actualisation. This can be achieved through initiatives such as **implementing real-time feedback loops to gather insights from both customers and employees or encouraging cross-functional collaboration** to create a seamless experience. Ultimately, it necessitates aligning the core beliefs and values of the organisation with behaviours that prioritise people.

Human-centricity should be seen as an ongoing journey. To continually enhance an organisation's level of human-centricity, it is vital to continuously monitor and enhance the experiences of its employees. By investing in employee training and development, an organisation can ensure that its workforce has the tools and resources needed to effectively serve people.

Moreover, human-centric design has seen limited attention in the engineering and design of industrial systems and processes. Integrating human-centred design into existing product development may necessitate the reengineering of processes, requiring the acquisition of essential skills and training for effective implementation. One of the primary barriers is the **need for upskilling and reskilling of human resources, as skills required to handle exceptional scenarios are critical for organisational adaptability**. While the skills required for future manufacturing are increasingly oriented towards mindset and creativity, identifying the skill sets necessary to respond effectively to such scenarios can be a challenging task.

Within our survey, companies were asked how and to what extent they were integrating workers in their decision-making, design, and development processes. Results show that 52.4% of companies allow employees to propose improvements via a suggestion scheme. Furthermore, over 40% of companies involve employees to a significant degree before adopting new technologies or altering processes. However, direct participation in decision-making and cross-functional teams is less common, with only about 25% of companies largely doing so.

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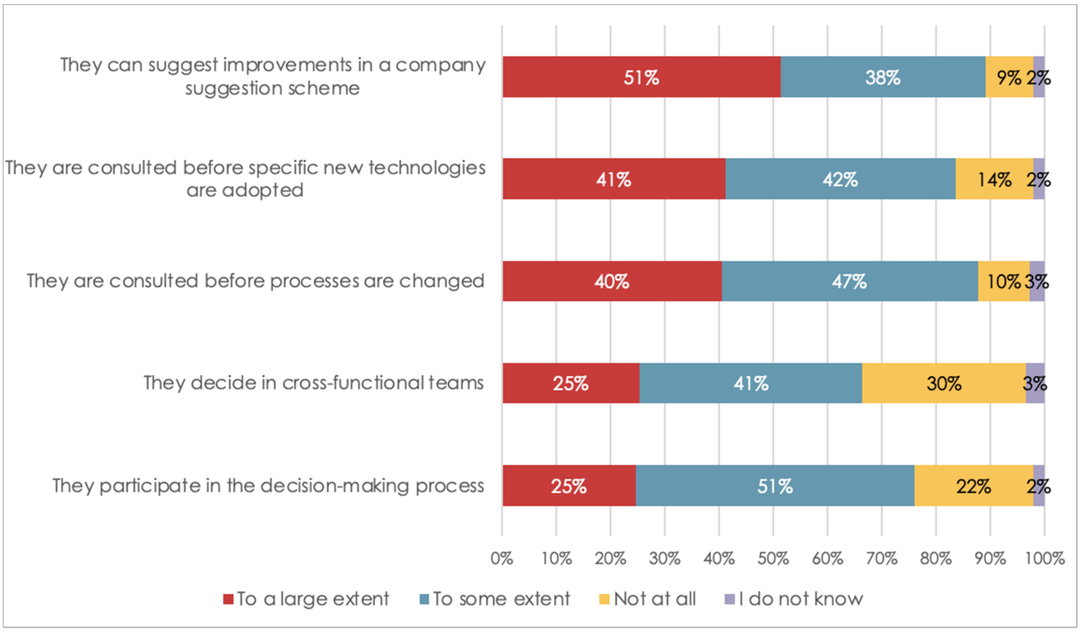
[55] Industry 5.0 and the Future of Work: making Europe the Centre of Gravity for future good-quality Jobs ESIR Focus Pape, 2023

[56] Interviews conducted between 16-10-2023 and 3-11-2023

When zooming into companies who responded to be up taking any technology that may have potential for human-centricity (Question 18), the share of positive responses slightly increases. Moreover, German and Swedish companies are the most likely to be integrating any kind of decision-making opportunity within their organisation.

**Figure 15 Survey responses on workers' involvement in decision-making, design, and development processes**




Source: Authors based on survey question 15: Which opportunities are integrated in your organisation involving workers in decision-making, design, and development processes? (N=147)

# 4. Research and innovation (R&I) investments

As described in the previous chapter, adopting human-centric approaches in technology development and deployment is an emerging niche that may lead to societal benefits, but requires further investments. This section provides an overview of the existing R&I investments in the EU's Horizon Framework Programme, as well as other relevant programmes at national level, and private venture capital funding.

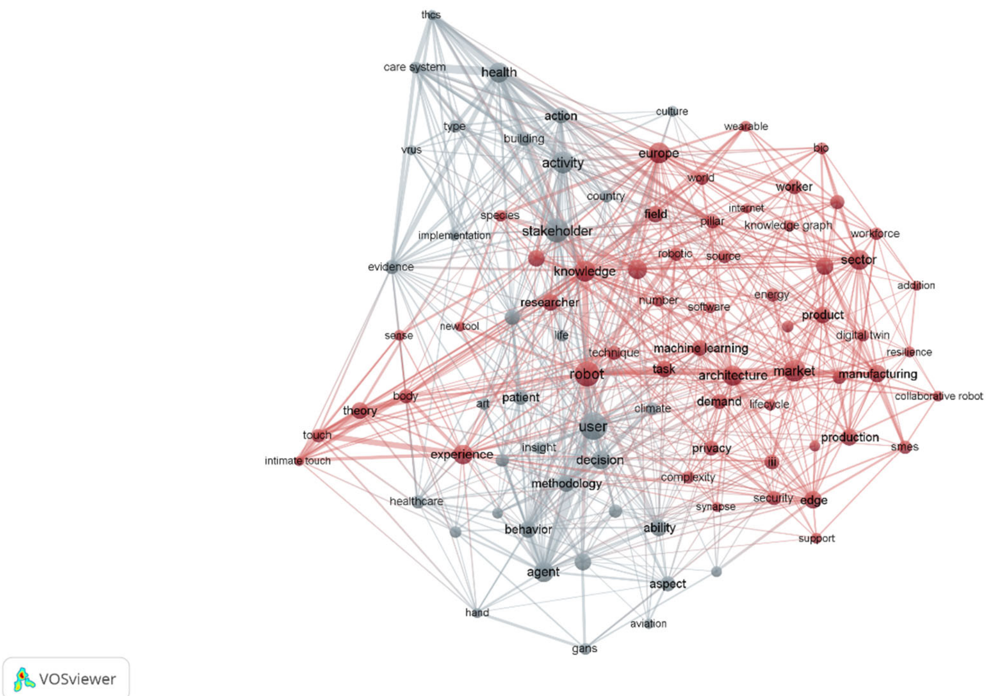
## 4.1. Investment trends in European Framework Programme (FP) projects

In , an association map illustrates keywords related to human-centred approaches to technologies within Horizon Europe projects. Given the recent initiation of the Horizon Europe Framework Programme, our analysis is based on a limited pool of 80 human-centred projects, resulting in a less extensive coverage of the association map.

Firstly, only two clusters are discernible, arguably associated with research or science-focused (grey) and industrial projects. This lack of clear distinction is evident both in their map positions and the keywords contained within. This observation suggests a potential trend where the boundaries between human-centred applied industrial projects and research/science-focused projects have become less pronounced, at least in their project descriptions.

Secondly, the terms "robot" and "user" are highly significant within the association map, as indicated by the size of their nodes. These terms occupy a central and closely connected position, highlighting their heightened relevance in the context of these projects.

**Figure 16 Association map of Horizon Europe projects**




Source: AIT

Note: Graph created with VOSviewer. The main keywords and terms are extracted from titles and abstracts of human-centred projects from Framework Programmes Horizon Europe. Nodes are placed to reflect the co-occurrence of terms with project descriptions whereas the node size refers to the frequency of use of the specific term. Colours refer to clusters of words that are especially related with each other.

Overall, human-centred projects within Horizon Europe exhibit distinct differences when compared to Horizon 2020 projects. These distinctions are particularly noticeable in the increased prevalence of terms related to the human body, which are also intertwined with technology-related terms like "robot" (as depicted in Figure 22). Furthermore, it is important to highlight that while robot-related terms held significance in Horizon 2020 projects, they now occupy a more central role within the landscape of Horizon Europe projects. Notably, they are more frequently associated with terms referring to collaborative or advanced types of robots, such as "collaborative robot," "(intimate) touch," "user," "experience," and "machine learning" (as illustrated in figure above).

Table below lists a number of relevant current or forthcoming calls of the Horizon Europe framework programme. Similar to the distribution of earlier Horizon Europe projects, we find current and future calls relating to human-centricity mainly in Pillar II (Global challenges & European industrial competitiveness). Within that pillar, they are mainly in clusters dealing with industry and digital topics (CL4), culture and inclusive societies (CL2), and climate, energy & mobility (CL5).

**Table 5 Selected existing and planned investments under Horizon Europe**

| Destination | Horizon Europe sub-call | Short description | # of sub-calls | Budget |
|---|---|---|---|---|
| HORIZON-CL4-2023-HUMAN-01 | All sub-calls | A human-centred and ethical development of digital and industrial technologies through a two-way engagement in the development of technologies, empowering end-users and workers, and supporting social innovation. This destination encompassed several sub-topics which give an orientation of the type of projects that were proposed under this destination:<br><br>Leadership in AI based on trust<br><br>An Internet of Trust<br><br>eXtended Reality (XR)<br><br>Systemic approaches to make the most of the technologies within society and industry<br><br>Digital Humanism and human compatible technologies<br><br>European standards for industrial competitiveness<br><br>International co-operation | 29 | €256.5 m |
| HORIZON-CL2-2024-TRANSFORMATIONS-01 | Beyond the horizon: A human-friendly deployment of artificial intelligence and related technologies (HORIZON-CL2-2024-TRANSFORMATIONS-01-06)<br><br>Assessing and strengthening the complementarity between new technologies and human skills (HORIZON-CL2-2024-TRANSFORMATION | Projects proposed for these calls should increase our understanding of or contribute to the following topics (among others):<br><br>Successful deployment of AI and its impact on the European economy and society<br><br>Analysis of the implementation of ethics principles for trustworthy AI<br><br>Potential and impact of new technologies such as AI and robotics to substitute or complement human skills | 2 | €20m |

| Destination | Horizon Europe sub-call | Short description | # of sub-calls | Budget |
|---|---|---|---|---|
| | S-01-11) | | | |
| HORIZON-CL5-2023-D6-01 | User-centric development of vehicle technologies and solutions to optimise the on-board experience and ensure inclusiveness (HORIZON-CL5-2023-D6-01-01) | Projects proposed for these calls should increase our understanding of or contribute to the following topics (amongst others):<br><br>Advanced vehicle technologies to optimise usability, perception and experience on-board<br><br>Enhance inclusiveness and trust in interaction between users and new automated modes of transport<br><br>Safety and security of vehicle occupants even when vehicle is driverless to prevent dangerous situations | 1 | €8m |
| HORIZON-CL4-2023-DIGITAL-EMERGING-01 | Industrial leadership in AI, Data and Robotics – advanced human robot interaction (AI Data and Robotics Partnership) (HORIZON-CL4-2023-DIGITAL-EMERGING-01-02) | Projects proposed for these calls should increase our understanding of or contribute to the following topics (among others):<br><br>Human robot interaction that adds value and improves quality of outcome for complex tasks (tasks where robots can add capabilities that extend human ability but require human interaction to be achieved)<br><br>Increase innovation potential for uptake of AI, data and robotics by improving ability of robots to work in collaboration with humans as equals | 1 | €30m |
| HORIZON-CL4-2024-HUMAN-01 | All sub-calls | A human-centred and ethical development of digital and industrial technologies through a two-way engagement in the development of technologies, empowering end-users and workers, and supporting social innovation. This destination encompassed several sub-topics which give an orientation of the type of projects that were proposed under this destination:<br><br>Leadership in AI based on trust<br><br>An Internet of Trust<br><br>eXtended Reality (XR)<br><br>Systemic approaches to make the most of the technologies within society and industry<br><br>Digital Humanism and human compatible technologies<br><br>European standards for industrial competitiveness | 3 | €56m |

| Destination | Horizon Europe sub-call | Short description | # of sub-calls | Budget |
|---|---|---|---|---|
| | | International cooperation | | |
| HORIZON-CL4-2024-HUMAN-02 | Support for transnational activities of National Contact Points in the thematic areas of Digital, Industry and Space (HORIZON-CL4-2024-HUMAN-02-34) | Projects proposed for these calls should increase our understanding of or contribute to the following topics (among others):<br><br>Facilitate trans-national co-operation amongst National Contact Points, encouraging cross-border activities, sharing good practices<br><br>Attract new players to strengthen human-centred approaches in the cluster, such as social innovation players, makers, youth associations | 1 | €5m |
| HORIZON-WIDERA-2024-ERA-01 | Next generation AI and Human Behaviour: promoting an ethical approach (HORIZON-WIDERA-2024-ERA-01-12) | Projects proposed for these calls should increase our understanding of or contribute to the following topics (among others):<br><br>Promote responsible, trustworthy and human-centric design and development of next generation of AI<br><br>Develop practical specific guidelines on the ethics of AI<br><br>Develop and validate education and training material referring to produced guidelines | 1 | €3m |

Note: Human-centred Horizon Europe destinations (calls) and sub-calls listed here are retrieved from the EC's online funding and tender portal (Single Electronic Data Interchange Area (*SEDIA*)). Calls were considered if they are either open, forthcoming or were closed in 2023. Human-centred calls in this table were identified by manually selecting relevant calls from a comprehensive list of calls that use keywords "human" or "people".

Going forward, it is essential to emphasise the human perspective in technological advancements and their industrial applications. Although this aspect is already acknowledged in past and running industrial R&D projects of H2020 and Horizon Europe, it is expected to remain significant and even more important in the future. The impact of automation, digitalisation and AI on workers and organisations, especially at the shop floor level, necessitates evaluation and adaptation. Thus, it is crucial to consider the human factor, the work community, and the organisational aspects when implementing automation and AI in factories. Additionally, user engagement and co-creation has gained prominence, and the human side of manufacturing plays a crucial role in shaping the evolving landscape of the industry, including skills requirements. Hence, this perspective raises intriguing research questions to be addressed in corresponding funded multidisciplinary R&D projects.

## 4.2. Available national public investments in R&D and technologies

The industry requires additional investments to facilitate the development and adoption of HCT. This is particularly crucial because HCT often entails intricate and costly research and development processes. These investments are essential for financing R&D endeavours that propel innovation and technological progress. In the absence of adequate funding, industries may find it challenging to keep pace with the swiftly evolving technologies and risk losing their competitive advantage.

Furthermore, to fully harness the potential of HCT, industries must have modern and technologically advanced infrastructure and facilities at their disposal. This entails investments to construct or upgrade facilities such as laboratories, manufacturing plants, data centres, and communication networks. These investments play a pivotal role in ensuring that the industry is well-equipped to effectively embrace and leverage HCT.

The figure below provides an overview of the share of manufacturing enterprises that received funding for R&D or other innovation activities in 2020, categorised by the type of funding, for countries where data was available. Amongst public funding sources, manufacturing enterprises primarily relied on funding from national central governments to finance their R&D activities. The importance of other financial support from EU institutions (e.g., ERDF) was the second most common type of funding that manufacturing enterprises received for their R&D activities.

**Figure 17 Share of manufacturing enterprises that received funding by type of funding for research and development (R&D) or other innovation activities in 2020**

| Country | National central government | Local or regional authorities | EU Horizon 2020 Programme | Other financial support from an EU institution |
|---|---|---|---|---|
| Belgium | 18% | 17% | 3% | 2% |
| Bulgaria | 10% | N/A | 0% | 10% |
| Czechia | 8% | 1% | 0% | 10% |
| Estonia | 9% | 0% | 1% | 5% |
| Greece | 8% | 6% | 1% | 2% |
| Croatia | 3% | 2% | 1% | 5% |
| Italy | 7% | 7% | 1% | 1% |
| Cyprus | 15% | 0% | 1% | 7% |
| Latvia | 1% | 1% | 1% | 7% |
| Lithuania | 3% | 1% | 0% | 17% |
| Luxembourg | 28% | N/A | 2% | N/A |
| Hungary | 5% | 1% | 1% | 7% |
| Malta | 4% | 2% | 0% | 2% |
| Austria | 18% | 11% | 4% | 4% |
| Poland | 2% | 1% | 1% | 3% |
| Portugal | 3% | 2% | 1% | 4% |
| Romania | 0% | N/A | 0% | N/A |
| Slovenia | 11% | N/A | 3% | 6% |
| Slovakia | 2% | 0% | 1% | 3% |
| Finland | 36% | 6% | 2% | 2% |
| Sweden | 5% | 2% | 1% | N/A |

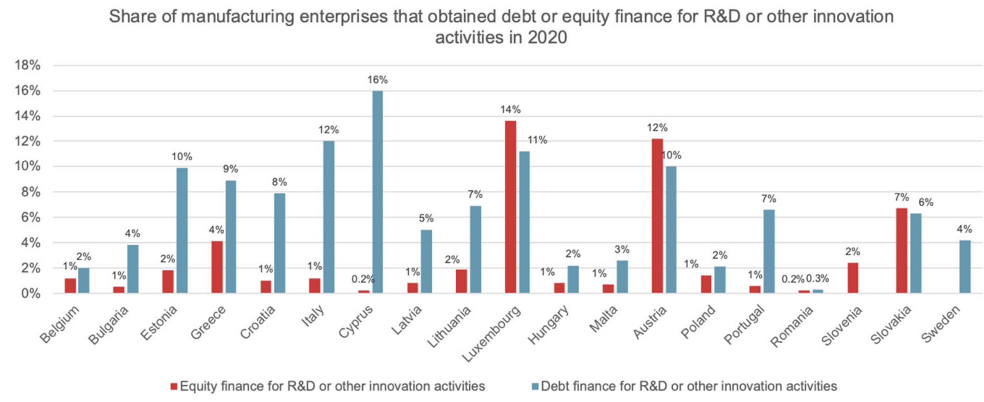
Source: CIS inn_cis12_pub.

Finland and Luxembourg are leading countries with the highest proportion of manufacturing enterprises funded by central governments. Not surprisingly, both countries have developed advanced industrial support programmes. However, **according to the results from the OECD STIP compass analysis, while there are handful of national/regional programmes dedicated towards resilience, sustainability and/or digitalisation of manufacturing sector, the human-centricity element is lacking** (see the next chapters).

In addition to public funding, equity and debt financing plays a significant role in supporting R&D activities in manufacturing enterprises. Results from the CIS 2020 survey indicate that, among the 19 surveyed countries, Luxembourg, Austria, and Slovakia emerge as nations where a higher percentage of manufacturing companies secured equity financing for their R&D initiatives[57].

[57] https://ec.europa.eu/eurostat/cache/metadata/en/inn_cis12_esms.htm

**Figure 18 Share of manufacturing enterprises that obtained debt or equity finance for R&D or other innovation activities in 2020**




Source: CIS inn_cis12_finrd

Public investments in human-centric technologies are instrumental in advancing their development and widespread adoption. Several public programmes, plans, and actions are available to support advanced technologies development within the European Union Member States (EU MS). However, few of the identified programmes are specifically targeting the human-centric aspects of technology development; even if several are touching on them. This shows the **need for more targeted investments at Member State level to address human-centric outcomes of technology development.** Below we provide examples of programmes identified that could prove interesting to learn from.

Germany has been actively championing the concept of Industry 4.0, which is centred on the integration of advanced digital technologies into manufacturing processes. While Industry 4.0 doesn't explicitly focus on human-centricity, it recognises the vital role of collaboration between humans and machines. The German government has provided substantial support for various research and innovation programmes, including the Hightech Strategy 2025 and the Industrial Data Space initiative.[58] These initiatives aim to advance digitalisation in manufacturing, stimulate economic growth, and concurrently address societal needs and ethical considerations. Additionally, within dedicated research programmes, the Ministry for Education and Research (BMBF), operating under the High-tech Strategy, allocates funding to projects at the interface of the economy and Work 4.0. These projects utilise digitalisation as a means to shape working conditions with a strong emphasis on human-centricity.

Furthermore, the German Ministry of Labour is actively engaged in assisting companies and public administrations through the "**New Quality of Work (INQA)" initiative**. This initiative focuses on adapting to evolving work environments while fostering a healthy and safe workplace culture. An essential regional implementation component comprises 12 regional "**Future Centres" (Zukunftszentren),** which receive co-funding from the European Social Fund (ESF). These centres are responsible for developing and testing innovative qualification concepts, with a special emphasis on small and medium-sized

[58] Jan, Jurjens. The Industrial Data Space is a digital industrial platform that spans across value chains in all sectors of the economy. Access at: https://ec.europa.eu/futurium/en/system/files/ged/industrial_data_space.pdf

enterprises (SMEs).[59] The overarching objective is to aid SMEs in the collaborative and co-creative integration of digital technologies and AI-based systems while prioritising a human-centric approach. Since 2018, under the INQA initiative, 28 experimental labs have received funding, including 11 labs specifically focused on the human-centred implementation of AI within companies.

**The "hKI-Chemie" project, titled "Human-Centred Artificial Intelligence in the Chemical Industry"** (2021-2024), is funded by the German BMBF. This project operates as a 'Verbundproject,' a collaborative effort involving research and industrial partners. It aims to address the challenge that full automation in the industry can be problematic because companies require flexibility. While humans excel in quick responses to changing situations, AI systems can efficiently process information and solve problems more rapidly. The project's objective is to leverage AI systems to empower individuals to make better decisions in complex scenarios. The goal here is not to replace humans with AI systems but rather to create integrated systems where humans and AI complement each other, resulting in superior outcomes.

The research partners in this project include the University of Duisburg-Essen (specifically the Chair of Distributed Systems and the Chair of Psychological Research Methods) and the Fraunhofer IIS, Project Group Comprehensible Artificial Intelligence. On the industrial side, partners include Continental Automotive GmbH, Evonik Industries AG, InfraServ Wiesbaden Technik GmbH & Co. KG, Boldly Go Industries GmbH, RheinByteSystems GmbH, as well as VDI Technologiezentrum.

Similarly, the **"RoSylerNT" project**, also sponsored by the BMBF, ran from 2018 to 2021 and involved the industrial robot manufacturer KUKA and the Sport University Cologne. This project focused on testing robotic systems for neuromuscular training, including a carrying aid designed to assist with heavy object handling. While there are already numerous studies on human-robot interaction, KUKA's experiments delved further into psychosocial aspects, including technological acceptance, fear, and confidence.[60]

In Finland, there are well-established ecosystems within the manufacturing and ICT sectors, each with a distinct focus. These ecosystems revolve around digitalisation and intelligent industry (DIMECC), digital fabrication and printed intelligence (Fab Labs & PrintoCent), digitalisation of manufacturing and engineering (Reboot IoT Factory and MEX), robotics (RoboCoast), AI solutions spanning various domains, and IoT (Analytics+, SuperIoT), as well as next-generation telecommunications (5G Test Network and 6G Flagship). The Finnish industry alliance has laid out a comprehensive "Industry 6.0" strategy aimed at enhancing collaboration among existing labs and testbeds to fully leverage the advantages of digitisation. While this strategy places significant emphasis on innovation in both digital and green technologies, it does not explicitly mention human-centric approaches. In a different context, the MyData initiative, concerning data and digitisation in the public domain, showcases a clear focus on human-centric principles.

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[59] Bundesministerium für Arbeit und Soziales, "ESF Plus-Programm 'Zukunftszentren,'" Access at: https://www.bmas.de/DE/Arbeit/Digitalisierung-der-Arbeitswelt/Austausch-mit-der-betrieblichen-Praxis/Zukunftszentren/zukunftszentren.html

[60] KUKA researches psychosocial aspects of human-robot collaboration. Access at: https://www.kuka.com/en-de/company/press/news/2020/09/kuka-researches-psychosocial-aspects-of-human-robot-collaboration

In the Netherlands, the **Smart Industry programme**[61] is designed to assist the Dutch industry in digitisation, featuring five key pillars. One of these pillars is focused on Human-Centricity, known as 'smart work.'[62] Additionally, there are initiatives such as the Robust AI programme and the ELSA labs, which are part of AI efforts led by the NWO (Netherlands Organisation for Scientific Research) and the Dutch AI Coalition.

In Belgium, the "**Proeftuinen voor industrie 4.0**" initiative is dedicated to establishing living labs for Industry 4.0. The primary focus here isn't solely on the technologies themselves but also on how employees embrace, learn, and apply these technologies in their work. For instance, in the living lab known as "Technology for Workable Work" (2022-2024), experts from Flanders Make, imec, Sirris, and HIVA (KU Leuven) collaborate to demonstrate how companies can make their work environments more conducive to productivity and employee well-being. Additionally, there are new guidance projects related to human capital (2021-2023). These six projects are an extension of the efforts initiated in the Industry 4.0 pilots. Their primary purpose is to assist companies in the implementation of new technologies within the workplace. These projects concentrate on understanding the impact of these technologies on both employees and the organisation as a whole. Examples include "XR@Work," which explores human-centred work practices using virtual and augmented reality, and "Dronedata," which investigates human-centred value creation through the utilisation of drones.

In addition, during the interviews, various national conceptual models for skills in the manufacturing industry related to human-centricity were discussed. For instance, the Teaching Factory (TF) concept[63] developed by the Laboratory for Manufacturing Systems and Automation (LMS) Greece or the Learning factory model[64] in Spain were highlighted. These initiatives focus on building relevant skills, facilitate connections among ecosystem players. The Teaching Factory concept, for example, involves engineers, foremen, production managers, operators, and students. The Factory Centre's day-to-day operations bridge the gap between regional and national industrial ecosystems. In addition, the Factory Centre designs training programmes that incorporate both synchronous and asynchronous learning approaches. For example, during the synchronous learning, individuals access the training platform that enables direct interaction with technology, offering hands-on training and opportunities to develop concrete implementation strategies for transferring technology to the factory, ultimately resulting in technology installations.

Furthermore, interviewees identified two distinct pathways for attaining HCT-related skills/knowledge. The first pathway involves participation in the European-funded high TRL projects. The second pathway revolves around the establishing competence centres, exemplified by the Factory Competence Centre in Greece described above. These centres collaborate directly with technology designers with the goal to transfer mature results to industry. The interviewees also emphasised that customisation of HCT offers an opportunity for Europe to achieve a competitive advantage in the field of HCT implementation.[65]

In addition, the table below lists further programmes, actions and instruments that are related to human-centricity.

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[61] TNO. Smart industry: digitisation of the manufacturing industry. Access at: https://www.tno.nl/en/digital/smart-industry/smart-industry-digitisation/
[62] Ibid.
[63] https://www.teachingfactory-cc.eu/en/home/
[64] https://tknika.eus/en/cont/proyectos/ethazi-3/
[65] Interviews conducted between 16-10-2023 and 3-11-2023

**Table 6 Programmes, actions and instruments that are related to industry 5.0 and human-centricity**

| Programme | Year | Country | Description |
|---|---|---|---|
| ACDH - Austrian Centre for Digital Humanities | 2014 | Austria | The Austrian Centre for Digital Humanities (ACDH) serves as a hub for digital methodologies and repositories in the humanities. These centres promote the application of digital methods across various branches of the humanities. |
| Action Plan for Digital Transformation of Slovakia | 2019 | Slovakia | The "Action plan for the transformation of Slovakia into a successful digital country and the development of the digital single market" outlines concrete steps for kickstarting the establishment of a sustainable and human-centric industry. |
| Artificial Intelligence 4.0 Programme | 2020 | Finland | "Artificial Intelligence 4.0" is a comprehensive programme aimed at expediting the integration of artificial intelligence and fostering the fourth industrial revolution in vital sectors like manufacturing and process industries. While primarily focused on Industry 4.0, several programme elements contribute to the concepts of Industry 5.0. |
| Civil Liability Regime for Artificial Intelligence | 2020 | EU | The European added value assessment (EAVA) suggests that a revision of the EU civil liability framework for artificial intelligence systems would likely result in significant economic and social benefits. |
| Company-Level Spaces for Learning and Experimentation with AI | 2020 | Germany | Through project funding, the initiative supports company-level spaces for AI experimentation with a particular emphasis on practical human-centred applications. |
| Digitalwallonia4.Ai | 2019 | Belgium | The programme in Wallonia aims to accelerate the adoption of artificial intelligence (AI) and bolster the Walloon ecosystem through awareness campaigns and training. |
| Human-Machine Interaction Research: Bringing Technology to the People | 2015 | Germany | The research programme on human-machine interaction is guided by principles of cooperation. |

| Programme | Year | Country | Description |
|---|---|---|---|
| Industry of the Future | 2016 | Belgium | The awareness and support programme in the domain of digitisation for manufacturing companies (Industry 4.0) seeks to enhance the competitiveness of manufacturers and create new digital innovation niches within Walloon industry's existing areas of specialisation. |
| Platform for Future Industry | 2019 | Poland | The Platform is dedicated to disseminating knowledge and skills vital for the success of Industry 4.0. It also provides expert advisory support to entrepreneurs, with several components of the programme contributing to the concepts of Industry 5.0. |
| Strategic Research & Innovation Partnership Factories of the Future | 2015 | Slovenia | SRIP FoF comprises eight vertical value chains, including robotic systems and components. |
| Technology Assurance Sandbox | 2021 | Malta | The sandbox initiative aims to offer a secure environment for individuals and companies developing solutions based on Innovative Technologies such as Blockchain and Artificial Intelligence, especially in critical deployment scenarios. |

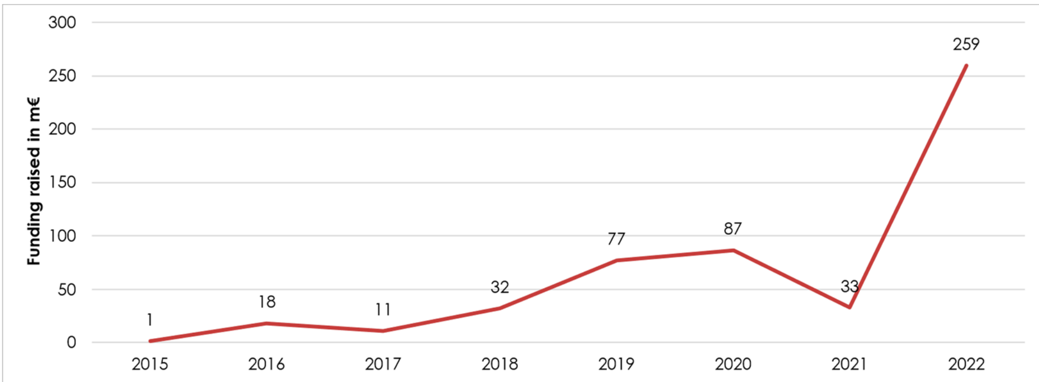
Source: authors based on STIP Compass

### 4.3. Private investments and VC analysis into startups

The scale of venture capital and private equity investment in HC tech companies has been calculated using a data from Crunchbase. Based on the startup analysis above, Figure 22 presents the evolution of the funding raised by companies developing human centric technologies. Annual investments are captured in the time period from 2015 to 2022, excluding exit type of rounds.

For the period 2015 to 2023 we captured 119 funding rounds leveraged by a total of 51 unique organisations, raising a total of EUR 456 million. The results suggest that the overall investment has been increasing for the considered period, with an average year growth of 143%.

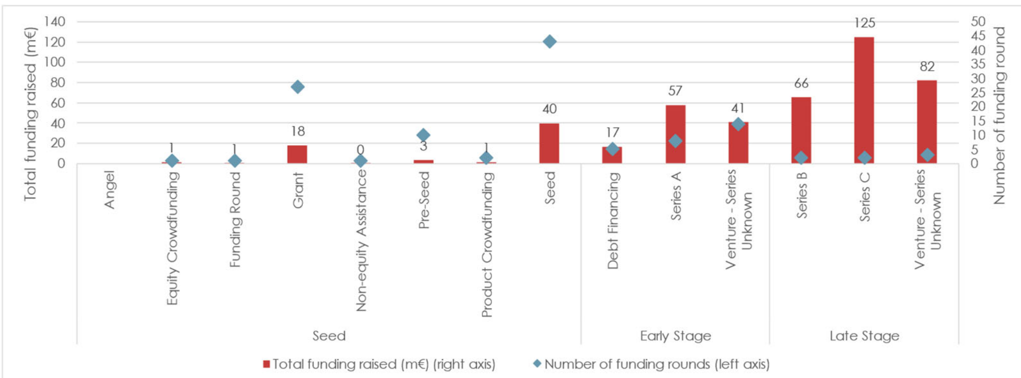
**Figure 19 Private funding raised by startups related to human-centric enabling technologies, based the EU27**




Source: Technopolis Group based on Crunchbase, 2023

Zooming in on the funding by stage into subclasses gives insight into specifically which rounds of funding received the greatest attention over the period 2010 to 2022 (see Figure below). While during this time period the greatest amount of funding for start-ups working on human-centric enabling technologies goes to late development, the majority of rounds are concentrated in seed type of funding, what could indicate that the HCT funding market is still in an early maturity stage.

**Figure 20 Total funding by stage and type of instrument into HC tech companies in the EU27**




Source: Technopolis Group based on Crunchbase, 2023

# 5. Framework conditions

This section maps the surrounding environment in which research and innovation actions related to human-centric approaches in technology development, deployment and adoption take place. It tackles global trends in society, workforce and governance, as well as the existing relevant European policy framework.

## 5.1. Trends in society, workforce, and governance

Societal changes, demographics and workforce, governance, regulations and ecosystem actors and other stakeholders are part of a necessary framework conditions and enablers which are crucial to successfully realise Industry 5.0.

In the social dimension, a human-centric approach needs to be developed into a socio-centric approach, addressing contemporary challenges, heterogeneous needs while integrating participation of the society to increase trust and acceptance.[66] Policymakers will need to focus on technology as a means to achieve societal goals beyond efficiency, such as sustainability and worker wellbeing. To achieve this objective, addressing main societal, demographic and governance trends is crucial to place worker wellbeing at the core of a human-centred industry. The Table below lists selected key trends that hinder and /or foster the implementation of Industry 5.0.

**Table 7 Main trends fostering or hindering the transition to Industry 5.0**

| Trends | Rationale |
|---|---|
| **Trends presenting challenges for Industry 5.0** | |
| Ageing society | For 2030, Eurostat projects for the EU a total population of 449 million. This number decreases successively to 447 million in 2040 and 441 million in 2050.[67] In addition, the size of the EU labour supply is expected to decrease by 16 over the projection horizon, with the largest decline in labour supply for males[68]. |
| Skill mismatch and labour shortages | On average, across the EU-27, 16.5% of manufacturing companies encounter challenges as there are few or no applicants, while 11.1% of companies indicated that they face difficulties in recruiting machine operators, craft, and skilled trades workers because applicants lack the right qualifications, skills, or experience[69]. This implies a significant challenge in finding suitable candidates for roles crucial to Industry 5.0. This suggests a potential shortage of individuals with the necessary technical skills and qualifications, which could impede the industry's growth and competitiveness.<br><br>At the EU level, there is an evaluation of Continuing Vocational Training (CVT)[70]. When examining the specific skills addressed by these training programmes in 2020, it becomes evident that several EU Member States primarily emphasised the development of management skills, rather than placing a central focus on professional IT skills. |

[66] Enabling Technologies for Industry 5.0 Results of a workshop with Europe's technology leaders.
[67] Eurostat EUROPOP2019. Also included in EC (2021): The 2021 Ageing Report
[68] European Commission (2021), The 2021 Ageing Report. Economic and Budgetary Projections for the EU Member States (2019-2070), p.32
[69] Flash Eurobarometer 529 European Year of Skills: Skills shortages, recruitment and retention strategies in small and medium-sized enterprises, 2023.
[70] See: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Continuing_Vocational_Training_Survey_(CVTS)_methodology.

| Trends | Rationale |
| --- | --- |
| Fear of job replacement due to technology | Cedefop's second European skills and jobs survey (ESJS2) shows that 38% of workers in the EU-27 Member States, Norway and Iceland (hereafter referred to as EU+) think that there is a chance they may lose their job in the next 12 months. Around 35% express great or moderate concern that new digital or computer technology will soon take over their main job or part of it. Workers in southern Europe (Spain, Malta, Greece, Cyprus, Portugal) are more concerned about being displaced by technology than their counterparts in other EU Member States (Austria, Norway, Iceland, Latvia, Czechia) and countries considered technological leaders (Estonia, Finland).[71]<br><br>More specifically, the job-task churning, and the routinisation that workers affected by technological change may breed feelings of job insecurity. EU+ adult workers in middle-skill occupations (e.g. skilled agricultural workers, craft and related trades, plant and machine operators) are more concerned about the prospect of employment loss than skilled and semi-skilled employees.[72] More afraid of job loss are workers operating robots at work (57%) and those who had to learn new computerised machines (50%). |
| AI posed challenges | The challenges posed by AI encompass several critical issues, such as the absence of transparency in human-AI collaboration, concerns related to safety, security, and trust in AI-based systems, the environmental impact of AI, including emerging approaches like frugal AI and the necessary engineering pipeline. Additionally, these challenges include the risks associated with misclassification, bias, and the creation of deepfakes. Many of these topics directly impact the human-centric nature of technology development and the intricate equilibrium between control, inclusivity, and minimising friction versus the pursuit of efficiency[73,] process optimisation, and, quite simply, technological opportunities.[74] |
| Negative impact of automation technologies on wages | In a recent comparative study exploring the connection between automation technologies and changes in employment and wages across 227 regions in 22 European countries from 1995 to 2017, the authors[75] amalgamated data from various sources to create a metric for technology adoption at both the regional and sectoral (within-region) levels. The study concluded that in specific sectors, there exists a **negative correlation between the integration of robots and wages** at the regional level: In regions that witness an employment increase, there is no significant wage variation linked to robot adoption. However, in regions specialised in services that don't experience employment growth, higher robot adoption is associated with reduced wages after a decade.[76] |

[71] Cedefop (2022). Setting Europe on course for a human digital transition: new evidence from Cedefop's second European skills and jobs survey. Luxembourg: Publications Office. Cedefop reference series; No 123, p.17

[72] Cedefop (2022). Setting Europe on course for a human digital transition: new evidence from Cedefop's second European skills and jobs survey. Luxembourg: Publications Office. Cedefop reference series; No 123, p.67.

[73] Cox, A. L., Gould, S. J., Cecchinato, M. E., Iacovides, I., & Renfree, I. (2016, May). "Design frictions for mindful interactions: The case for micro boundaries." In *Proceedings of the 2016 CHI conference extended abstracts on human factors in computing systems* (pp. 1389-1397).
For additional references, see: "Frontiers. Human-robot collaboration in industry 5.0: a human-centric AI-based approach." Retrieved from https://www.frontiersin.org/research-topics/29584/human-robot-collaboration-in-industry-50-a-human-centric-ai-based-approach#articles. and "Outlook on human-centric manufacturing towards Industry 5.0." *Journal of Manufacturing Systems*, Volume 62, January 2022, Pages 612-627. Retrieved from https://www.sciencedirect.com/science/article/abs/pii/S0278612522000164.

[74] See for instance: "Report on the key findings from the Theme Development Workshop 'AI Mitigating Bias & Disinformation' November 2022 – Executive Summary, May 18, 2022, Retrieved from: https://www.vision4ai.eu/wp-content/uploads/2023/01/Report-on-the-key-findings-from-the-Theme-Development-Workshop-_AI_-Mitigating-Bias-Disinformation.pdf

[75] Petit, F., Jaccoud, F., & Ciarli, T. (2023). *Heterogeneous Adjustments of Labor Markets to Automation Technologies*. CESifo, Munich, 2023

[76] Ibid. See also: Jurkat, A., Klump, R., and Schneider, F. (2022). *Tracking the Rise of Robots: The IFR Database*. Jahrbücher für Nationalökonomie und Statistik, 242(5-6):669–689. See also Acemoglu, D. and Restrepo, P. (2020). Robots and jobs: Evidence from US labor markets. *Journal of Political Economy*,

| Trends | Rationale |
|---|---|
| Technological sovereignty | The covid pandemic and related supply chain issues as well as a rising geopolitical rivalry between the US and China have recently emphasised considerations regarding technological sovereignty[77]. In the context of a crisis where inter-regional value-chains might be cut-off or significantly slowed down but also simply in economic terms, it is important for the EU to build up capacity in key technological fields. A recent European commission report[78] suggests that the EU should do more to secure technological sovereignty for the future, at least with regards to technologies that are expected to be high in terms of value-added. Our analysis of potentially human-centred technology production (patents) for the European market very much suggests a similar situation to be true also for this particular subset of technologies, with Chinese and US companies featuring very prominently in technology production that might facilitate human-centricity. |
| **Thriving Societal, Demographic, and Workforce Dynamics in Industry 5.0** | |
| Higher job satisfaction | Analysis from ESJS2 indicates that the majority of workers in digital jobs are highly content with their work (53%), surpassing their counterparts in less digitally intensive roles (43%) and exceeding the proportion of very satisfied technology non-users (43%). This job satisfaction premium can be attributed to the extrinsic and intrinsic job characteristics, such as reduced routinisation, heightened job-skill requirements, increased job complexity, and non-manual tasks, which render more digitally intensive jobs more appealing. |
| Productivity increase brought by technological uptake | Within the group of 'high-productivity regions,' industry-intensive regions witness the most significant rise in employment due to the integration of robots. In regions with a median change in robot penetration, which are included in the industry-intensive cluster (60%), this corresponds to a 3.1% increase in employment. Among the 'low-productivity regions,' agriculture-intensive regions benefit the most. In this agriculture-intensive cluster, the median change in robot penetration is approximately 438%, indicating a substantial 32.4% increase in employment.[79] |
| Physical and mental health and well-being of the workers | Human-centricity enabling technologies assist workers in gaining better control over and managing the risks and impact of the new working environment on their mental health and well-being. Digital solutions and wearables could create fresh avenues for notifying workers and their general practitioners about critical health conditions, both physical and mental, while also aiding workers in adopting healthy behaviours in the workplace. |
| Workers‘ rights | Human centricity enabling technologies have the potential to improve workers' fundamental rights, working conditions and overall work-life balance if well implemented. |

128(6):2188–2244.

[77] European Parliament, Directorate-General for External Policies of the Union, Raza, W., Grumiller, J., Essletzbichler, J., Pintar, N. (2021). *Post Covid-19 value chains – Options for reshoring production back to Europe in a globalised economy*, Publications Office, https://data.europa.eu/doi/10.2861/118324

[78] European Commission, Directorate-General for Research and Innovation, Di Girolamo, V., Mitra, A., Ravet, J. et al. (2023). *The global position of the EU in complex technologies*, Publications Office of the European Union.

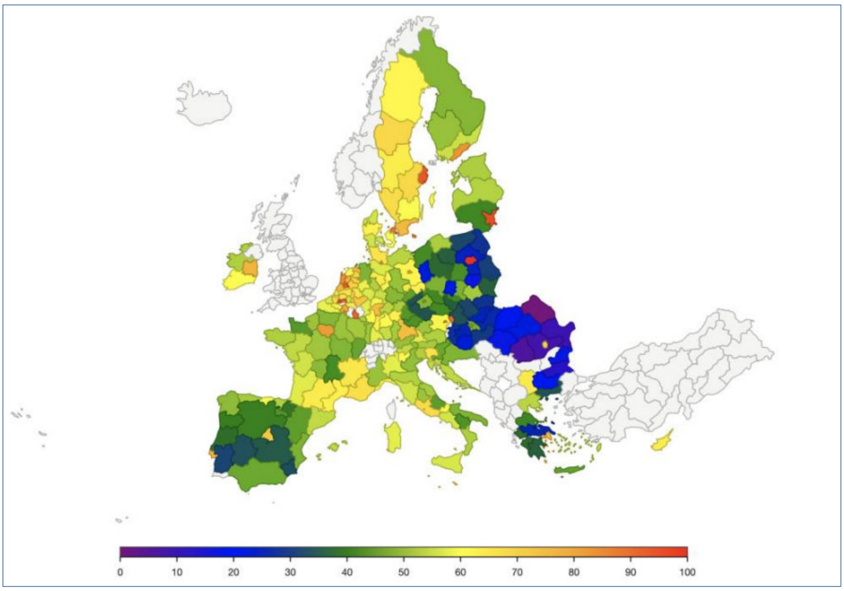
[79] Ibid.

| Trends | Rationale |
|---|---|
| Growing importance of good jobs (see Figure 2) | Following the ESIR Focus paper, Industry 4.0 and the current twin transition policies fail to put humans at the centre of the industrial transformation, while the Industry 5.0 approach places a stronger emphasis on "good jobs" since it features a human-centric, resilient and sustainable approach to industrial transformation. |

Source: Authors. A more detailed overview of trends is provided in the annex.

The projection of the future regional intensity and distribution of new high-quality jobs in the EU is provided figure below. The map locates the regions in which the technology specialisation and the presence of appropriate domain knowledge and skills create fertile grounds for creating the good jobs of the future (the higher the score, the higher the likelihood of good jobs). The map reveals, for example, the concentration of skills needed for good jobs in more developed regions (e.g., capitals). In addition, the ESIR focus paper has highlighted that complex skills tend to correlate with good jobs and excellent working conditions as they provide workers with greater leverage vis à vis their employers. Complex skills encompass complex problem-solving, judgment & decision-making, and deductive & inductive reasoning. They are also strongly associated with recognition, achievement, working conditions or independence. However, the focus paper highlights that the EU does not currently have a comprehensive strategy for the systemic transformation of the economy, which includes adequate consideration for the quantity and quality of future jobs.[80]

**Figure 21 Map of future regional intensity and distribution of new high-quality jobs in the EU (ESIR experts' own calculations)**




[80] Industry 5.0 and the Future of Work: making Europe the centre of gravity for future good-quality Jobs, ESIR Focus Paper, European Commission DG RTD, Brussels, 2023.

Source: Industry 5.0 and the Future of Work: making Europe the centre of gravity for future good-quality Jobs, ESIR Focus Paper, European Commission DG RTD, Brussels, 2023.

The shift towards Industry 5.0 necessitates comprehensive actions within the governmental and political realms. This involves adopting 'agile government' strategies, comprehending the intricate, interconnected systems of industrial ecosystems and labour markets. Furthermore, Industry 5.0 requires a deep understanding of the various policy domains in which human-centric considerations intersect with technology, such as AI, Data, and Robotics, among others.

## 5.2. European policy framework

The European Commission (EC) has articulated its vision for Industry 5.0 in a series of policy documents. The core tenet of this vision is to 'prepare and transform European industry and society'.[81] Throughout these documents, the focal points are resilience, sustainability, and principles of regenerative and circular economies, are all linked to high-level EC objectives like increased autonomy and adaptability.[82] According to the EC, 'transformation' primarily involves mainstreaming resilience, sustainability, regenerative, and circular[83] economy principles into all its policies, and their subsequent implementation, ranging from Horizon Europe to national resilience and recovery plans.

In the post-Covid era and amid the various crises currently affecting Europe and the world, the Resilience and Recovery Funds (RRF) can and should be harnessed to pave the way for change. Furthermore, 20% of the budget allocated to Member States has been designated for digitisation, with a portion of this 20% specifically aimed at the digital transformation of businesses and industries.[84]

The EC has implemented an array of policy instruments which can be linked to the advancement of Industry 5.0. This includes for example the skills agenda, the green and circular economy agenda, and the industrial strategy. Additionally, DG RTD has established a high-level expert group (ESIR)[85], an Industry 5.0 award ceremony, a community of practice, and a roundtable.[86]

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[81] European Commission, Directorate-General for Research and Innovation, Renda, A., Schwaag Serger, S., Tataj, D.et al., Industry 5.0, a transformative vision for Europe – Governing systemic transformations towards a sustainable industry, Publications Office of the European Union, 2022, https://data.europa.eu/doi/10.2777/17322

[82] Directorate-General for Research and Innovation, "Industry 5.0," Access at: https://research-and-innovation.ec.europa.eu/research-area/industrial-research-and-innovation/industry-50_en; "Industry 5.0: Towards Sustainable, Human-Centric, and Resilient European Industry," Access at: https://research-and-innovation.ec.europa.eu/knowledge-publications-tools-and-data/publications/all-publications/industry-50-towards-sustainable-human-centric-and-resilient-european-industry_en; "Enabling Technologies for Industry 5.0," Access at: https://research-and-innovation.ec.europa.eu/knowledge-publications-tools-and-data/publications/all-publications/enabling-technologies-industry-50_en

[83] European Commission. Energy, Climate change, Environment- Eco Innovation. 2023. Access at: https://ec.europa.eu/environment/ecoap/about-eco-innovation/policies-matters/quiet-process-eco-innovation-industrial-emissions- directive_en

[84] European Commission. Recovery and Resilience Scoreboard. 2023. Access at: https://ec.europa.eu/economy_finance/recovery-and-resilience-scoreboard/index.html

[85] European Commission. Research and Innovation- ESIR. 2023. Access at: https://ec.europa.eu/info/research-and-innovation/strategy/support-policy-making/support-eu-research-and-innovation-policy-making/esir_en

[86] Directorate-General for Research and Innovation, "Industry 5.0," Access at: https://research-and-innovation.ec.europa.eu/research-area/industrial-research-and-innovation/industry-50_en

When it comes to the safety and well-being of workers, the EC has developed a range of instruments, including legislation, strategies, and spending programs. Table below provides key examples of strategies, policies, studies and reports primarily relevant for fostering human-centric approaches. The development process of the roadmap on human-centric approaches to technologies and innovations in industry draws insights from these policy initiatives.

**Table 8 Selected EU-level initiatives connected to workplace safety and skills**

| Strategies/policies | Legal basis, and selected relevant policy documents | |
|---|---|---|
| • European Pillar of Social Rights<br>• European employment strategy<br>• Pact for Skills<br>• Digital Education action plan | • Directive 89/391/EEC - Framework Directive on Safety and Health at Work (Occupational safety and health (OSH) Framework Directive).<br>• Directive 89/654/EEC - Minimum safety and health requirements for the workplace<br>• Regulation (EU) 2016/425 - Personal Protective Equipment (PPE)<br>• Directive 2003/10/EC - Noise at Work<br>• Directive 2004/37/EC – Exposure to carcinogens and mutagens at work<br>• Directive 2009/104/EC - Use of Work Equipment<br>• Directive 2013/35/EU - Electromagnetic Fields Exposure at Work<br>• Directive (EU) 2019/983 - Protecting Workers from Exposure to Harmful Substances:<br>• Directive (EU) 2019/1158 - Transparent and Predictable Working Conditions<br>• Directive 2009/104/EC - Use of Work Equipment<br>• Directive 2013/35/EU - Electromagnetic Fields Exposure at Work<br>• Directive (EU) 2019/983 - Protecting Workers from Exposure to Harmful Substances:<br>• Directive (EU) 2019/1158 - Transparent and Predictable Working Conditions | • Study supporting the evaluation of the Council Recommendation of 19 December 2016 on Upskilling Pathways: New Opportunities for Adults (2022)<br>• Skills for smart industrial specialisation and digital transformation (2019) |

Source: Authors

In addition, human-centricity is directly/indirectly supported by several EU-funding programmes/policy implementation instruments. The table below provides short description of EU programmes that support human centricity.

**Table 9 Short descriptions of EU programmes supporting human centricity**

| Programme | Description |
|---|---|
| Horizon Europe | One of the expected impacts of Cluster 4 within the Horizon Europe is a human-centred and ethical development of digital and industrial technologies, through a two-way engagement in the development of technologies, empowering end-users and workers, and supporting social innovation.[87] In the Cluster 4 WP 2023-2024, the human-centred and ethical development destination is structured into seven areas: a) leadership in AI based on Trust; b) an Internet of trust; c) extended reality; d) systemic approaches to make the most of the technologies within society and industry; e) digital Humanism and human compatible technologies; f) European standards for industrial competitiveness; g) international cooperation.<br>In addition, within the Horizon Europe pillar III, the European Institute of Innovation and Technology (EIT) supports human-centricity. EIT Knowledge and Innovation Community (KIC) Digital and Manufacturing are relevant. For example, the DE4HUMAN project coordinated by EIT Manufacturing provides training to help enhance human-centric factories by leveraging traditional manufacturing and digital methods. It teaches design through the three pillars of Design4Empower, Design4Safety and Design4Inclusivity. It provides modular learning for up-skilling EU SMEs in manufacturing and engineering.[88]<br>In addition, the EIT is managing the Deep Tech Talent initiative that offers courses and funding to develop and scale up new or existing curricula in deep tech (including technologies relevant for Industry 5.0 and related to human-centricity).[89] |
| Digital Europe Programme | Following the Work Programme for 2021-2022, the Digital Europe Programme (DEP) aimed to develop an European human-centred AI-solutions as well as promote the deployment of key digital technologies with respect for Union values, and from a human-centric perspective.[90] In addition, the testing and experimentation facilities (TEFs) established under DEP offer a combination of physical and virtual facilities, in which technology providers can get primarily technical support to test their latest AI-based software and hardware technologies (including AI-powered robotics) in real-world environments.[91] However, it should be noted that human-centricity is not mentioned as one of the TEF's objectives. |
| Erasmus + | The Erasmus + programme through its broad lifelong learning dimension and cross-disciplinary collaborative approaches across the sectors aims to contribute to equipping Europeans with the necessary skills and developing innovative practices in relation to the New European Bauhaus with the ambition to help make the Green Deal a cultural, human-centred positive and tangible experience.[92] One of the project funded by Erasmus+, BuTH-AI, Building Trust in Human-Centric Artificial Intelligence, offers education modules on the use of AI and practical considerations for data protection, cybersecurity, and ethical principles and the European Union's Human-Centric Approach to AI. |
| European Social Fund+ (ESF+) | While ESF+ does not directly support human-centricity, one of its key objectives is to support the implementation of the European Pillar of Social Rights.[93] The 20 principles of the Pillar of Social Rights encompass fair working conditions, equal |

[87] Horizon Europe, Cluster 4 Work Programme for 2023-2024, https://research-and-innovation.ec.europa.eu/funding/funding-opportunities/funding-programmes-and-open-calls/horizon-europe/cluster-4-digital-industry-and-space_en
[88] Internet source: https://www.eitmanufacturing.eu/news-events/activities/de4human-project/
[89] See: https://www.eitdeeptechtalent.eu/
[90] DIGITAL Europe Work Programme 2021-2022
[91] See: https://digital-strategy.ec.europa.eu/en/faqs/testing-and-experimentation-facilities-tefs-questions-and-answers
[92] Erasmus + annual work programme 2023
[93] See: https://ec.europa.eu/social/main.jsp?catId=1226&langId=en

| Programme | Description |
|---|---|
| | opportunities and access to the labour market and social protection and inclusion, all of which are important for enabling Industry 5.0 and human-centricity[94]<br>In addition, through the strand of EU Programme for Employment and Social Innovation (EaSI), ESF+ can support the development of adequate social protection systems and labour market policies.[95] |
| European Globalisation Adjustment Fund (EGF) | EGF does not directly address human-centricity, however, it can be used to co-finance measures related to career advice, finding a job, education, training and re-training, mentoring and coaching, entrepreneurship and business creation.[96] |

Source: Authors

The policy framework supporting the development of HC focused technologies and organisations remains incomplete. What seems to be missing is a comprehensive strategy for systematically transforming the economy, which should encompass a thorough consideration of both the quantity and quality of future jobs[97].

The table below offers an overview of the current strategies, policy priorities, and key strategic documents at the EU level connected to HC approaches to technology development and adoption.

**Table 10 Selected strategies, policy priorities, and key strategic documents at EU level**

| Strategies/policies | Legislation, work programmes, and other strategic documents or programmes supporting HCT | Studies, reports, staff working documents, and other relevant policy documents |
|---|---|---|
| • The New European Innovation Agenda<br>• European Research Area Strategy and ERA policy agenda 2022-2024<br>• EU industrial strategy<br>• Industrial ecosystems<br>• Digital Decade<br>• Data Strategy<br>• European Green Deal<br>• European AI Strategy | • Horizon Europe Regulation and selected work programmes<br>• Digital Europe Regulation and selected work programmes<br>• Council Regulation establishing European partnerships. Key HCT related partnerships include Made in Europe and ADRA<br>• RRF and ERDF operational programmes, smart specialisation strategy and related documents<br>• ERA Industrial Technology Roadmaps<br>• AI Act<br>• Net Zero Industry Act<br>• Data Governance Act, Data Act and Digital Markets Act | • Industry 5.0 and the future of work – Making Europe the centre of gravity for future good-quality jobs, 2023<br>• DG RTD, Industry 5.0, a transformative vision for Europe – Governing systemic transformations towards a sustainable industry 2021<br>• DG RTD, Industry 5.0 – Towards a sustainable, human-centric and resilient European industry (2021)<br>• Enabling Technologies for Industry 5.0 – Results of a workshop with Europe's technology leaders, 2020 |

Source: Authors

[94] European pillar of social rights: From principles to Action for a strong Social Europe. Internet source: file:///Users/orestasstrauka/Downloads/Pillar_factsheet_nov_EN_2023-11-20.pdf
[95] See: https://ec.europa.eu/social/main.jsp?catId=1081
[96] See: https://ec.europa.eu/social/main.jsp?catId=326
[97] ibid, ESIR, 2023

## 5.3. The role of standardisation

Besides the EU-level initiatives, there are notable advancements at the private sector level. It is worth noting that various technical standards and certification schemes exist to support industries in their transition towards becoming human-centred organisations and to embrace the opportunities presented by advanced technologies.

Standardisation can play a crucial role in pursuing Industry 5.0 objectives as it establishes a framework for organisations to follow common practices, thereby ensuring quality, safety, and work efficiency. Although standards are not legally binding regulations, they function as a form of self-regulation, encouraging the adoption of best practices, driving innovation, and enhancing competitiveness in the market.

**Table 11 Relevant standards related to human-centricity at organisational or technology level**

| Standards related to human centricity | Standards, technical reports, technical specifications on ergonomics | Standards related to aspects of human centricity in specific technologies |
|---|---|---|
| • Ergonomics of human-system interaction — Part 210: Human-centred design for interactive systems<br>• Ergonomics of human-system interaction — Part 220: Processes for enabling, executing and assessing human-centred design within organisations<br>• The human-centred organisation — Guidance for managers<br>• Guidance on human aspects of dependability<br>• Corporate governance of information technology<br>• Human resource management — Learning and development<br>• Systems and software engineering — System life cycle processes<br>• Systems and software engineering — Systems and software Quality Requirements and Evaluation (Square) — Guide to SQuaRE<br>• Information technology — Process assessment — Part 5: An exemplar software life cycle process assessment model<br>• IEEE P70xx series | • Software ergonomics for multimedia user interfaces<br>• Ergonomic design of control centres<br>• Ergonomic requirements for the design of displays and control actuators<br>• Ergonomics of human-system interaction - Usability methods supporting human-centred design<br>• Ergonomics of human-system interaction — Specification for the process assessment of human-system issues<br>• Ergonomics — General approach, principles and concepts<br>• Ergonomics of human-system interaction - Auditing procedure for the development of interactive products based on DIN EN ISO 9241-210<br>• Resource-saving application of methods and tools for the anthropocentric design of effective interactive IT systems<br>• Ergonomics of human-system interaction – Part 820: Ergonomic guidance on interactions in immersive environments including augmented reality, and virtual reality | • Artificial intelligence — Overview of trustworthiness in artificial intelligence<br>• Artificial intelligence — Overview of ethical and societal concerns<br>• Common Industry Format for usability (CIF) - General framework for usability-related information<br>• Common Industry Format (CIF) for usability test reports<br>• Common Industry Format for Usability (CIF): Context of use description<br>• Common Industry Format for Usability (CIF): User needs report<br>• Common Industry Format for Usability (CIF): User requirements specification<br>• Common Industry Format for Usability (CIF): Evaluation report<br>• Software ergonomics for multimedia user interfaces — Part 1: Design principles and framework, Part 2: Multimedia navigation and control, Part 3: Media selection and combination<br>• Robots and robotic devices — Safety requirements for industrial robots — Part 1: Robots; Part 2: Robot systems and integration<br>• Robots and robotic devices — Collaborative robots |

Source: Authors

Companies are equally supported through a range of certificates as exemplified in the table below.

**Table 12 Certificates related to human-centred technologies**

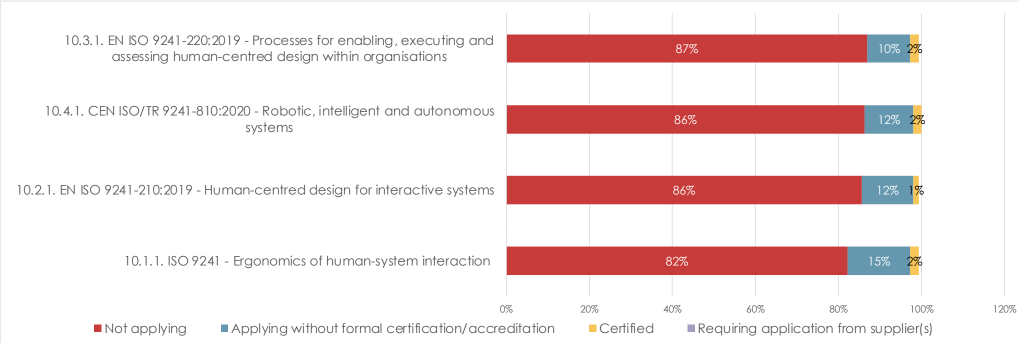
| Certificate | Description |
|---|---|
| Certified Tester Test Automation Engineer (CT-TAE) | Test automation is a pivotal element within the framework of Industry 5.0, where the integration of advanced technologies necessitates thorough testing. CT-TAE certification assures that professionals possess the expertise required to design, implement, and maintain automated testing processes. This ensures the reliability and performance of Industry 5.0 systems. |
| CPUX | The Certified Professional for Usability and User Experience (CPUX) certification holds great significance in the context of Industry 5.0 due to its emphasis on usability and user experience design. In this domain, where human-centric technologies prevail, it is imperative to ensure that these technologies are intuitive, user-friendly, and responsive to user needs to ensure a successful implementation. |
| Ergonorm | This certification centres on ergonomics, the science behind designing work environments, equipment, and systems to optimise human well-being and performance. In Industry 5.0, where human-machine collaboration takes centre stage, ergonomics ensures that workstations, interfaces, and automation systems are designed to enhance worker safety, comfort, and productivity. |
| IOT devices certification by TÜV | TÜV (Technischer Überwachungsverein) certification for IoT devices holds a critical role in Industry 5.0. As IoT devices are integral for data collection and automation in this context, such certification becomes paramount in guaranteeing the reliability and security of these devices. |
| LUMA Human-Centred Design (HCD) Practitioner Certification | LUMA certification equips professionals with the skills required to develop products and systems that prioritise user needs. This makes it a valuable certification for individuals involved in the design and implementation of human-centric technologies within the Industry 5.0 framework. |

Source: Authors

In general, the overview of existing standards and certificates highlights the extensive range and depth of standards related to human-centricity that should be taken into account during the development of Industry 5.0. These principles encompass human-centric design practices, ergonomic standards for ensuring workplace safety, and ethical standards governing technology development and usage, all with the ultimate goal of improving well-being and prosperity. Given the diverse technologies associated to Industry 5.0, including robotics and AI, context-specific human-centric standards will provide valuable insights for its successful implementation.

As reported from the survey carried out in the context of this study and showcased in figure below, **the level of uptake of human-centric related standards is currently very low**. More than 80% of the surveyed companies are not applying any human centric standards. When asked on other ISOs adopted, we found that 10% of the companies were applying Quality management systems (ISO 9001) and Environmental management (ISO 14000) standards.

**Figure 22 Usage of human centric related certifications**




Source: Authors based on survey question 10: Is your organisation applying a dedicated standard? (N =147)

The interviews conducted for this study complement the survey results on standards and certifications. In general, interviewees identified that currently there is insufficient utilisation of certificates, some industry players note the absence of relevant standards and there is an overall lack of awareness about standards related to HC. For example, while exoskeletons are addressed by European directives, such as the Machinery Directive and the Medical Device Regulation, the directives do not provide precise guidelines mitigating risks associated with the use of exoskeletons[98]. In addition, despite attempts in the US, Germany, and France to establish standardised protocols for exoskeletons, interviewees highlighted that there is a growing fragmentation at the global level.[99]

While each technological domain poses unique challenges related to standards, the interviewed industry representatives expressed the need for more precise and updated regulations and certifications rather than adopting new ones. Many existing standards were deemed inadequate for advanced manufacturing and human-centric technologies.[100]

## 5.4. Gap analysis towards human-centric design, deployment and adoption of technologies

Continuing the assessment of technology adoption as an opportunity for a more human-centric industry, we evaluate the barriers and drivers influencing the human-centric design, as well as deployment and adoption of technologies in a human-centric manner. To provide a comprehensive overview of the identified challenges across the study, key barriers preventing and drivers fostering the uptake of human centric solutions, are summarised in the following table.

**Table 13 Barriers to human-centric technology design, deployment, and adoption**

| Challenge/barrier/driver | Description |
|---|---|
| | **Technology development/design phase** |
| Multidisciplinary approach | Difficulty in adopting a multidisciplinary approach is a major challenge. Human-centric technologies (HCT) require a deep understanding of |

[98] Relevance of hazards in exoskeleton applications: a survey-based enquiry, *Journal of NeuroEngineering and Rehabilitation,* 2023.
[99] Interviews conducted between 16-10-2023 and 3-11-2023.
[100] Interviews conducted between 16-10-2023 and 3-11-2023.

| Challenge/barrier/driver | Description |
|---|---|
| | human behaviours, ergonomics, cognitive processes, and the socio-cultural dimensions of the manufacturing workforce. Multidisciplinary collaborations pose challenges in terms of resources, communication, alignment of objectives, and the integration of distinct perspectives into a cohesive design. |
| Lack of synergies / alignment between practical guidelines and standards | Lack of synergies and alignment between practical guidelines for businesses to design and develop human-centric technologies is a significant challenge. Additionally, there is a need for novel safety, ethical, and security standards. |
| Customisation and complex design process | As reported in previous section, human centricity very often means "not off the shelf" technologies. High customisation increases the complexity of the design process, which often requires adapting technology to the specific needs of each client. The tailoring needs of human-centred design is very often resource-intensive both at the design and adoption phase. |
| **Technology adoption/implementation phase** | |
| Understanding of business case and return on investment | Managers often struggle to recognise the long-term potential of enabling technologies that may enable human-centric outcomes, some without a compelling business case. This can lead them to favour fully automated technologies, which are traditionally viewed as more cost-effective. Technology adoption challenges frequently revolve around investment priorities, with many decisions prioritising cost over human-centric design processes and active worker involvement. |
| Multidisciplinary needs and responsibility distribution | Multidisciplinary requirements in the deployment of human-centric solutions complicate their implementation. Determining responsibility for this implementation, whether it falls on the HR department, management, or the tool provider, can be challenging. |
| Skilled workforce attraction | Attracting a skilled workforce is a challenge. Specific attention should be given the key skills for the future of manufacturing. For example, digital literacy as a holistic skill to interact with, ability to use and design new AI and data analytics solutions while critically interpreting results, creative problem solving in times of abundant data and technological opportunities in smart manufacturing systems, open-mindedness towards constant change, and transformation skills that constantly question the status quo and initiate knowledge transfer from other domains. |
| Interoperability with existing technologies and processes | Ensuring the harmonious integration of modern technology with existing infrastructure remains a critical concern. |
| Scaling up human-centric initiatives | Scaling up human-centric initiatives often necessitates additional resources, including personnel, funding, and time. This can strain existing budgets and workloads. Scaling human-centred design processes also requires a robust and scalable IT infrastructure. |
| GDPR and data privacy concerns | GDPR and data privacy concerns are intricately linked to data collection and processing associated with human-centric technologies. These concerns pose challenges during both the technology design and deployment phases. Workers' concerns have been highlighted in interviews and in the findings of the H2020 project HUMAN[101] (INT2). |

[101]Sobah Abbas Petersen, Felix Mannhardt, Manuel Oliveira, Hans Torvatn. A Framework to Navigate the Privacy Trade-offs for Human-Centred Manufacturing. 19th Working Conference on Virtual Enterprises (PRO-VE), Sep 2018, Cardiff, United Kingdom. pp.85-97, 10.1007/978-3-319-99127-6_8. hal-02191193

| Challenge/barrier/driver | Description |
|---|---|
| | Manufacturers must ensure compliance with external regulations and integrate these technologies in line with their internal standards.<br>In the context of extensive data collection by technologies, privacy concerns were also identified as a challenge by interviewees. Interviewees mentioned that there are no ethical guidelines regarding technologies such as exoskeletons or collaborative robotics that collect sensitive information (employees' body functions). Another example highlighted by interviewee is the data collection by cameras that are monitoring employee movement. While the initial objective of the camaras is to facilitate cobot implementation, they often raise data privacy concerns. Resolving data privacy issues, ensuring compliance with GDPR, was argued by interviewees to be crucial element for gaining workers' trust and technology acceptance. One way to mitigate the challenge is to foster dialogue between management, technology providers, workers and worker representatives to achieve better understanding of the technology and its implications. |
| Cultural resistance | Cultural resistance is a palpable challenge in introducing any advanced manufacturing technologies in the manufacturing sector. Many employees perceive them as akin to automation tools that might replace human roles. This perception is rooted in the broader narrative of automation leading to job losses, even though human-centric technologies aim to enhance, rather than replace, human capabilities. Clear communication and education are crucial to address this misperception. |
| Organisational readiness for change | Organisational readiness for change, including aspects such as structure, processes, and investments, is crucial for successful human-centric transformations. |
| Managerial skills gap | The lack of managerial skills to lead human-centric initiatives is critical for the successful implementation of HC approaches to technologies and organisational change. |
| Keeping up with technological innovations in education | Adapting to technological innovations and translating them into new skills is a challenge for educators. Firstly, there is currently no taxonomy of human-centric skills. Secondly, this adaptation within educational organisations can be a drawn-out process, primarily because it necessitates the re-skilling of staff members before curricula can be updated. |
| Accreditation challenges | There is a notable absence of standardised accreditations tailored for blue-collar workers, exacerbated by company owners' hesitancy to invest in providing their employees with formal courses. |

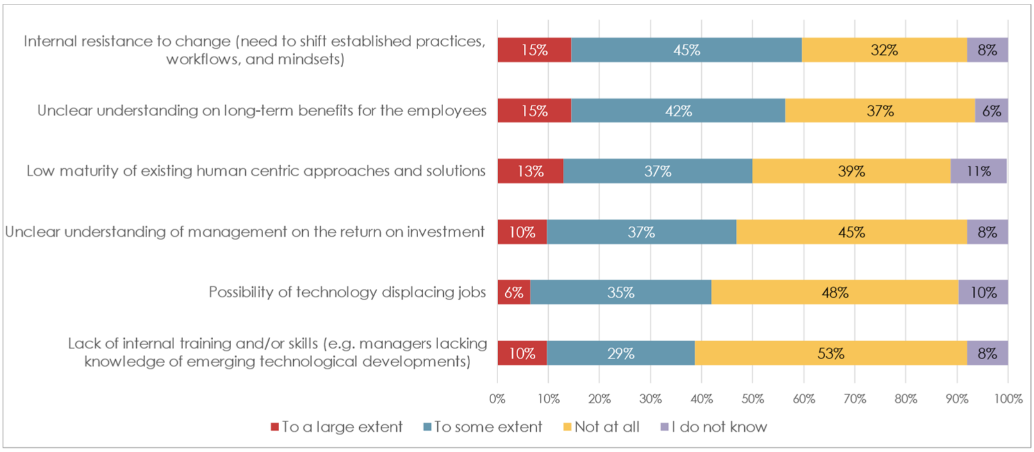
Source: Authors

When asked about the challenges hindering the uptake of human centric technologies, the **primary issue reported by the surveyed companies was the lack of clarity regarding the long-term benefits for employees**. Of the respondents, 14.5% acknowledged this obstacle to a large extent, while 41.9% indicated its importance only to some extent. Similarly, internal resistance to change, encompassing the necessity to shift established practices, workflows, and mindsets, was identified as a significant hurdle by 14.5% of respondents to a large extent.

Furthermore, the low maturity of existing human-centric approaches and solutions was cited by 37.1% of companies as a challenge. A lack of internal training and skills, specifically managers' understanding of emerging technologies, was noted by 53.2% of respondents to some extent as an obstacle. Equally, unclear management understanding of the return on investment from these technologies was seen as a challenge by 45.2% of participants.

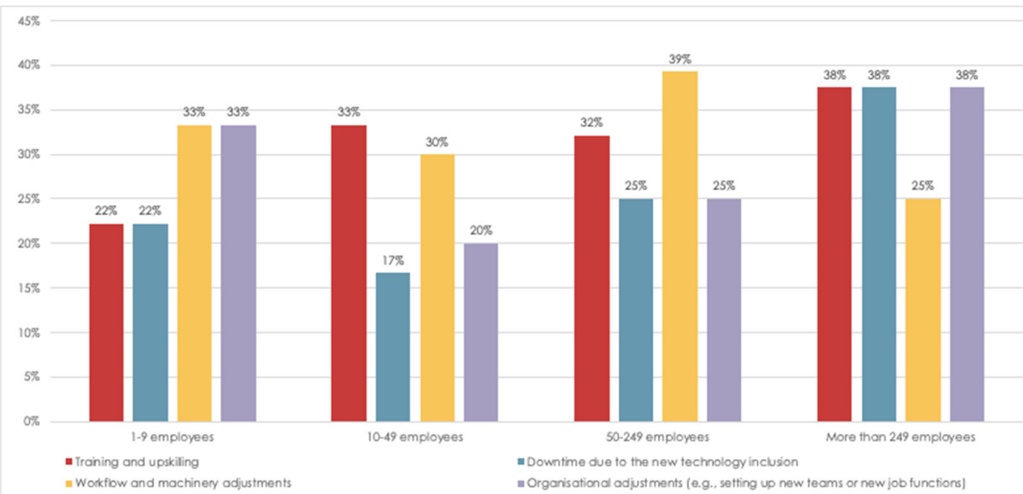
The concern about technology displacing jobs was the least indicated challenge, yet 35.5% still saw it as a potential issue to some extent. These factors illustrate the complexity of integrating human-centric technology within organisational structures and the importance of addressing both cultural and educational components to facilitate adoption.

**Figure 23 Challenges encountered by companies adopting technologies considering human-centric aspects**




Source: Authors based on survey question 25: Since you have indicated to have invested in technologies considering human-centric aspects, could you please indicate the extent to which the following factors challenged the implementation of a human-centric approach in your production processes? (N=62)

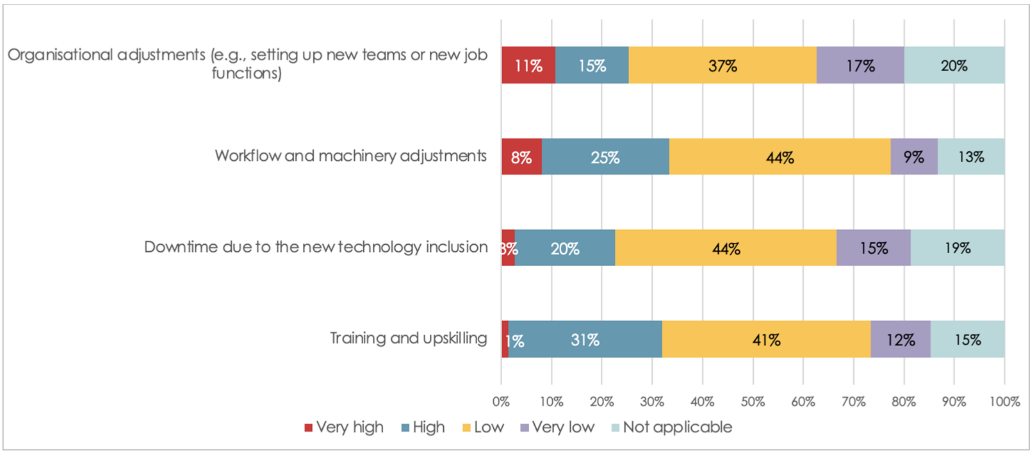
**Figure 24 Technology implementation costs for surveyed organisations**




Source: Authors based on survey question 24: Based on your experience, how costly was the implementation of human-centred technology within your organisation on the following aspects? (N=75)

Organisations also reported that the most significant costs associated with implementing technologies were incurred in workflow and machinery adjustments. This was particularly the case in larger companies, with those having 50-249 employees and more than 249 employees indicating 25.6% and 21.4% respectively as having high costs in this area. Training and upskilling also represented a notable expense, especially in firms with 10-49 employees, where 20.9% identified it as a costly aspect. Downtime due to new technology integration and organisational adjustments, such as setting up new teams or job functions, were also identified as significant cost factors across different company sizes.

**Figure 25 Implementation costs of manufacturing technologies**

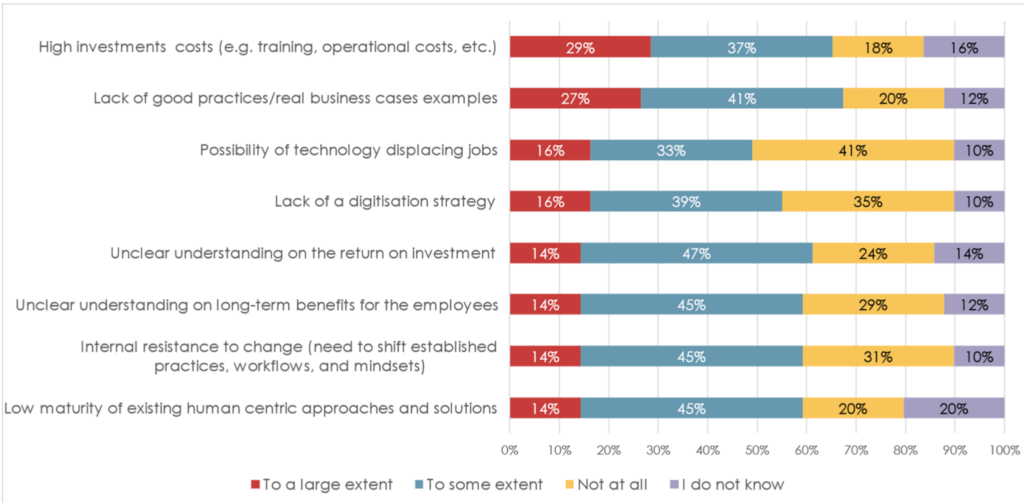



Source: Authors based on survey question 24: Based on your experience, how costly was the implementation of human-centred technology within your organisation on the following aspects: training and upskilling, workflow and machinery adjustments, downtime due to the new technology inclusion and organisational adjustments (e.g. setting up new teams or new job functions)?

For companies that have not yet invested in manufacturing technologies, high investment costs were identified as a prominent barrier, with almost one-third acknowledging this challenge to a large extent. Consistent with findings from interviews and desk research, the concern about high costs was followed by the lack of good practices or real business cases, identified as a challenge by 68% of respondents to some extent or to a large extent. Interestingly, the lack of a digitisation strategy was a concern for 39% of non-investing companies, while internal resistance to change was less of a barrier compared to investing companies, where 45% considered it to some extent as a challenge.

The potential of technology displacing jobs, although a concern for both groups, seems to be less of a barrier for companies that have not yet invested in technologies considering human-centric approaches (33%) compared to the 35.5% of companies that have adopted technologies considering human-centric aspects. Overall, while both investing and non-investing companies share concerns about the maturity of human-centric approaches and the clarity of ROI, cost factors appear more hindering for companies yet to make an investment.

**Figure 26 Challenges encountered by companies not yet having taken up manufacturing technologies**




Source: Authors based on survey question 26: Since you have indicated to have invested in technologies considering human-centric aspects, could you please indicate the extent to which the following factors challenged the implementation of a human-centric approach in your production processes? (N=62)

## 5.5. Gap analysis for improving the ecosystem for human-centric organisational innovation

Enhancing human-centric organisational innovation requires implementing supportive regulatory frameworks, promoting education and awareness, offering funding and incentives, establishing industry-specific standards, and fostering collaboration platforms to facilitate cooperation among various stakeholders.

We categorise the main ecosystem actors which have a strong impact on the development and adoption of HC practices on the organisational level into six groups:

- **Intermediaries** such as research institutes, universities and other organisations offering learning opportunities. These actors can establish research centres in which experts from different disciplines come together and create innovative solutions. They can also define and offer educational, internship and training programmes for students and industry professionals to develop knowledge and skills required for HC practices in manufacturing. Especially for skills development, these study programs should cover principle and methodologies (e.g., VU Design Thinking: Ideation, from master program of media and human centred computing at TU Wien).[102]

- **Niches and solutions of innovative business models** such as start-ups, consultancy and advisory service providers. These actors can develop HC design frameworks that guide organisations in creating products and workplaces that put the needs and wellbeing of employees at the centre. Furthermore, they could

[102] 187.B09 Design Thinking: Ideation | TU Wien

provide digital platforms for training with regards to special needs of manufacturing workers. For instance, EDIH AI5 Production workshops conducted by AIT provided a platform for discussing current topics and gaining a better understanding of the opportunities and risks of AI in production).[103]

- **Associations and infrastructures** such as living labs, social partners and key stakeholder associations. These ecosystem actors can provide digital platforms for gathering employees feedback about the working conditions, personal development and safety concerns. For example, the KTH Live-In Lab was created as a co-creative open platform to facilitate the adoption of innovative technologies for more sustainable building [104]. Further, by establishing HC design labs, they can adapt to design and deployment of HC technologies, making the collaboration among different people more engaging and effective.

- **Certification, verification and standardisation bodies**: These ecosystem enablers can offer tools and services to assess workplace HC to improve employee comfort and well-being. Further, to ensure compliance with HC regulations and standards, HC metrics, KPIs and maturity model can be defined and promoted to facilitate the monitoring of HC implementation.

- **Public programmes and funding agencies:** These actors can offer research and development grants, technology adoption grant, worker well-being initiatives to support the implementation of HC practices and technologies. Especially, financial support for SMEs that may require additional resource and technological investments. Further by providing network of excellence, they can encourage international and domestic collaboration between manufacturers, labour unions, research institutes and governmental bodies. To acquire skills required for Eco-design and HCD, these enablers can offer scholarships and grant to students or workers for pursuing related high quality educational programs.

- **Industry actors such as technology innovators, employers, investors and collaborators:** These actors can establish mechanisms for feedback and suggestions for regularly improvement of work and worker conditions. Further by offering programmes that support the physical and emotional well-being of workers. To foster a range of HC skills, increasing team diversity and building task forces consisting of developers, engineers, marketing experts and designers could be helpful.

In general, several measures can be highlighted for creating the connections and networks within the HCT ecosystem.

First, the collaborative EU-funded research and innovation projects strengthen the ecosystem for technology development with human-centric approaches and foster innovation. Projects such as DIY4U, iPRODUCE, OPEN!NEXT and INEDIT have built tools fostering collaboration with manufacturers of detergent and furniture. The tools involve the customer in the product design process. For example, the INEDIT project to facilitate collaboration on furniture design developed the DesignTogether platform. The platform

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[103] Industrie 5.0 und menschzentrierte Produktion | AI5Production 187.B09 Design Thinking: Ideation | TU Wien

Molinari, M., Vogel, J. A., Rolando, D., & Lundqvist, P. (2023). Using living labs to tackle innovation bottlenecks: the KTH Live-In Lab case study. Applied Energy, 338, 120877.

includes a website, mobile and immersive virtual reality app that foster co-creation. Another example is provided by the Horizon 2020 project iPRODUCE - “A Social Manufacturing Framework for Streamlined Multi-stakeholder Open Innovation Missions in Consumer Goods Sectors”. The project has developed a social manufacturing platform to enable multi-stakeholder interaction and collaboration to support user-driven open-innovation and co-creation. The social manufacturing platform involves manufacturing companies, their associations/ networks, Fablabs/ makers spaces, DIY communities and other innovation players at the local level. To reduce costs for SMEs and bring products to market faster OPEN!NEXT project has developed open-source hardware designs. Insights from the Beyond 4.0 project also highlight how advanced manufacturing technologies necessitate organisational changes such as multidisciplinary, worker empowerment and co-creation processes something that was also highlighted through interviews conducted in the scope of this study.[105]

The second measure that fosters the HCT ecosystem is **teaching methods based on knowledge triangle integration, involving representatives from education, industry and research fields**. For example, the Teaching Factory concept follows a two-way knowledge transfer channel (from academia to industry and from industry to academia), where manufacturing topics are the basis for new synergy models between academia and industry. The concept has been developed through European funded projects such as the Knowledge Alliance project KNOW-FACT.

Third, the HCT ecosystem can be fostered by the **Network Intelligence framework** which is a structured methodology designed to enhance entrepreneurial talent by leveraging the potential of interconnected ecosystems. Key components include the Network IQ Index, a metric used to measure the strategic networking capabilities of individuals or groups, and the Purpose-Network Fit model, which optimises existing networks and facilitates the construction of new networks crucial for entrepreneurial growth. This framework, exemplified by initiatives like the Network Intelligence Academy, emphasises the importance of networks in driving innovation, collaboration, and business growth within industrial ecosystems. The Network Intelligence Academy's insights, as highlighted by EntreUnity's findings, showcase how the Network Intelligence framework shapes industrial ecosystems. Academy’s alumni transitioned from academia to business, fostering partnerships, securing funding, and advocating crucial Sustainable Development Goals (SDGs). The example of the Network Intelligence Academy emphasises the significance of harnessing networks within ecosystems for innovation, collaboration, and resource-sharing.[106]

Finally, **skills intelligence** can be highlighted as an important measure to foster the HCT ecosystem. For instance, in the article *Skills Intelligence in the Steel Sector,* the framework of skills intelligence in the steel sector is presented reflecting the theoretical developments and the application of tools in the European projects BEYOND 4.0 and ESSA. The main findings suggest that skills intelligence in the steel sector is **not limited to the preparation and presentation of data but also creating governance structure to mitigate skills imbalances**. The authors argue that the concept of skills intelligence provides the foundation for identifying and tailoring skills to the needs of the sector. [107]

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[105] Why Do Employees Participate in Innovations? Skills and Organizational Design Issues and the Ongoing Technological Transformation, Nathalie Greenan and Silvia Napolitano, 2021
[106] Industry 5.0 and the Future of Work: making Europe the centre of gravity for future good-quality jobs ESIR Focus paper, 2023
[107] Skills Intelligence in the Steel Sector Karina Maldonado-Mariscal , Mathias Cuypers , Adrian Götting and Michael Kohlgrüber, 2022

# 6. Policy recommendations

As European economies embark on their transition towards Industry 5.0, policymakers must prioritise technology as a means to achieve societal objectives that go beyond mere efficiency. These objectives include employees' well-being, economical, societal, and environmental aspects.

Effectively addressing key societal, demographic, and governance trends is imperative to centre employees', societal and environmental wellbeing. The vision of the roadmap is to establish sustainable, resilient, human centric, and competitive industry and society with the help of human-centric approaches to technologies and organisational practices. The actions proposed are meant for implementation with a horizon towards 2030.

The concept of human-centricity adopted is based on a holistic approach that extends beyond the traditional focus on designing user-friendly interfaces for digital technologies. While ergonomics, safety, and task completion remain essential aspects of human-centricity, the broader perspective includes the multifaceted interactions between humans, technology, society and the environment. The used concept of human-centricity recognises that the impact of technology extends beyond improving user experience, but also permeates ethics, employee well-being, human-machine collaboration, organisational transformation, and the interplay between economy and ecology. Human-centricity involving broader systemic dynamics fosters organisational and social innovation, promotes co-creation, and drives the adoption of new industrial practices, technological advancements and business models that also focuses on social and environmental aspects.

However, according to the ecosystem mapping and the survey of manufacturing companies, it is important to highlight that within the ecosystem surrounding technologies relevant to human-centricity, a **broadening and upgrade of human-centric design concepts and practices are needed to include more purpose-driven and systemic design considerations**. To operationalise this vision, the European Commission could consider implementing public measures to support R&I efforts of companies that promote human centricity and stimulate demand for HC throughout the entire ecosystem, including employees, customers, and the public.

Investing in and conducting R&D, in conjunction with considerations for non-technological, organisational, and economic aspects, facilitate the advancement and adoption of technologies enabling human-centric manufacturing. Consulted stakeholders believe that policymakers should play a more active role in **advancing the development of technologies with human-centric approaches**. They argue for a comprehensive effort to **promote, implement, and support human-centricity at the organisational level**. This approach focuses on improving organisational effectiveness by, for instance, emphasising essential skills, cultivating a forward-thinking mindset, and involving employees in decision-making. This shift could also involve the labour unions in future projects, demonstrating a move towards more inclusive governance.

Additionally, consulted stakeholders indicate that policymakers are well-placed to introduce measures that allow companies to demonstrate the economic benefits of prioritising employee engagement and well-being over the short, medium, and long terms. Policymakers are also well-placed to initiate a European-wide initiative in which leading Member States could share good practices with counterparts across the Union. This would promote a Union-wide exchange of knowledge, innovation, and expertise. By collectively supporting this multifaceted initiative, the European Commission could take on a role of not just as a facilitator, but as a driving force fostering the evolution of technologies and organisational practices into a crucial foundation of a thriving, interconnected ecosystem favouring human-centricity.

**Table 14 Summary of policy recommendations**

| Action line | Actions | Key stakeholders |
|---|---|---|
| **Education and training** | | |
| Provide appropriate (certified) training to mitigate skills shortages and mismatches | Develop foresight capabilities to identify skills and employee needs related to purpose-driven, human-centric technology development and adoption<br><br>Collaborate with associations and companies to establish a skillset taxonomy for purpose-driven & human-centric (HC) technology adoption | EU and MS policy makers, Research and education |
| | Create multidisciplinary, agile and distributed training programmes to foster HC and systemic design skill development | Research and education |
| | Advocate for flexible regulatory frameworks to support funding and accreditation of innovative non-standard educational programmes | EU and MS policy makers, Research and education |
| **Establishing platforms, infrastructures and interlinkages in the ecosystem** | | |
| Facilitate knowledge exchange and dissemination between ecosystem enablers and actors | Establish European platform / observatory to monitor education-related actions, initiatives, offerings, impact assessments and related KPIs in the field of purpose-driven, human-centric and systemic design of technologies, while at the same time avoid duplication and promote synergy with existing platforms | EU and MS policy makers, ecosystem |
| | Encourage open innovation orchestrators like DIHs to develop open social innovation approaches[108] for the adoption of technologies and practices that promote Industry 5.0 human-centric and sustainability goals, as well as for lifelong learning. This would also include skills training programmes encompassing human-centric and systemic design approaches that can be applied to technology and organisational practices; engaging industry, R&I actors, education, fablabs, DIHs and the community<br><br>Leverage Digital Innovation Hubs (DIHs) and related centres of competences in bolstering companies' adoption of HC practices via coaching, awareness raising building networks/connections | EU and MS policymaker, ecosystem |

[108] Gegenhuber, Thomas, and Johanna Mair. "Open social innovation: taking stock and moving forward." *Industry and Innovation* (2023): 1-28.

| Action line | Actions | Key stakeholders |
|---|---|---|
| | with educational actors | |
| | Strengthen knowledge and experience exchange between research and industry with practical field training or internships in industrial organisations | EU and MS policymaker, Research and education, industry |
| | Foster collaboration between SSH (Social Sciences and Humanities) and HC approaches to technology-related engineering | EU, MS policy makers, SSH researchers |
| Create testing facilities and shared infrastructure | Develop synergies and enhance awareness of Testing and Experimentation Facilities and/or EDIHs (European Digital Innovation Hub) under Digital Europe Programme as a valuable testing ground for activities promoting human-centric and systemic approaches to technology development<br><br>Utilise Europe's extensive fablabs and Makerspaces network for prototyping, testing and replicating training programmes and providing necessary infrastructure to broaden the adoption of human-centric approaches to technology and organisational practices across the different communities and manufacturing actors | Labour and employer's associations, EU and MS policymaker |
| | Develop and use demonstrators and "sandboxes"[109] (i.e., specific technical environments for development teams) for human-centric and purpose-driven technology development experiments and dialogues at the organisational level | HCT ecosystem<br><br>Research and Education, Industry |
| **Organisational environment** | | |
| Integrate HC in certifications and standards for business to design and develop human centric enabling technologies and practices | Align and promote existing -related standards and certifications addressing human centric aspects in technologies and organisations<br><br>Create a certification for maturity of HC in the Industry 5.0 organisation | EU, MS, Industry, Standardisation and Certification Organisations |
| | Integrate HC standardisation and certification into educational programmes and offer internal training to managers and employees on how to use HC standards | Research and Education, industry |
| | Integrate HC in corporate reporting | EU, MS, Research, Industry |

[109] According to EPRS Briefing on Artificial Intelligence Act and Regulatory Sandboxes, Sandboxes generally refer to regulatory tools allowing businesses to test and experiment with new and innovative products, services or businesses under supervision of a regulator for a limited period of time. Another example of sandbox is provided by Agile Data on Development Sandboxes: An Agile Core Practice.

| Action line | Actions | Key stakeholders |
|---|---|---|
| Provide guidance for organisations for integrating HC in their practices, especially in the design and technology development | Provide guidance and toolkits on HC approaches to technologies and organisations such as pilot industry 5.0 compass/self-assessment tool following the maturity model towards human centric approaches, that also includes a set of KPIs/OKRs related to technologies and organisational practices[110] | EU<br><br>Key HCT ecosystem actors |
| | Measuring HC at the individual, organisational, sectoral and macroeconomic level | EU, Research, Industry, Unions |
| Establish company practices for the stakeholder participation in decision-making processes in the adoption of actions towards human centricity | Shape the organisational and institutional context for greater participation of key stakeholders and employee involvement.<br><br>Integrate workers in the technology development/adoption process (dedicated resources and time)<br><br>Consider the diverse needs of employees and tailor solutions accordingly | Research and Education, Industry |
| | Develop public pre-commercial and innovation procurement stipulations that promote the adoption of HC approaches to Technologies and involve employees in the procurement process | EU, MS |
| | Develop a knowledge bank on HC workplace innovation<br><br>Support, fund and disseminate use-cases that provide evidence on socio-economic benefits of technologies contributing to HC goals or developed and/or integrated with human-centric methods. | EU, MS, Unions |
| | Launch programme that supports strategic alliances and platforms supporting the mutual learning and the uptake of HC approaches to technologies and organisational innovation in the industry | EU, MS |
| **Technological developments** | | |
| Adjust/launch R&D funding programmes and policy framework promoting human-centric approaches in technology development | Linking HC with broader policy agenda and integrating HC in existing initiatives related to twin transition | EU and MS policymakers |
| | Support technological developments and adoption in key technology areas that might facilitate human-centricity. | EU and MS policymakers |

[110] The main purpose of the Objectives and key results (OKR) is to define company’s and team’s "objectives" and define the measurable "key results" of each achievement of the objectives.

| Action line | Actions | Key stakeholders |
| --- | --- | --- |
| | Inclusion of multidisciplinary (including SSH) within the topics of HCT-related calls | EU and MS policymakers |
| | Increase knowledge of and synergies between different funding streams, instruments, EU initiatives, and national/regional programmes related to Industry 5.0 and HC approaches to technology and organisations<br><br>Development of policy mix supporting the design, deployment and uptake of HC enabling technologies and organisational models | EU and MS policymakers |
| | Development of HC-related anticipatory governance framework towards anticipating future technological developments and promoting positive industry and societal outcomes | EC |
| Develop HC in using collaborative and smart robots, leading to an empowered collaborative worker with optimised and trustful user experience and effective collaborative task performance | Develop open-source solutions for HC approaches to technology development | Industry, clusters, research, EU, MS |
| | Develop socially adaptive robots | Industry and Industry clusters, research |
| | Integrate ergonomics in design of collaborative robots, making human-robot collaboration safer and healthier | Industry and Industry clusters, research, EU, MS |
| Develop HC in using physical and cognitive augmentation (cognitive augmentation: Extended Reality (XR), including Augmented Reality (AR), Mixed Reality, (MR) and Virtual Reality (VR) tools; physical augmentation; exoskeletons), leading to an empowered worker that has new capabilities for operating, maintaining, training, guiding and co-designing of workplaces | Develop human body capability-enhancing technologies | Industry, clusters, research and education institutions |
| | Develop human-centric Virtual, Augmented and Mixed Reality user interfaces | Industry, clusters, research and education institutions |
| | Develop human centric Extended Reality (XR) for skill development | Industry, research |
| Develop HC in using AI (Artificial Intelligence), Big Data and digital twins, leading to an analytical and smarter worker with better simulation, monitoring and planning activities characterised by data protection and unauthorised use of data | Ensure privacy measures for human-centred AI and Big Data applications | EU, MS, Industry and clusters, research and education institutions |
| | Enable a Human Digital Twin | Industry and clusters, research community |
| | Promote the development of human-centred AI | Industry clusters, research and education |

| Action line | Actions | Key stakeholders |
|---|---|---|
| | | institutions |
| | Develop core infrastructures for human centricity-oriented experimentation towards human-centred AI and Big Data | Industry, research |
| Develop HC in smart devices and new forms of interfaces (e.g., wearables) that increase individual competences and usability of manufacturing equipment, give feedback on well-being and achievements, leading to higher work satisfaction, wellbeing, and diversity (involving vulnerable users) | Develop industrial wearables that provide an input-output loop to support workers' wellbeing and performance | Research and education institutions |
| | Develop situation-aware assistance systems | Industry, research |

Source: Authors

This section builds upon insights obtained from stakeholder consultations, data analysis, and a thorough literature review. It outlines the essential steps required to realise the objectives set forth in the four dimensions of this roadmap.

## 6.1. Education and training: Provide appropriate (certified) training to mitigate skills shortages and mismatches

As mentioned in the ESIR report on Industry 5.0 and the Future of Work, the Industry 5.0 approach has to include skills needed for future of work as an essential dimension of future sustainable development, at the same level as other essential goals such as protecting climate and biodiversity and, more broadly, ensuring long-term resilience.

Therefore, specific attention should be given to anticipating the needed key skills for the future of manufacturing. In addition, the creation of an Industry 5.0 skill taxonomy/ conceptualisation is valuable for structuring traditional educational programmes and identifying skill gaps.

While the creation of an Industry 5.0 skill taxonomy is valuable for structuring traditional educational programmes and identifying skill gaps, it is equally important to consider multidisciplinary and adaptable training programmes. This is particularly significant because (digital) skills related to human-centred industrial applications evolve rapidly and continually. To facilitate the development of training programmes that can adjust to this dynamic environment, it is important to develop flexible regulatory frameworks related to accreditation and funding.

Adapting to technological innovations and translating them into new skills pose a challenge for educators. This adaptation within educational organisations can be a drawn-out process, primarily because it necessitates the re-skilling of staff members before curricula can be updated. In addition, there is a lack of managerial skills to lead human-centric initiatives is critical for the successful implementation of HC approaches to technology.

Given the rapid pace of technological advancements, organisations must regularly assess future skill needs and potential shortages among their employees to align with Industry 5.0

requirements. Developing a training strategy that educates both management and technical personnel about human-centric processes and technologies can enhance the overall human experience and organisational performance. To achieve this, managers and engineers should receive additional education in Human Factor engineering and Socio-Technical systems to incorporate human-centric principles into their work

There is a notable absence of standardised accreditations tailored for blue-collar workers, exacerbated by company owners' hesitancy to invest in providing their employees with formal courses. In addition, there is a need for more degrees of freedom for testing and experimenting with innovative HC approaches to technology and organisational practices - related educational approaches and that the regulatory framework should adapt to the increased flexibility.

The table below presents a summary of key findings and related actions and key stakeholders. An extended table with detailed action milestones is available **in** Error! Reference source not found.

**Table 15 Measures recommended on education and training**

| Action | Key stakeholders |
|---|---|
| **Develop foresight capabilities to identify skills and employee needs** related to purpose-driven, human-centric technology development and adoption<br><br>Collaborate with associations and companies to **establish a skillset taxonomy** for purpose-driven & human-centric (HC) technology adoption | EU and MS policy makers, Research and education |
| Create **multidisciplinary, agile and distributed training programmes** to foster HC related skill development | Research and education |
| Advocate for flexible regulatory frameworks to support funding and accreditation of innovative non-standard HC-related educational programmes | EU and MS policy makers, Research and education |

Source: Authors

## 6.2. Establishing platforms, infrastructures, and interlinkages in the ecosystem

This kind of measures proposed under this stream of recommendations relate to the following three areas, which will be outlined in more detailed below:

- Facilitate knowledge exchange and dissemination between ecosystem enablers and actors
- Facilitate open innovation and collaborative approaches between industry, research, education and social sectors
- Create testing facilities and shared infrastructure

**A. Facilitate knowledge exchange and dissemination between ecosystem enablers and actors**

While numerous universities and educational institutions offer a diverse range of courses aimed at enhancing both theoretical and hands-on skills in human-centred technologies and the associated methodologies and processes, this information often remains unnoticed. Moreover, due to the relatively recent emergence of the topic of human-centred industry transformation, many ecosystem actors lack a comprehensive understanding of its scope, leading to underutilisation of HC approaches to technology and organisation education opportunities.

To tackle these challenges, a unified European platform could consolidate information on HC approaches to technology and organisations-related educational offerings, initiatives, and actions, creating a one-stop resource for interested parties. To optimise resources and avoid duplication, this platform should build upon existing specialised platforms like the Industry 5.0 Community of Practice, the Distributed Design Platform, DIH network, the Deep Tech Talent, EIT Manufacturing, etc. It would provide valuable insights into the evolving landscape of HC related education (in its more holistic sense as defined in this report). To achieve this, specific tools for monitoring and assessing the impact of HC research, innovation and education programmes are necessary. It is vital to continually enhance the quality of HC education by identifying unexpected outcomes and implementing dynamic measures for training transfer, encompassing attitudinal, behavioural, and performance indicators.

All actors involved in the development, implementation and promotion of HC (research institutes, technology providers, service companies, manufacturing companies, etc.) can learn from the well-documented HC cases and the different ways in which HC can be used to implement workplace innovations. Such cases would also make it possible to better track and assess the impact of HC at individual and organisational level.

To address skills gaps and meet the needs of the workforce, cooperation between governments, businesses, and social partners is necessary. Collaborative efforts amongst these stakeholders will help create comprehensive solutions for skills development in the context of HC technologies. To enhance the practical understanding of HC enabling technologies and practices, the exchange of knowledge and experiences between the research and industry sectors should be strengthened. This could be achieved in form of practical field training or internships for students and professionals. Incentivising companies to share data, find ways to collaborate or building bridges for human-centric design cooperation between industry and research sector would also be needed.

So far, there are few opportunities for joint learning and exchange of good practice (e.g. communities of practice) focusing on HC at regional, sectoral, national or European level. The Industry 5.0 Community of Practice[111] is a good step in this direction that can be built upon to encourage further initiatives from ecosystem players. Further recommended actions are outlined below.

The table below presents a summary of key findings and related actions and key stakeholders. An extended table with detailed action milestones is available in **Error! Reference source not found.**.

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[111] Industry 5.0 - European Commission (europa.eu)

**Table 16 Measures recommended to facilitate knowledge exchange and dissemination between ecosystem enablers and actors**

| Action | Key stakeholders |
|---|---|
| • Establish **European platform / observatory to monitor human-centric and systemic design education-related actions, initiatives, offerings,** impact assessments and related KPIs in the field of purpose-driven, human-centric technologies, while at the same time avoid duplication and promote synergy with existing platforms | EU and MS policy makers, ecosystem |
| • Strengthen knowledge and experience exchange between research and industry with **practical field training or internships in industrial organisations** | EU and MS policymaker, Research and education, industry |
| • Develop a **knowledge bank on workplace innovation** informed by purpose, human-centricity & other Industry 5.0 goals<br>• Support, fund and disseminate **use-cases that provide evidence on socio-economic benefits** of technologies contributing to human-centric goals or developed and/or integrated with human-centric approaches | EU, MS, Unions |
| • Launch **programme that supports strategic alliances and platforms supporting the mutual learning** and the uptake of HC approaches to technologies and organisational innovation in the industry | EU, MS |

Source: Authors

**B. Facilitate open innovation and collaborative approaches between industry, research, education and social sectors**

For a successful design and adoption of HC related Technology and organisational practices, open innovation approaches are required to facilitate collaboration among different R&I actors such as industry, research and innovation (R&I) actors, educational institutions, Fab Labs, Digital Innovation Hubs (DIHs), and the broader R&I community. For example, while various living labs and fablabs related to Industry 5.0 have been established, there is a need for improved coordination among these initiatives.

This would foster a culture of openness and shared knowledge in the development and implementation of HC approaches in both technology development, R&I and organisations. While involving unions and stakeholders in every R&D project may not always be practical, it is recommended to maintain flexible engagement strategies that allow for adaptability. Unions can provide valuable assessments of needs and can be important partners in the development of human-centred solutions.

In addition, supporting multidisciplinary project teams involving Social Sciences and Humanities (SSH) should be pursued to achieve a holistic understanding of the challenges surrounding the implementation of human-centric solutions. Human-centric approaches to technologies require a deep understanding of human behaviours, ergonomics, cognitive processes, and the socio-cultural dimensions of the manufacturing workforce. Multidisciplinary collaborations pose challenges in terms of resources, communication, alignment of objectives, and the integration of distinct perspectives into a cohesive design.

The table below presents a summary of key findings and related actions and key stakeholders. An extended table with detailed action milestones is available in **Error! Reference source not found.**.

**Table 17 Recommended measures to facilitate open innovation and collaborative approaches between industry, research, education and social sectors**

| Action | Key stakeholders |
|---|---|
| • **Encourage open innovation orchestrators to develop open social innovation approaches**[112] for the adoption of technologies and practices that promote Industry 5.0 human-centric and sustainability goals, as well as for lifelong learning. This would also include skills training programmes encompassing human-centric and systemic design approaches that can be applied to technology and organisational practices; engaging industry, R&I actors, education, fablabs, DIHs and the community<br>• Leverage Digital Innovation Hubs (DIHs) and related centres of competences in bolstering companies' adoption of HC practices via coaching, awareness raising building networks/connections with educational actors | EU and MS policy makers, ecosystem |
| • Foster collaboration between SSH (Social Sciences and Humanities) and HC approaches to technologies-related engineering in research and industry | EU, MS policy makers, SSH researchers |

Source: Authors

### C. Create testing facilities and shared infrastructure

Based on the analysis in this Roadmap, it is clear that European manufacturing companies and startups already have access to a variety of testing facilities and entrepreneurial infrastructure for the development, prototyping, and testing of new technologies and business concepts. These resources encompass incubators, fablabs, makerspaces, and publicly funded EU initiatives like the European Digital Innovation Hubs. While these facilities deliver valuable services to industry, there is a need to enhance their perception among other ecosystem stakeholders, such as social partners. This realisation underscores the potential within the ecosystem surrounding human-centric approaches to technology and organisational innovation, provided that the extensive network of testing facilities and shared infrastructure is efficiently leveraged and expanded where necessary.

Social partners should be encouraged to acknowledge the value of "testing facilities," including European Digital Innovation Hubs (EDIHs). This recognition can serve as a catalyst for the development and experimentation of HC related training programmes for technology developers. To promote hands-on training in emerging industrial technologies, the **establishment of open pilot areas or factories is essential, as is the creation of more synergies with fablabs, makerspaces, and applying demonstrator and sandboxes approaches for human-centric experiments and dialogues at organisational level.** These areas act as practical training grounds for the incorporation of such new approaches into technology development, enabling individuals to gain first-hand experience with the latest innovations in HC approaches to technology. Also, embracing the learning and teaching factory concept, where individuals receive training alongside experts and industry professionals, underscores the importance of continuous learning and alignment with real-world industry needs.

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[112] Gegenhuber, Thomas, and Johanna Mair. "Open social innovation: taking stock and moving forward." *Industry and Innovation* (2023): 1-28.

**Table 18 Recommended measures to create testing facilities and shared infrastructure**

| Action | Key stakeholders |
|---|---|
| • **Develop synergies and enhance awareness of Testing and Experimentation Facilities and/or EDIHs** (European Digital Innovation Hub) under Digital Europe Programme as a valuable **testing ground for activities promoting human-centric and systemic approaches to technology development** | Labour and employer's associations, EU and MS policymaker |
| • Utilise Europe's extensive fablabs and Makerspaces network for prototyping, testing and replicating training programmes and providing necessary infrastructure to broaden the adoption of human-centric approaches to technology and organisational practices across the different communities and manufacturing actors<br>• Develop and use demonstrators and "sandboxes"[113] (i.e., specific technical environments for development teams) for human-centric experiments and dialogues at the organisational level | Ecosystem members from across all different sectors (eg. research, industry, fablab and makerspaces, education) |

Source: Authors

## 6.3. Measures to support technological developments

The importance of skills and human aspects related to new technology development has been recognised as prominent challenges in current Horizon Europe Framework Programme. The realisation that technology development in itself is not sufficient and that human aspects relating to this development need to be taken into account is already evident in H2020 project calls. There is, however, still a need to further integrate aspects related to human-centricity in R&D funding programmes as well as link the topic more prominently to the broader EU policy agenda. This goes hand in hand with raising awareness of different funding opportunities that already exist, e.g. in the form of national/regional programmes, or launching new tailored programmes, focusing on specific technologies that were identified as priority for achieving human-centric outcomes through technology development.

Bringing together diverse actors of different backgrounds might enable the integration of expertise and knowledge for developing technologies that address the needs and challenges of diverse stakeholders. In addition, supporting technology foresight to identify opportunities in this fast developing emerging field would be desirable.

This section presents a summary of key findings and related actions and key stakeholders. The following are **recommended as technology and R&I areas for strengthened policy focus**:

A. Adjust/launch R&D funding programmes and policy framework favouring outcome oriented human-centric approaches to technology development and organisational innovation

[113] According to EPRS Briefing on Artificial Intelligence Act and Regulatory Sandboxes, Sandboxes generally refer to regulatory tools allowing businesses to test and experiment with new and innovative products, services or businesses under supervision of a regulator for a limited period of time. Another example of sandbox is provided by Agile Data on Development Sandboxes: An Agile Core Practice

B. Foster **HC in using collaborative and smart robots,** leading to an empowered collaborative worker with optimised and trustful user experience and effective collaborative task performance.

C. Foster **HC in using physical and cognitive augmentation**, leading to an empowered worker that has new capabilities for operating, maintaining, training, guiding, and co-designing of workplaces.

D. Foster **HC in using AI (Artificial Intelligence), Big Data and digital twins**, leading to an analytical and smarter worker with better simulation, monitoring and planning activities characterised by data protection and unauthorised use of data.

E. Foster **HC in smart devices and new forms of interfaces** (e.g., wearables) that increase individual competences and usability of manufacturing equipment, give feedback on well-being and achievements, leading to higher work satisfaction, wellbeing, and diversity (involving vulnerable users).

The tables below provide more details for the R&I policy and technology areas identified as priority for strengthened policy support to improve human-centric outcomes of technologies. An extended table with detailed action milestones is available in **Error! Reference source not found.**.

**Table 19 Actions recommended for adjusting/launching R&D funding programmes and policy framework for technologies and R&I practices enabling human-centricity**

| Action | Key stakeholders |
|---|---|
| • Increase knowledge of and synergies between different funding streams, instruments, EU initiatives, and national/regional programmes related to Industry 5.0 and HC approaches to technology<br>• Development of policy mix supporting the design, deployment, and uptake of HC approaches in R&I<br>• Link HC with broader policy agenda and integrate HC in existing initiatives related to twin transition | EU and MS policymakers |
| • Support technological developments and adoption in key HC approaches in diverse technological areas | EU and MS policymakers |
| • Inclusion of multidisciplinary actors (including SSH) within the topics of HC focused R&I-related calls | EU and MS policymakers |
| • Development of HC-related anticipatory governance framework | EC and MS policymakers |

Source: Authors.

**Table 20 Actions for developing HC in using collaborative and smart robots, leading to an empowered collaborative worker with optimised and trustful user experience and effective collaborative task performance**

| Action | Key stakeholders |
|---|---|
| **Develop open-source solutions for HC approaches and designs in technology development**<br><br>In terms of developments of collaborative and smart robots, EU-wide promotion and teaching platforms aimed at enhancing access to technology and fostering learning need to be included. In parallel, open-source solutions for HC approaches to technology development are recommended to support collaboration within the industry environment towards human-centric innovation by 2024. | Industry and Industry clusters, research community, EU, MS |
| **Develop socially adaptive robots**<br><br>To create optimised collaboration between workers and robots, it is proposed to delve deeper into the realm of socially adaptive robots, with dedicated research on socially situated learning, anthropomorphising in human-robot interactions and the integration of human-centric values in robot performance reporting. | Industry and Industry clusters, research community |
| **Integrate ergonomics in design of collaborative robots, making human-robot collaboration safer and healthier**<br><br>A focus on ergonomic design for collaborative robots seeks to ensure safety and health of the workers. Through pan-European partnerships, programmes promoting the integration of ergonomics research with robotics will be developed, accompanied by the creation of training materials for robot operators and users to guarantee proper ergonomic practices during collaborative endeavours. | Industry and Industry clusters, research community, EU, MS |

Source: Authors.

**Table 21 Actions for developing HC in using physical and cognitive augmentation (cognitive augmentation: Extended Reality (XR), including Augmented Reality (AR), Mixed Reality, (MR) and Virtual Reality (VR) tools; physical augmentation; exoskeletons)**

| Action | Key stakeholders |
|---|---|
| **Develop human body capability-enhancing technologies**<br><br>To develop physical augmentation technology through human body capability-enhancing technologies, it is essential to consider ethical and societal questions pertaining to human augmentation, as well as to map which technologies can support the human body in which context, also considering special or individual needs of users (e.g., vision impairments, height, etc.). | Industry and Industry clusters, research and education institutions |
| **Develop human-centric Virtual, Augmented and Mixed Reality user interfaces**<br><br>Human-centric virtual, augmented and mixed reality user interfaces should be developed to enable remote monitoring, control of work processes and personalize feedback based on performance data | Industry and Industry clusters, research and education institutions |
| **Develop human centric Extended Reality (XR) for skill development**<br><br>Training sessions with customized scenarios that simulate realistic environments and situations can help workers to acquire essential knowledge more efficiently | Industry, research |

| Action | Key stakeholders |
|---|---|
| and develop superior skills | |

Source: Authors.

**Table 22 Actions for developing HC in using AI (Artificial Intelligence), Big Data and digital twins, leading to an analytical and smarter worker with better simulation, monitoring and planning activities**

| Action | Key stakeholders |
|---|---|
| **Ensure privacy measures for human-centred AI and Big Data applications**<br><br>Privacy measures for AI and Big Data applications are required. For Big Data, additional data handling protocols – in terms of correct handling and storing of data and for visualisations of Big Data – are recommended as well. | EU, MS, Industry and Industry clusters, research and education institutions |
| **Enable a Human Digital Twin**<br><br>Digital Twins currently exist mostly for objects. In the future, a Human Digital Twin can lead to a better understanding and support of the human needs for bi-directional learning and evolution in interactive systems | Industry and Industry clusters, research community |
| **Promote the development of human-centred AI**<br><br>To ensure human-centred AI, developers need to be supported in creating lawful, robust, and ethical AI to amplify the abilities of humans | Industry and Industry clusters, research and education institutions |
| **Develop core infrastructures for human centricity-oriented experimentation towards human-centred AI and Big Data**<br><br>The development of core infrastructures for experimentation towards human-centred AI and Big Data are needed to strengthen Europe's position as a facilitator for human-centred AI and Big Data | Industry, research |

Source: Authors

**Table 23 Actions for developing HC in smart devices and new forms of interfaces (e.g., wearables) that increase individual competences and usability of manufacturing equipment, give feedback on well-being and achievements, leading to higher work satisfaction, wellbeing and diversity (involving vulnerable users)**

| Action | Key stakeholders |
|---|---|
| **Develop industrial wearables that provide an input-output loop to support workers' wellbeing and performance**<br><br>Developing industrial wearables that support workers' wellbeing and performance necessitates researching the requirements of wearable standards in the EU, research and development on multi-sensory wearables that can analyse and interpret relevant input data from the workers to assess their affective and cognitive states. Based on the analysed input streams, wearables then can guide the workers on the job. | Research and education institutions |

| Action | Key stakeholders |
|---|---|
| **Develop situation-aware assistance systems**<br><br>Context aware assistance systems need to be developed to interpret and react accordingly to the human action and communication by providing real-time and context specific information. | Industry, research |

Source: Authors

## 6.4. Organisational environment

**A. Integrate HC in certifications and standards for business to design and develop human centric technologies and practices.**

While there are currently several established standardisation bodies and certifications overseeing the design and development of HC products, there is a clear need for increased promotion and harmonisation of these diverse standards and certifications.

Policymakers within the European Union and its Member States could take proactive measures, either by enacting regulations mandating the incorporation of HC principles in the design of products and services, or by providing incentives (such as grants) to businesses, especially SMEs, that demonstrate a strong commitment to HC practices.

Most of the managerial and employee training programmes do not incorporate training related to the use of HC standards. It is important to also educate managers and engineers in Human Factors Engineering (HFE) and Socio-Technical Systems (STS) to incorporate human-centric principles in their work. However, it should be also acknowledged that organisations are best equipped to identify their skill needs and support them in responding to skill mismatches through workplace innovation and learning.

There is a growing trend, and even an obligation, for some companies to report on their human capital activities, for example in sustainability reports, intellectual capital reports or ESG (environmental, social and governance) reports. However, these reports usually do not cover activities in relation to HC.

**Table 24 Recommended actions to integrate HC in certifications and standards for business to design and develop human centric technologies and practices**

| Action | Key stakeholders |
|---|---|
| Align and promote existing -related standards and certifications addressing human centric aspects in technologies and organisations<br><br>Create a certification for maturity of human-centricity in the Industry 5.0 organisation | EU, MS, Industry, Standardisation and Certification Organisations |
| Integrate HC standardisation and certification into educational programmes and offer internal training to managers and employees on how to use HC standards | Research and Education, industry |
| Integrate HC in corporate reporting | EU, MS, Research, Industry |

**B. Provide guidance for organisations for integrating HC in their practices, especially in the design and technology development**

Companies need guidance to incorporate human centricity and the EC could facilitate that these tools are further developed and diffused. In general, the organisational readiness to change, including structure, processes, and investments, is crucial for successful human-centric transformations. However, conflicting requirements of different stakeholders, including goals, motivations, needs, and existing skills, can hinder change processes and technology adoption. Methods and tools need to be able to balance different objectives in terms of speed, accuracy, efficiency, pressure and workload.

Overall, the industry should formalise the evaluation and oversight of HC approaches to technology development and adoption practices within companies. It is not only important that companies use KPIs to manage the product development and production process, but also that some of these measures are collected in a standardised way in order to analyse and compare the development of HC on a sectoral, regional and macroeconomic level.

**Table 25 Recommended measures on guidance for organisations for integrating HC in their practices, especially in the design and technology development**

| Action | Key stakeholders |
|---|---|
| Provide guidance and toolkits on HC approaches to technologies and organisations such as pilot industry 5.0 compass / self-assessment tool following the maturity model towards human centric approaches, that also includes a set of KPIs related to technologies and organisational practices[114] | EU, key HCT ecosystem actors |
| Measuring relevant aspects related to human-centricity at the individual, organisational, sectoral and macroeconomic level | EU, Research, Industry, Unions |

**C. Establish company practices encouraging stakeholder participation in decision-making processes in the adoption of actions towards human centricity**

Greater employee involvement in decision-making and processes is key for the diffusion of HC in different industries and organisations. Overall, there should be a focus on stakeholder empowerment in the organisation. In addition, addressing workers' concerns about job security due to technological advancements is essential to reduce resistance, too. It is important to provide motivation and incentives for employees to become innovative and actively participate in human-centric initiatives, and to offer learning opportunities across all layers of the organisation. For this, it is important to create more opportunities for dialogue within and across organisations, especially when it comes to the inclusion of multidisciplinary experts in technological transformation projects such as automation.

In industrial practice, shop-floor workers could be also more directly involved in the procurement process to allow the different decision criteria (e.g. cost considerations vs. usability) to be balanced.

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[114] The main purpose of the Objectives and key results (OKR) is to define company's and team's "objectives" and define the measurable "key results" of each achievement of the objectives.

**Table 26 Recommended measures on establishing company practices for the stakeholder participation in decision-making processes in the adoption of actions towards human centricity**

| Action | Key stakeholders |
|---|---|
| • Shape the organisational and institutional context for greater participation of key stakeholders and employee involvement.<br>• Integrate workers in the technology development/ adoption process (dedicated resources and time)<br>• Consider the diverse needs of employees and tailor solutions accordingly | Research and Education, Industry |
| • Develop public pre-commercial and innovation procurement stipulations that promote the adoption of HC approaches to technologies and involve employees in the procurement process | EU, MS |
| • Develop a knowledge bank on workplace innovation informed by purpose, human-centricity & other Industry 5.0 goals<br>• Support, fund and disseminate use-cases that provide evidence on socio-economic benefits of technologies contributing to human-centric goals or developed and/or integrated with human-centric approaches | EU, MS, Unions |

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# ANNEX 1 EXTENDED POLICY RECOMMENDATIONS

**Table 27 Actions for providing appropriate (certified) training to mitigate skills shortages and mismatches**

| Action | Ideas for milestones towards 2035 | Key stakeholders |
|---|---|---|
| Develop foresight capabilities to identify skills and employee needs related to purpose-driven, human-centric technology development and adoption | Launch a foresight exercise on HCT-related skills and employee needs (2025)<br><br>Establish a monitoring and foresight system to track and explore future developments in HCT-related employee skills and jobs (2027)<br><br>Launch annual insights publication on European HCT-related employee skills and jobs (2028) | EU and MS policy makers |
| Collaborate with associations and companies to establish a skillset taxonomy for purpose-driven & human-centric (HC) technology adoption | Develop first version of a HC skill taxonomy and a method to ensure continuous adaptation (2025)<br><br>Establish taxonomy and revise training delivery mechanisms to incorporate Industry 5.0 skills (2027) | Research and education |
| Create multidisciplinary, agile and distributed training programmes to foster HC and systemic design skill development | Establish EU-wide promotion and teaching platforms for users, with support from robotics developers or Digital Innovation Hubs (DIHs).<br><br>Develop complementary HC-related programmes to improve or build on existing offerings (2027)<br><br>Utilise principles of human-centricity and innovative teaching methods (e.g., gamification) to bridge skill gap between engineering and soft skills (2028)<br><br>Offer training programmes within a Massive Open Online Course (MOOC) where applicable (2028)<br><br>Offer appropriate versions of HC skills training in schools and universities (2029) | Research and education |
| Advocate for flexible regulatory frameworks to support funding and accreditation of innovative non-standard educational programmes | Conduct an EU-wide study on flexible regulatory frameworks to support funding and accreditation of innovative non-standard educational programmes (2025)<br><br>Prepare guidance and mutual learning opportunities for MS on flexible regulatory frameworks to support funding and accreditation of innovative non-standard educational programmes (2025)<br><br>Established flexible regulatory frameworks that support education programmes (2030) | EU and MS policy makers, Research and education |

Source: Authors

**Table 28 Actions to facilitate knowledge exchange and dissemination between ecosystem enablers and actors**

| Action | Ideas for milestones towards 2035 | Key stakeholders |
|---|---|---|
| Establish European platform / observatory to monitor education-related actions, initiatives, offerings, impact assessments and related KPIs in the field of purpose-driven, human-centric and systemic design of technologies, while at the same time avoid duplication and promote synergy with existing platforms | Identify related platforms and develop plan to integrate into common observatory that covers the whole field of HCT (2025)<br><br>Develop system of tools and KPIs that can assess impact and quality of HC-related education programmes (2026)<br><br>Integrate this system of tools with European Digital Skills Certificate (2026)<br><br>Launch the reduced pilot platform (2027)<br><br>Working system to assess education programmes, available in observatory platform (2027)<br><br>Platform accessible and useful for all ecosystem actors, tailored also for specific audiences (e.g., less tech savvy, older) (2030) | EU and MS policy makers, ecosystem |
| Encourage open innovation orchestrators like DIHs to develop open social innovation approaches[115] for the adoption of technologies and practices that promote Industry 5.0 human-centric and sustainability goals, as well as for lifelong learning. This would also include skills training programmes encompassing human-centric and systemic design approaches that can be applied to technology and organisational practices; engaging industry, R&I actors, education, fablabs, DIHs and the community | Launch innovation programmes that address barriers for collaborative innovation efforts on HCT (2027)<br><br>Enable the connection and scaling up of HCT practices across EU ecosystems through the Horizon Europe European Innovation Ecosystems funding programme (2025)<br><br>A dedicated institution for collaborative open innovation for HCT | EU and MS policymaker, ecosystem |
| Leverage Digital Innovation Hubs (DIHs) and related centres of competences in bolstering companies' adoption of HC practices via coaching, awareness raising building networks/connections with educational actors | Launch a pilot programme within DIHs, integrating HC KPIs and involving various ecosystem stakeholders (2024)<br><br>DIHs proactively track HC Key Performance Indicators (KPIs) as part of their digitalisation efforts (2025)<br><br>DIH are implementing the ongoing monitoring and evaluation activities with an objective to | EU<br><br>MS |

[115] Gegenhuber, Thomas, and Johanna Mair. "Open social innovation: taking stock and moving forward." Industry and Innovation (2023): 1-28.

| Action | Ideas for milestones towards 2035 | Key stakeholders |
|---|---|---|
| | guide the revitalisation or enhancement of HC (2030) | |
| Strengthen knowledge and experience exchange between research and industry with practical field training or internships in industrial organisations | Scale up learning factories and innovative similar approaches and establish exchange programmes on HCT between research and industry (2025)<br><br>Create a non-profit space through which stakeholders from industry and manufacturing can share experiences and good practice examples (2025)<br><br>Disseminate good practice examples of HC in manufacturing (2025) | EU and MS policymaker, Research and education, industry |
| Foster collaboration between SSH (Social Sciences and Humanities) and HC approaches to technology-related engineering | Pilot incentive programme to encourage collaboration between SSH professionals and engineers (2024)<br><br>Full scale incentive programme that encourages organisations and institutions of engineering and SSH to create opportunities for knowledge exchange, joint training, and collaborative projects, fostering a culture of multidisciplinary cooperation and understanding (2026) | EU, MS policy makers, SSH researchers |

Source: Authors

### Table 29 Actions for creating testing facilities and shared infrastructure

| Action | Ideas for milestones towards 2035 | Key stakeholders |
|---|---|---|
| Develop synergies and enhance awareness of Testing and Experimentation Facilities and/or EDIHs (European Digital Innovation Hub) under Digital Europe Programme as a valuable testing ground for activities promoting human-centric and systemic approaches to technology development | Launch a programme to integrate HCT in and across EDIHs (European Digital Innovation Hub) and other testing facilities (2025)<br><br>Organise a (EU-wide) stakeholder event to showcase HCT in testing facilities (2027) | Labour and employer's associations, EU and MS policymaker |
| Utilise Europe's extensive fablabs and Makerspaces network for prototyping, testing and replicating training programmes and providing necessary infrastructure to broaden the adoption of human-centric approaches to technology and organisational practices across the different communities and manufacturing actors | Identify need for further Fab Labs etc. in terms of technology but also geographical coverage (2027)<br><br>Expand the presence of Fab Labs and living labs as spaces for co-creation involving industry, education, and research in the EU (2030) | HCT ecosystem |
| Develop and use demonstrators and | Develop demonstrators and sandboxes | Research and |

| Action | Ideas for milestones towards 2035 | Key stakeholders |
|---|---|---|
| "sandboxes"[116] (i.e., specific technical environments for development teams) for human-centric and purpose-driven technology development experiments and dialogues at the organisational level | (2027) | Education, Industry |

Source: Authors

**Table 30 Actions to integrate HC in certifications and standards for business to design and develop human centric technologies and practices**

| Action | Ideas for milestones towards 2035 | Key stakeholders |
|---|---|---|
| Align and promote existing -related standards and certifications addressing human centric aspects in technologies and organisations | Conduct a study to analyse the standardisation landscape and the development of HCT (2025)<br><br>Launch a working group for establishing global standards in collaboration with international bodies (2025)<br><br>Establish a qualification scheme to provide employers and employees with a basic understanding of various HC-related intelligent systems (2027)<br><br>Awareness measures for SMEs (2027)<br><br>Publish a common strategic paper on aligning global standards for HCT (2027)<br><br>Launch specific measures for SMEs (2030)<br><br>Integrate HC standards into quality standards for the manufacturing sector (2030) | EU, MS, Industry, Standardisation and Certification Organisations |
| Integrate the topic of HC standardisation and certification into educational programmes and offer internal training to managers and employees on how to use HC standards | Integrate HC in the curricula in selected HE and VET organisation (2027)<br><br>Selection and showcasing the best practice examples across industries and regions (2027) | Research and Education, industry |
| Create a certification for maturity of HC in the Industry 5.0 organisation | Launch a working group (2024)<br><br>Define maturity levels of human centricity | EU, Standardisation Organisations, Research |

[116] According to EPRS Briefing on Artificial Intelligence Act and Regulatory Sandboxes, Sandboxes generally refer to regulatory tools allowing businesses to test and experiment with new and innovative products, services or businesses under supervision of a regulator for a limited period of time. Another example of sandbox is provided by Agile Data on Development Sandboxes: An Agile Core Practice.

| Action | Ideas for milestones towards 2035 | Key stakeholders |
|---|---|---|
| | for organisations (2026)<br><br>Iteratively design the certification (2027)<br><br>Awareness measures for SMEs (2028)<br><br>Launch certification (2028) | |
| Integrate HC in corporate reporting | Analyse and map current reporting standards (ESG, CSR etc.) (2025)<br><br>Promote pioneers in reporting about HC (2027) | EU, MS, Research, Industry |

Source: Authors

**Table 31 Actions to create guidance for organisations for integrating HC in their practices, especially in the design and technology development**

| Action | Ideas for milestones towards 2035 | Key stakeholders |
|---|---|---|
| Provide guidance and toolkits on HC approaches to technologies and organisations such as pilot industry 5.0 compass/self-assessment tool following the maturity model towards human centric approaches, that also includes a set of KPIs/OKRs related to technologies and organisational practices[117] | Pilot Industry 5.0 compass/self-assessment tool integrating HC (2025)<br><br>Launch EU-wide Industry 5.0 compass/self-assessment tool localised to all languages (2027)<br><br>Promotion of guidelines and tools by the European Commission and national governments (2027)<br><br>Wide industry use of the tool (2030) | EU, key HCT ecosystem actors |
| Integrate workers in the development process (dedicated resources and time) | Acknowledged and validated procedures to involve the experience of the workforce into industrial R&D projects | Industry, EC, MS; Research and Education |
| Raise awareness about the value added of HCD | Best practices and validated protocols (2027)<br><br>Show the potential of using ESF (2030) | EU, MS, Industry, Research and Education |
| Consider the diverse needs of employees and tailor solutions accordingly | Provide support to workers in tasks requiring social and responsibility competencies (2030) | Industry<br><br>Labour unions |
| Measuring progress in HC practices at the individual, organisational, sectoral and | Define Key Performance Indicators (KPIs) to measure workflow optimisation and the relationship between HC and traditional KPIs | EU, Research, Industry, Unions |

[117] The main purpose of the Objectives and key results (OKR) is to define company's and team's "objectives" and define the measurable "key results" of each achievement of the objectives.

| Action | Ideas for milestones towards 2035 | Key stakeholders |
|---|---|---|
| macroeconomic level | (2025)<br><br>Launch company surveys in the MS (2027)<br><br>Include HC-related questions in the regular Eurofund surveys and establish benchmarks (2027)<br><br>Develop metrics for evaluating well-being and technology intervention outcomes (2027)<br><br>Industry 5.0 monitoring framework as an integral part of ERA monitoring mechanism (2027) | |

Source: Authors.

**Table 32 Actions related to company practices for the stakeholder participation in decision-making processes in the adoption of actions towards human centricity**

| Action | Ideas for milestones towards 2035 | Key stakeholders |
|---|---|---|
| Shape the organisational and institutional context for the participation of key stakeholders. | Provide guidelines and incentives for including and employing HC experts in companies (2025)<br><br>Develop methods for organisational innovation, adopting more agile, value-driven and human-centric organisational models and to enable employees to provide feedback (2027)<br><br>Develop training offerings for HC experts (2027) | Research and Education, Industry |
| Develop public pre-commercial and innovation procurement stipulations that promote the adoption of HCT and involve employees in the procurement process | Established working group including MS representatives with an objective to develop good practices of HCT pre-commercial and/or innovation procurement (2024)<br><br>Map practices and methods for employee involvement in procurement processes (2025)<br><br>Development of Pilot programmes at the EU and MS for pre-commercial and/or innovation procurement of HCT (2025)<br><br>Launch of full-scale pre-commercial and/or innovation procurement programmes at the EU and MS (2026)<br><br>Develop guidelines from employee involvement in procurement processes (2027) | EU, MS |

| Action | Ideas for milestones towards 2035 | Key stakeholders |
|---|---|---|
| Support, fund and disseminate use-cases that provide evidence on socio-economic benefits of technologies contributing to HC goals or developed / integrated with human-centric approaches<br><br>Develop a knowledge bank about HC workplace innovation | Showcase successful examples of HC integration (including HCD) to demonstrate its advantages, build on local DIHs and service providers (2024)<br><br>Launch the project for the HC knowledge bank (2025)<br><br>Integrate HCT in EU R&I communication and promotional activities (e.g., in the EU R&I days, through a new award, prize, organise yearly conferences on "HC best practices" on the European level) (2024) | EU, MS, Unions |
| Launch programme that supports strategic alliances and platforms supporting the mutual learning and the uptake of HC approaches to technologies and organisational innovation in the industry | Launch pilot call for SMEs and large companies across all sectors to join HC-related strategic alliance or platform (2024)<br><br>Launch of strategic alliance or platforms for HC-related mutual learning and the uptake support programme (2026)<br><br>Follow-up the findings and disseminate further the good practices (2027) | EU, MS |

Source: Authors

**Table 33 Actions for adjusting/launching R&D funding programmes and policy framework promoting human-centric approaches in technology development**

| Action | Ideas for milestones towards 2035 | Key stakeholders |
|---|---|---|
| Linking HC with broader policy agenda and integrating HC in existing initiatives related to twin transition | HC integrated in EU initiatives, such as the digital agenda and Green Deal (2025)<br><br>Framework for integration of HCT R&D project results, decision-making processes and future policy development (2026)<br><br>Whole-of-governance approach is actively pursued to foster the uptake and development of HCT (2030)<br><br>HC is an integral part of forthcoming industry and skills related regulations and legislations (2035) | EU and MS policymakers |
| Support technological developments and adoption in key HCT areas | Pilot calls focused both on lower and higher TRL (2025)<br><br>Policy support instruments for the development/uptake of HCT (2026) | EU and MS policymakers |
| Inclusion of multidisciplinary (including SSH) within the topics of HCT-related calls | Multidisciplinary R&D project teams that focus on technological and non-technological aspects as prerequisites in | EU and MS policymakers |

| Action | Ideas for milestones towards 2035 | Key stakeholders |
|---|---|---|
| | call topics (2030) | |
| Increase knowledge of and synergies between different funding streams, instruments, EU initiatives, and national/regional programmes related to Industry 5.0 and HC approaches to technology and organisations<br><br>Development of policy mix supporting the design, deployment and uptake of HC enabling technologies and organisational models | Alignment and promotion of different funding streams, instruments, EU initiatives, and national/regional programmes related to HCT part of Industry 5.0 CoP activities (2024)<br><br>Framework for a policy mix that recognises that a human-centred approach requires not only funding technically oriented R&D projects but also organisational adjustments and ecosystem design. This includes skills development, innovative business models, corporate social responsibility frameworks, participatory design, non-financial reporting, and new ergonomics standards (2025) | EU and MS policymakers |
| Development of HC-related anticipatory governance framework towards anticipating future technological developments and promoting positive industry and societal outcomes | Development of forward-looking HCT assessment for better needs anticipation and gathering strategic intelligence (2024)<br><br>Development of mechanisms ensuring stakeholder engagement throughout HCT-related policy cycle (2024) | EC |

Source: Authors

**Table 34 Actions for developing HC in using collaborative and smart robots, leading to an empowered collaborative worker with optimised and trustful user experience and effective collaborative task performance**

| Action | Ideas for milestones towards 2035 | Key stakeholders |
|---|---|---|
| Develop open-source solutions for HCT development | Create dedicated interdisciplinary conferences/events for human-centred technology for the industry environment (2024)<br><br>Launch a feasibility study to explore options for open-source building blocks for wider use (2025)<br><br>Create an open-source inventory of building blocks with validated human centricity quality for different application contexts (2026) | Industry and Industry clusters, research community, EU, MS |
| Develop socially adaptive robots | Conduct research to study how various degrees of anthropomorphisation can enhance or hinder human-robot interaction (including ecological valid testbeds) (2024)<br><br>Develop appropriate, well-validated interface paradigms for socially adaptive robots (2026)<br><br>Conduct research on recognition of affective and mental modes towards improved adaptivity of robots (2028) | Industry and Industry clusters, research community |

| Action | Ideas for milestones towards 2035 | Key stakeholders |
|---|---|---|
| Integrate ergonomics in design of collaborative robots, making human-robot collaboration safer and healthier | Collaborate within pan-European partnerships to develop programmes that promote integration of ergonomics in design (2024)<br><br>Support deeper integration of ergonomics research with robotics (2025)<br><br>Develop training programmes and materials for robot developers to ensure proper ergonomic practices (2027) | Industry and Industry clusters, research community, EU, MS |

Source: Authors

**Table 35 Actions for developing HC in using physical and cognitive augmentation (cognitive augmentation: Extended Reality (XR), including Augmented Reality (AR), Mixed Reality, (MR) and Virtual Reality (VR) tools; physical augmentation; exoskeletons**

| Action | Ideas for milestones towards 2035 | Key stakeholders |
|---|---|---|
| Develop human body capability-enhancing technologies | Develop an ethical framework on human body capability enhancing technologies (2026)<br><br>Research on how far human augmentation should go, the framework of different steps, and develop guidance (2027)<br><br>Develop industrially relevant building blocks towards the development of human-centric augmentation (physical and cognitive) (2027)<br><br>Create mapping of human body capability-enhancing technology to use case and context (e.g., exoskeleton for physical strength support) (2028)<br><br>Create true human-centred augmentation (physical and cognitive) (2030) | Industry and Industry clusters, research and education institutions |
| Develop human-centric Virtual, Augmented and Mixed Reality user interfaces | Develop validated human centricity guidelines for designing for Virtual, Augmented and Mixed Reality user interfaces (2027)<br><br>Exploit AI approaches to enhance human centricity of Virtual, Augmented and Mixed Reality (2025)<br><br>Develop standardised means to validate and certify the human centricity of Virtual, Augmented and Mixed Reality (2026)<br><br>Develop novel human-centred evaluation approaches for XR (2027)<br><br>Efficient, safe XR technology for training non-skilled workers (2027)<br><br>Create personalised delivery techniques for training (2027)<br><br>Develop XR technologies to achieve enhanced | Industry and Industry clusters, research and education institutions |

| Action | Ideas for milestones towards 2035 | Key stakeholders |
|---|---|---|
| | telepresence (2030)<br><br>Develop XR to support specific, personalised needs of their users and to augment their skills (2030) | |
| Develop human centric Extended Reality (XR) for skill development | Identify European needs for skill development based on XR technology potential (e.g., application context specific challenges) (2024)<br><br>Trigger a European inventory of XR based skill development solutions (2024)<br><br>Call research and innovation actions for XR-based skill development solutions for challenging manufacturing topics (e.g., time-critical machine repairment training solutions) (2025)<br><br>Develop industrially relevant building blocks towards the development of human centric XR based skill development solutions (2026) | Industry, research |

Source: Authors

**Table 36 Actions for developing HC in using AI (Artificial Intelligence), Big Data and digital twins, leading to an analytical and smarter worker with better simulation, monitoring and planning activities characterised by data protection and unauthorised use of data**

| Action | Ideas for milestones towards 2035 | Key stakeholders |
|---|---|---|
| Ensure privacy measures for human-centred AI and Big Data applications | Establish a legal framework and explicit means to map legal frameworks into the development of human-centred AI and Big Data (2027) | EU, MS |
| Establish protocols and human-centred means for handling Big Data | Ensure compliance with legal requirements (e.g., for data storing, handling, etc.) (2025)<br><br>Create suitable Big Data visualisation techniques and workflows and appropriate technology building blocks (2027). | Industry and Industry clusters, research and education institutions |
| Enable a Human Digital Twin | Modelling of different users, their preferences, behaviours, and workflows (2025)<br><br>Investigate the measuring and understanding individual humans and groups of humans through novel quantitative methods (2027) | Industry and Industry clusters, research community |
| Promote the development of human-centred AI | Support technology developers in creating trustworthy AI that is lawful, ethical, and robust including the development of an human centricity quality factors framework (2024)<br><br>Develop suitable explainable AI workflows and building blocks (2027)<br><br>Apply ethical rules for decision-making systems | Industry and Industry clusters, research and education institutions |

| Action | Ideas for milestones towards 2035 | Key stakeholders |
|---|---|---|
| | centred around humans (2027) | |
| Develop core infrastructures for human centricity-oriented experimentation towards human-centred AI and Big Data | Develop feasibility and requirements elicitation towards human centricity infrastructures (e.g., future human centricity optimisation) to push the EU as place for human-centred AI and Big Data (2024)<br><br>Setup of human centricity development infrastructures (e.g., simulating human-centred AI solutions in terms of human machine interface approaches) (2026)<br><br>Setup of larger testbeds in real situations to improve and iterate (2028) | Industry, research |

Source: Authors.

**Table 37 Actions for developing HC in smart devices and new forms of interfaces (e.g., wearables) that increase individual competences and usability of manufacturing equipment, give feedback on well-being and achievements, leading to higher work satisfaction, wellbeing and diversity (involving vulnerable users)**

| Action | Ideas for milestones towards 2035 | Key stakeholders |
|---|---|---|
| Develop industrial wearables that provide an input-output loop to support workers' wellbeing and performance | Identify European needs for wearable standards and device ecosystems to provide support in manufacturing (2025).<br><br>Develop multi-sensory wearables that monitor workers' wellbeing and performance (2026)<br><br>Develop standardised means to validate and certify the wearable based interaction in manufacturing (2026)<br><br>Develop wearables that provide feedback and guidance on the job for higher work satisfaction and wellbeing and maintain workers' autonomy (2028) | Research and education institutions |
| Develop situation-aware assistance systems | Understand what (type of) assistance is needed and accepted (2025)<br><br>Unifying input from diverse sensors for developing "situation awareness" (2026)<br><br>Develop basic technology building blocks to provide European solutions to advanced human-centric assistance in production (2028) | Industry, research |

Source: Authors

# ANNEX 2 ROADMAP METHODOLOGY

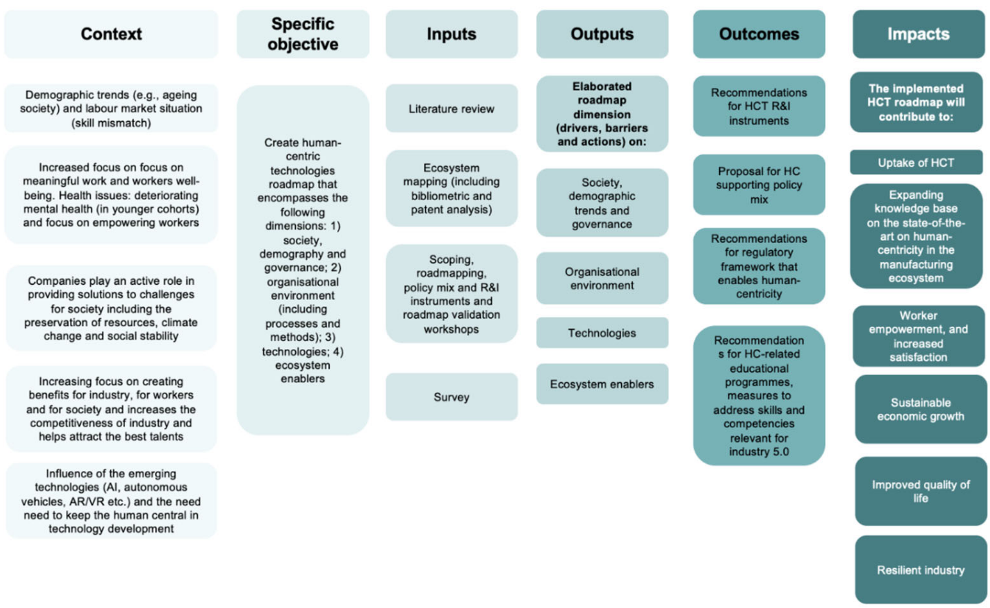
The development of a roadmap – the main aim of the study – started with an important caveat – namely, a rather diffuse concept on what human -centricity could mean and should deliver. Therefore, the study approach started with developing a conceptual framework (see figure below) which required parallel work on:

- Developing a working definition on human centricity and exploring which elements would need to be covered in the roadmap;
- Collecting facts and figures about the state of the art on human-centricity in terms of enabling technologies, stylised organisational and framework conditions that foster/hamper its uptake. Identification of key R&I actors, organisational processes, skills needed, etc.

The work was greatly facilitated through a set of co-creation workshops with a range of stakeholders. They provided input and direction and served as sparring element throughout the study and allowing us to deepen our understanding and corroborate our ideas and desk research based findings.

A prerequisite element for the development of a roadmap is a good understanding of the ecosystem in which such a roadmap is set. Therefore, a range of methods were applied to map out this ecosystem, along with its structures and functions of the various actors in such a system.

**Figure 27 Roadmap conceptual framework**




Source: Authors

The core of the ecosystem analysis is the quantitative mapping of the R&I ecosystem on human-centric enabling technologies (HCT), comprising a detailed characterisation of the ecosystem along different dimensions such as topical, national, and institutional composition, as well as R&I actors and their collaborations within framework programmes. This section is dedicated to the conceptual and methodological underpinning of the analysis.

The three most popular and commonly used indicators of knowledge creation and innovation are patent applications, collaborative research projects, and scientific publications. Patents primarily result from the industrial innovation efforts of firms, while publications typically arise from scientific research. EU-funded joint projects may be considered to encompass both scientific and industrial innovation efforts, as they bring together industry firms, universities, and research organisations. Consequently, during the process of the ecosystem mapping, various research methods played a crucial role in gathering the necessary data and forming the empirical evidence. The following methods were used to obtain relevant data and insights:

**Desk research:** Through desk research, a systematic examination of existing literature, reports, and documents related to human-centric technology was conducted. This included reviewing academic papers, industry publications, government reports, and online resources to create a comprehensive overview of the ecosystem. This method enabled the acquisition of insights into the developments, trends, challenges, and emerging technologies within the human-centric tech space. The insights obtained from the desk research serve as the foundational knowledge upon which this report is built.

**Patent analysis**: The analysis of patents allowed for the identification of the innovators and geographical areas of innovation. While technology possesses the potential to enhance work by making it safer, simpler, more environmentally friendly, and more human-centric, it’s important to note that the mere identification of such technology doesn’t guarantee its application with a human-centric focus. The range of technologies, spanning from AI to wearables, which have the potential to render manufacturing processes more human-friendly, is wide and increases in human-centricity ultimately hinge on how they are used.

Consequently, discerning whether a patent constitute a human-centric technology presents a unique challenge in comparison to other data sources. This is due to the fact that patents often comprise highly detailed technological descriptions, which may or may not explicitly indicate their application in products or applications. The determination of a patent’s human-centricity depends on its specific use in products or machinery. Therefore, the patents identified and scrutinised in this report are to be viewed as only a proxy for the development of human-centred technologies, without necessarily encapsulating the current implementation of human-centred technologies.

In order to identify patents that could facilitate a more human-centric industry, both from a global and European standpoint, the following steps were adhered to:

Using a comprehensive set of keywords (see figure below) that are developed within the project using desk research as well as the study of human-centred patents, project and publications, we identified patents published by the main patent offices that may potentially enable human-centred technologies. Only patents that prominently feature these keywords (in the title or abstract of the patent document) are taken into account.

After analysing global patents, we focused mainly on patents that were published by the European patent office (EPO) and patents that were filed as an international patent application, typically seeking protection status globally. While patents filed in the other main patent offices might capture the current development of technologies potentially enabling human-centricity overall, patents specifically filed for protection within Europe are arguably more relevant for European industry applications.

**Bibliometric analysis:** Through bibliometric analysis, active organisations and countries in the field of human-centricity were identified. Various keyword searches were employed to locate research organisations, key funding bodies, and observe patterns among "active" countries. The analysis commenced with a broad search query using "human-centred" and its spelling variants from 2020 to the present, without restrictions on country, field of science, language, or publication type. Additionally, a similar search was conducted by combining the aforementioned query with a broader range of keywords (such as manufacturing) to detect differences or overlaps. The list of keywords as for the EU projects below was slightly refined for this purpose. These searches were carried out using the Scopus database, chosen for its comprehensive coverage of conference proceedings, a primary source of academic publishing in technological and engineering fields.

**EU projects analysis:** The EU framework programmes serve as the primary EU funding instrument to strengthen the European research area and promote collaboration amongst Member States. Identifying human-centred projects allowed for tracking the evolution of this topic over time, such as by comparing Horizon 2020 with Horizon Europe projects. Additionally, it served as a means to identify key players in the European research landscape. As a deep dive, a case-study approach was employed to a cluster of relevant projects, namely the ACE cluster, comprising of five EU-funded research projects (2016-2020), namely A4BLUE, Factory2Fit, HUMAN, INCLUSIVE, and MANUWORK. Within this cluster, knowledge and technology providers have teamed up with industrial partners to pioneer innovative solutions aimed at bridging the gap toward the factories of the future.

Below is a table enumerating the keywords employed for the analysis of EU projects.

**Table 38 Keywords informing the project, patent and bibliometric searches**

| Category | Keywords |
|---|---|
| Goals/values of HC | human-centred-technology; human-centred-manufacturing; human-centred-industry; people-centred-technology; people-centred-manufacturing; people-centred-industry; user-centred-technology; user-centred-manufacturing; user-centred-industry; worker empowerment; worker augmentation; human augmentation / augmented humanity; augmented intelligence; learning organisation; learning-factory; learning ecosystem, collaborative learning |
| Processes | human-centred design; value-sensitive design; positive design; participatory design; co-design AND human-centred; co-design AND people-centred; inclusive design; user-centred evaluation; inspection-based evaluation; experience-driven design; user modelling |
| Methods | participatory methods; usability test; human-in-the-loop; emotion recognition; intention recognition; proactive ergonomics; contextual Inquiry |
| Technology | Adaptive/adaptable workplace/shop-floor; human-centred workstation/workplace/shop-floor; human-centred artificial intelligence; |

| Category | Keywords |
|---|---|
| | explainable artificial intelligence; cobot/collaborative robot; human-robot-collaboration; human digital twin; human-machine system; human-cyber-physical systems; human-computer-interaction/interface; human-automation-interaction/integration ; human-automation-cooperation; human-machine-interaction/interface; human-technology interaction/interface; internet of everything human-centric-lighting |

Source: Authors

Note: For the individual searches the terminology was adapted as appropriate.

**National programmes**: Examining funded research programmes with a human-centred focus allows for an investigation into the collaborative nature of knowledge production. The goal of this analysis was to comprehend if (and how) the topic is approached at the national level.

**Start-up analysis**: In this start-up analysis, companies operating in the human-centric technology sector were profiled. The focus of the analysis was on exploring their business models, products, services, and innovation strategies. By identifying emerging players and disruptive innovations, this analysis offers insights into the entrepreneurial dynamics and potential disruptors within the ecosystem. The database used for this analysis is the commercial platform Crunchbase. Presented below is a table listing the keywords employed in the start-up analysis:

**Insights from the three organised workshops** played a role in contributing to the gathered insights.

**Table 39 Keywords used in the start-up search**

| Category | Keywords |
|---|---|
| Technology groups already predefined in Crunchbase | Internet of things, Artificial Intelligence, Augmented/Virtual Reality, Robotics, Industrial Automation; Human Computer Interaction; Industrial Manufaturing |
| Standalone keywords to be searched in the company's description | Cobot; collaborative robots; human-machine collaboration; human-robot interaction; wearable devices; Safety systems; exoskeletons; smart wearables; human-centric; education technologies worker augmentation; workforce analytics; skills analytics; coaching and career navigation; collective intelligence; learning & development; human resources technologies; organisational upgrade; teal; e-learning; workplace tech; employee experience; remote work; collaborative work management; human-centric; workers safety; ergonomics, work augmentation; |

Source: Authors

The concept of “human-centric” (or its direct translation) may not universally encapsulate the idea of human-centricity in all languages. Different languages may employ terms that better align with their respective cultural contexts.

In this study, we primarily gathered information using the term “human-centred” (or its various spellings) for EU-level searches in English. We also conducted broader searches, as previously mentioned. For searches at the national level, we extended our scope to encompass terms like 'human focused' or 'human-friendly'.

An illustrative example is the "Human-friendly automation" value manifesto, which strives to advance knowledge in AI and digital automation for the effective organisation of human work. This initiative, driven by industry, advocates for principles such as "Humanity and Autonomy", "Openness & Transparency", "Development & Empowerment", and "Holism & Long-term orientation" – employing very similar terminology to describe human-centricity.

Overall, the insights gained from the research methods provide a comprehensive view of the current state of human-centric technology, user perspectives, technological advancements, and the impact of entrepreneurial initiatives.

**Roadmapping activities via stakeholder engagement**

Technology and industry technology roadmaps have become widely used in the past for the management of complex technologies where a number of different actors are involved, who only jointly can master specific challenges. Roadmaps align the activities in an industry and are particularly helpful to reduce uncertainty and give orientation for different organisations.

Roadmaps are strategic plans with a clear timeline showing the paths or routes for reaching specific goals. Roadmapping is a goal-oriented approach supporting the development of complex solutions, technologies, products or processes. Different types of roadmaps can be classified for different applications and actors. More broadly, science roadmaps, technology roadmaps, industry technology roadmaps, product technology roadmaps and product-portfolio roadmaps have been described in the literature.[118] While the former three types of roadmaps cover the development of a specific scientific field, technology or industry, the latter two specify in more detail the long-term strategy of companies for development products grounded on different technologies.

A roadmap can help to align the activities of different actors and is also crucial for research, technology and innovation policy to base their decisions on a commonly agreed plan. Thus, decision makers in firms, research actors, funding agencies and ministries are amongst others the target groups addressed by a roadmap.

In the context of long-term planning of research, technological development and innovation the European public-private partnerships regularly develop roadmaps, referred to as Strategic Research and Innovation Agendas (SRIA). In this context, for instance, the Processes4Planet or Made in Europe partnership could be mentioned which published

[118] Kappel (2000): Perspectives on roadmaps: how organisations talk about the future, in: The *Journal of Product Innovation Management*, 18, pp. 39-50

SRIAs. These roadmaps define specific pathways, technologies and needs for the development and deployment of specific technologies for the manufacturing industry in Europa to address sustainability and competitiveness goals.

Moreover, in the context, of Industry 4.0 companies, interest groups and academics have developed roadmaps.[119] However, roadmaps for industry 5.0 or roadmaps specifically focussing on human-centricity have to the best of our knowledge not been published so far.[120]

Some institutions and studies have been published in the past to give advice how to effectively develop roadmaps (Guidelines), which will be described briefly next and delivers a first departure point for the further discussion.

The International Energy Agency (IEA) has promoted the development of roadmaps to support the transformation of the energy and industrial sector and has published a series of global roadmaps devoted to low-carbon energy technologies. The IEA argues that roadmaps allow achieving consensus for the development of specific technologies, help to priorities technology development but also point on policy and regulatory frameworks, investment needs and public engagement.

The IEA Energy Technology Roadmaps Guideline, for instance, serves as a point of departure for the design of a couple of roadmap on the national and international level, not only focussing in the energy-related topics.[121] IEA suggests four steps for the development of roadmaps encompassing:

- Planning and preparation
- Visioning/roadmapping
- Roadmap development
- Roadmap implementation and revision

Planning and preparation include the selection of methodologies used in the workshops as well as data analysis and research for already existing strategies and projects.

The roadmapping phase is a crucial and important step when developing roadmaps. It was decided to formulate a generic vision valid for all industry sectors and to define more specific sectoral visions addressing specifics of each industry. Goals defined by policy such as the EU's 2050 targets and the Paris Agreement usually serve as important orientation for developing the roadmaps.

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[119] See for instance for the case of companies: https://www.prosysopc.com/blog/industry-4.0-roadmap/; and: Ghobakhloo, M. (2018): The future of manufacturing industry: a strategic roadmap toward Industry 4.0, *Journal of Manufacturing Technology Management* Vol. 29 No. 6, pp. 910-936

[120] Although not a roadmap in the traditional sense, mentioned can be the paper of Pizon, J., Gola, A. (2023): Human–Machine Relationship—Perspective and Future Roadmap for Industry 5.0 Solutions. *Machines* 2023, 11, 203

[121] IEA (2014): *Energy Technology Roadmaps a guide to development and implementation*, International Energy Agency, Paris.

Based on the vision, specific R&D themes and topics with a timeline for the short-, medium, and long-term development can be defined in a participatory process with different stakeholder groups and technical experts. Based on a back casting approach the participants are asked to define those R&D projects that are required to reach the vision.

Besides the definition of R&D priorities and projects specific policy measures and framework conditions can be identified which are considered as important complementary activities to be realised to achieve the vision. Thus, a roadmap defines how and over which timeline to develop the processes and technologies including also supporting activities as logistics, awareness, legislation, i.e. framework conditions.

The Science, Technology and Innovation Policy Roadmap Guideline for the SDGs published by the inno4s network is another framework that proposes the following six steps for developing roadmaps:

1. Scope and ambition
2. Baseline analysis
3. Vision and goals
4. Innovation pathways
5. Policy action plan
6. Implementation and policy learning

Before starting with the development of the roadmap, the scope of the roadmap and the strategic context needs to be defined in a pre-stage. The time horizon, the boundaries, purpose, the target groups and the governance approach (e.g. steering committee) are to be fixed. Specific sectors or value chains needs to be defined in collaboration with the contracting authorities of a roadmap. The entire process is a highly participatory process and involves the engagement of various experts from different areas and countries from industry, academia, intermediaries, interest groups and policy.

Both frameworks have also been taken into account during the preparation of the ERA Industrial Roadmap for Low-Carbon Technologies and the Roadmap on Circular Technologies.

Depending on the specific context and goal, roadmaps reveal different element. Traditionally, technology roadmaps reveal information about the steps for the development of different technologies, typically assessed by the development stage (e.g. TRL) and the relationship to each other aiming to reach a certain goal.[122] The goal and results of the technological development usually allows to develop new products and services which finally are launched in the future on different markets.

Apart from the planning of the technology portfolio the required R&D themes (R&D Programme) the technological development is based upon might be described in more

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[122] E.g. Phaal, R., Muller, G. (2009): An architectural framework for Roadmapping: Towards visual strategy, in: *Technological Forecasting and Social Change*, 76.

detail in a roadmap. Important development steps in relation to infrastructures, human resources and the input resources might be planned as well.

Although, there is not standard for the architecture of a technology roadmap and specific goals and the technological and sectoral context need to be taken into account, technology roadmaps reveal at least three types of elements:

- **Resources** (e.g. infrastructure, skills, material).
- **Technologies** (e.g. pathways, milestones on the short, medium and long term).
- **Applications and context** (e.g. products, solutions, markets, social trends).

In total, three workshops with multiple stakeholders were carried out.

# ANNEX 3 ANALYSIS OF SOCIAL, DEMOGRAPHIC AND WORKFORCE TRENDS

### Demographic trends

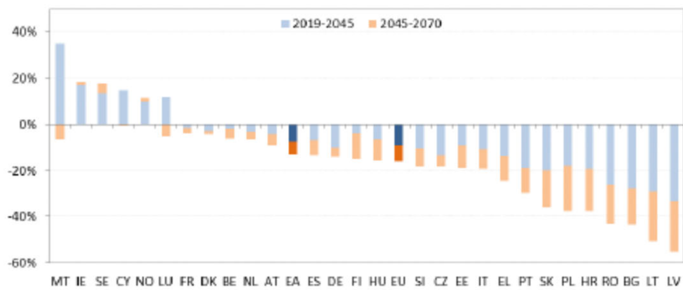
The projected demographic shifts necessitate consideration from various perspectives. In 2030, Eurostat projects for the EU a total population of 449 million. This number decreases successively to 447 million in 2040 and 441 million in 2050.[123] The **population decline** varies between the MS. While some still grow until 2030, (e.g., Spain, Germany) others will already see a large decrease (e.g., Italy, Poland, or Romania).

The European Commission provided in its Ageing 2021 Report projections on the changes of the population up to 2070, suggesting a significant **change in the age structure** with the effect of a severe decrease of the population 0 to 69 – of which typically the age group of 15 or 20- to 64-year-old ones is considered potential working-age population.[124] The European Commission report limits the working-age population to the group 20- 64, and shows that the participation rate of the group of 20-24 years in the labour market decreased and continues to decrease due to longer education periods. The size of the **EU labour supply is expected to decrease** by 16 over the projection horizon, with the largest decline in labour supply for males. Overall, the projections expect an increased participation rate of those aged 20-64 from 78.2 in 2019 to 80.7 in 2070. This would be mainly driven by a higher participation of women and older workers (55-64 years old)[125]. The projected decline in the labour supply is particularly strong until 2045.

### Pressures on the workforce

The overall population decline in Europe and the expected lower share of available workforce is coupled with a replacement demand – people who leave the labour market due to retirement, relocation, or other personal reasons.

**Figure 28 Percentage change in labour supply of population 20-64 years, 2019-2070**




Source: European Commission, the 2021 Ageing Report

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[123] Eurostat EUROPOP2019. Also included in EC (2021): The 2021 Ageing Report

[124] European Commission (2021), The 2021 Ageing Report. Economic and Budgetary Projections for the EU Member States (2019-2070). https://economy-finance.ec.europa.eu/system/files/2021-10/ip148_en.pdf

[125] European Commission (2021), The 2021 Ageing Report. Economic and Budgetary Projections for the EU Member States (2019-2070), p32.

There are substantial differences in labour supply projections across Member States. They range from an increase of 26 in Malta to a fall of 48 in Latvia. The labour force would be larger in 2070 than in 2019 for only five Member States (Malta, Ireland, Sweden, Cyprus, Luxembourg). In six other Member States (Poland, Croatia, Romania, Bulgaria, Lithuania and Latvia), labour force is predicted to shrink by a third or more.

The decline in labour input will affect overall GDP growth – the Ageing Report 2021 indicates that "Most EU Member States are projected to experience null or negative contributions of labour input, due to adverse demographic developments"[126], the exemptions where labour will contribute to growth are Denmark, Ireland, France, Cyprus, Luxembourg, Malta, and Sweden. Therefore, GDP growth needs to be almost entirely driven by labour productivity. In a number of countries, in particular catching-up EU-15 MS, an increase in capital intensity will contribute to the growth.

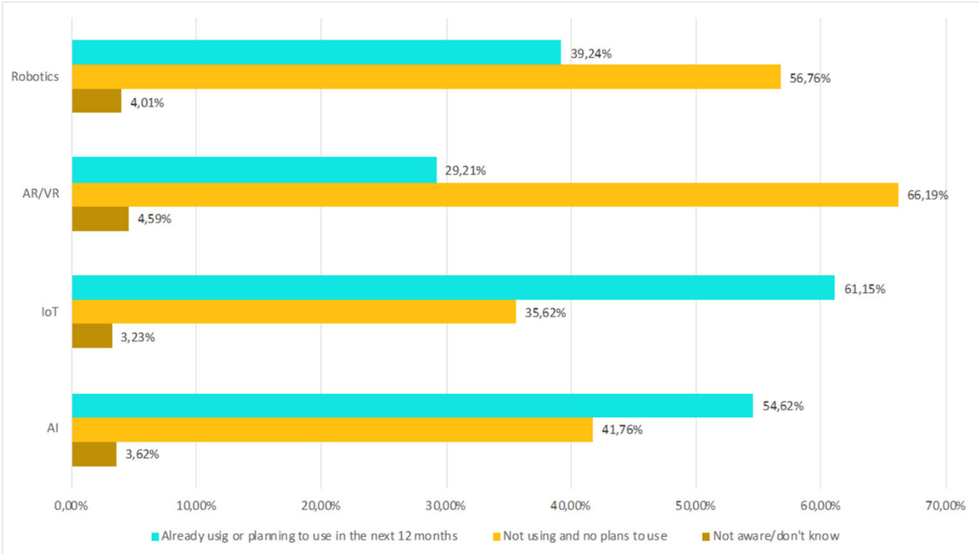
Besides the demographic pressures, there are policies that affect the supply and production processes, in particular the Green Deal and the Fit for 55 strategy. Both are factored in projections by CEDEFOP on future skill demand. Why do these strategies matter? For economic sectors, this would imply fewer activities in some energy-related sectors and more activities in manufacturing sectors such as renewables and energy-efficient equipment. The circular economy will also be reinforced (CEDEFOP 2023). These are politically driven trends which companies have to bear in mind and implement in their strategies and investment decisions, and which will directly or indirectly impact their production processes and workforce.

**General technology factors**

Several indicators can be used to tell the story about the current situation. While some advanced technologies such as augmented reality/virtual reality are often considered human-centred, others may offer more potential. Therefore, the adoption level provides relevant information. The ATI survey 2018 which covered seven EU- MS (DK, FR, DE, IT, PL, ES, SE) asked about the implementation status of several advanced technologies.

[126] European Commission (2021), The 2021 Ageing Report. Economic and Budgetary Projections for the EU Member States (2019- 2070), p 40.

**Figure 29 Status of selected adopted advanced technologies (2018)**




Data: ATI, Source: Technopolis Group

The survey highlights four technologies of particular interest: robotics, augmented and virtual reality (AR/VR), Internet of Things (IoT), and Artificial Intelligence (AI). In summary, IoT boasts the highest adoption rate at 60, followed by AI (54), robotics (40), and AR/VR with the lowest adoption at 30. Noteworthy are the findings regarding the percentage of respondents who neither use nor plan to use these technologies. In this regard, AR/VR is the least favoured, with two-thirds of respondents showing disinterest, followed by robotics, which more than half of the respondents (56) have no immediate plans to implement.

At the national level, disparities in adoption rates are evident. Sweden, for instance, leads in IoT, robotics, and AR/VR, often closely followed by Denmark, where adoption ranges from 30 to 40 in these technologies, except for AR/VR. Conversely, Poland has the lowest adoption rate for these four technologies, but the highest per- centage of respondents who do not use them and have no intentions to do so.

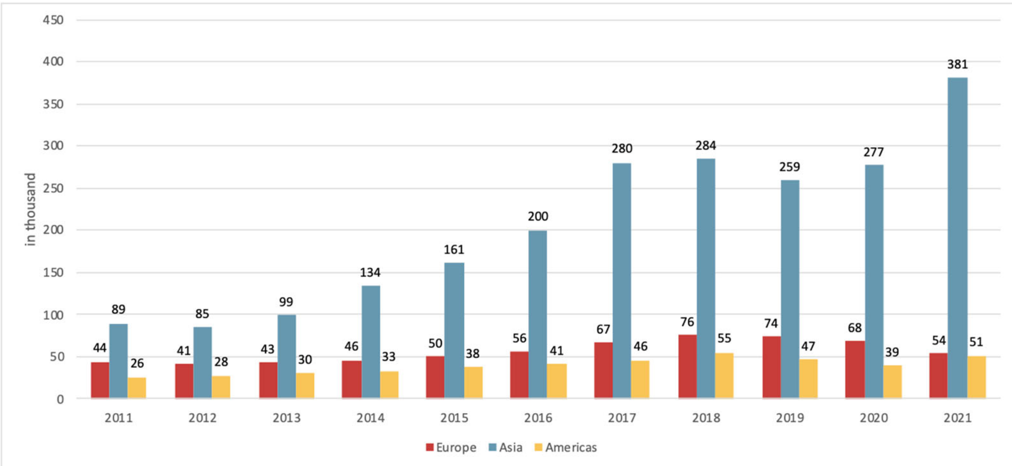
Within each technology, varying levels of adoption are observed. For example, in AR/VR, the proportion of those who have already implemented the technology ranges from 9 in Germany to 20 in Sweden. As for AI, the percentage of respondents who have no plans to use it ranges from a low of 16 in Sweden to a high of 40 in Poland.

The increasing prevalence of industrial robots, often operating autonomously and primarily deployed to en- hance production efficiency, serves as a clear indication of the ongoing transformation in industrial production processes. Notably, the majority of these robots are concentrated in Asia. According to the International Federation of Robotics (IFR, 2022), the electronics industry surpassed the automotive sector in terms of annual installed robots in 2020.

In 2021, a significant portion of installations (26) occurred within the electronics industry, closely followed by the automotive sector (23), with parts suppliers driving the latter's growth. Other notable sectors include the metal and machinery industry (12), plastics and chemical products industry (5), and the food and beverages industry (3). As of 2021, the industrial robot stock in Europe stood at 678,000 (IFR, 2022). Europe has experienced an average annual growth rate of 8 since 2016, while Asia has seen a more rapid growth rate of 14.

When examining robot density, Europe had 129 units per 10,000 employees, compared to Asia with 156 units and the Americas with 117 units. Notably, in 2021, four out of every five installations were concentrated in five countries: China (52), Japan (9), the USA (7), the Republic of Korea (6), and Germany (5).

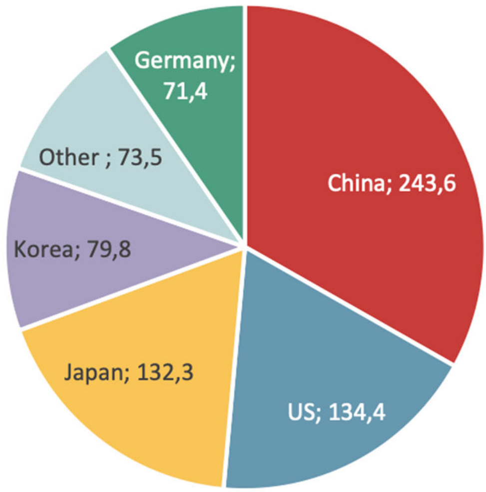
**Figure 30 Annual installation of robots Europe – Asia – Americas (2011-2021)**




Source: IFR: World Robotics 2022 Industrial Robots

In relation to dominance of annual installation of industry robots in Asia, the figure below displays that the project sales of collaborative robots worldwide in 2025 will be led by China, United States and Japan.

**Figure 31 Projected sales of cobots worldwide in 2025 (in million)**




Source: Statista. Projected sales of collaborative robots worldwide in 2025, by main country. https://www.statista.com/statistics/748142/estimated-collaborative-robot-sales-worldwide-by-main-country/

## General skill trends

Currently, and as anticipated in the short and long run, a skills gap exists. In high-demand occupations, there is a shortage of individuals possessing the requisite skill set. Conversely, in occupations that are becoming obsolete, there is an excess of individuals.

There are initiatives that assess the extent to which jobs are likely to change or become obsolete due to digital technologies[127] as well as forecasts on the professional areas where shortages are expected and where there is a skills surplus (CEDEFOP 2016). Drawing from CEDEFOP's Skills Forecast project and its established database[128], we have access to data regarding the demand and job openings for various occupations from 2010 to 2035.

For instance, let us consider *'Plant and machine operators and assemblers'* (ISCO 8) and *'Technicians and associate professionals'* (ISCO 3), key occupations in manufacturing processes. The projected data between 2025-2035 shows an average annual increase of 0.8 for the former and 1 for the latter technicians. This growth rate is somewhat lower than that for higher-skilled *'Professionals'* (ISCO 2), which experience an average annual increase of 1.3. In absolute numbers, this translates to an additional demand of 7 million plant and machine operators and assemblers, approximately 17 million technicians, and nearly 26 million professionals in the EU.

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[127] For example, the Jobfuturomat of the German Institute for Employment Research (IAB). Access at: https://job-futuromat.iab.de/en/

[128] CEDEFOP. Digitalisation AI and Future of Work. Access at: https://www.cedefop.europa.eu/en/projects/digitalisation-and-future-work. The forecasts adjust the Eurostat forecasts by integrating the Green Deal and Fit for 55 strategies and the effects of the COVID-19 pandemic. Compared to the EUROSTATPOP2019 estimates, the CEDEFOP estimates are more pessimistic.

When comparing the two key variables of replacement demand and expansion demand (which together determine the net number of job openings) for the past decade (2010-2020) with a projected period such as 2025-2035, we observe significant differences. In the past decade, there was a high annual average growth in the expansion demand for technicians (almost 30) and professionals (~20). Conversely, there was negative growth and an absolute decline of -1.3 for plant and machine operators.

Digitalisation has already had an impact on the jobs of plant and machine operators. While there is still demanded to replace personnel, there is no growth impetus in terms of expansion. According to the analysis of the job futuromat (see footnote 127), 5 out of 6 core tasks of machine and plant operators (83) can be automated. This includes tasks such as machine/plant setup, operation, and quality inspection/assurance. The only core task not susceptible to automation is servicing, repair, and maintenance.

This transformation exemplifies how jobs are changing in terms of tasks. Several tasks may disappear due to automation[129], but this shift equally provides opportunities for job enrichment. While heavy or monotonous tasks may be replaced by automation, **workers may transition to more engaging and enriching jobs**. However, this often requires **upskilling and training** to learn and perform other tasks, which aligns with the human-centred approach.

The demographic effects, coupled with the impact of digitalisation on the workforce and their current and future skills potential, may pose a significant challenge for companies and management.

**Accidents at work**

A key factor for worker's well-being is the fact to remain unharmed. A decreasing accident at work rate is therefore an important indicator. According to Eurostat, in 2021 there were 2.88 million non-fatal accidents at work that resulted in at least four calendar days of absence of work. Almost 3.350 accidents were fatal. Most accidents happen in the construction sector, followed by mining and manufacturing. In terms of fatal accidents per 100 000 employed persons (incidence rate), the Netherlands is the safest workplace with less than 0.5 fatal accidents (followed by Greece, Finland, Sweden and Germany) while Latvia has the highest rate with 4.29 fatal accidents (followed by Lithuania, Malta, France, and Romania).[130]

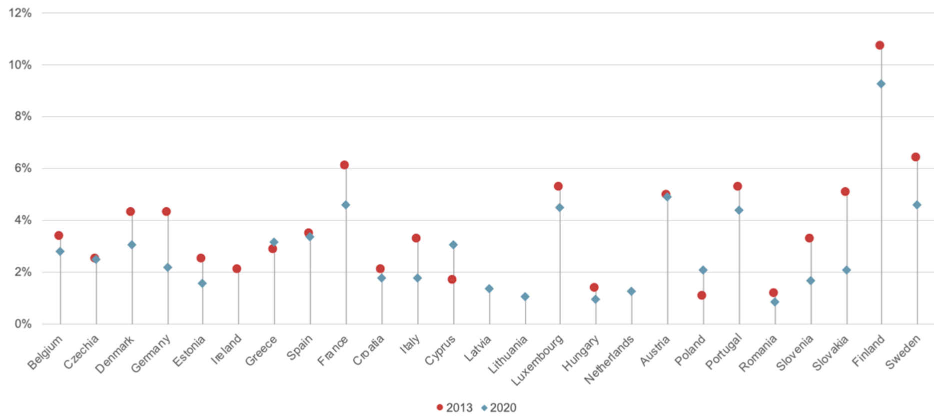
Reporting on non-fatal accidents at work as included in is somewhat more problematic. Very low numbers may suggest an under-reporting problem: workers may have no incentive to report, little compensation, or there are non-binding legal obligations for the employers. Very low numbers of non-fatal accidents were reported in countries with rather high fatal accidents rates such as Romania, Bulgaria, Latvia, and Lithuania while insurance-based accident reporting countries such as France, Portugal or Spain report very high incidences.

[129] See for example Nedelkoska, L. and G. Quintini (2018), "Automation, skills use and training", OECD Social, Employment and Migration Working Papers, No. 202, OECD Publishing, Paris. http://dx.doi.org/10.1787/2e2f4eea-en

[130] Eurostat: Statistics Explained - Accidents at work statistics https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Accidents_at_work_statistics

The manufacturing sector had the highest share of non-fatal accidents (almost 20) and the third highest in terms of fatal accidents (15) in 2021.

**Figure 32 Accidents at work**




Data: Eurostat, LFS - hsw_ac5b

# ANNEX 4 INDUSTRY OPPORTUNITIES IN A RESOURCE-CONSTRAINED AND GEOPOLITICALLY COMPLEX GLOBAL ENVIRONMENT

In the industrial context, the demand for a more human-centred approach has arisen due to concerns that traditional methods of technology design often disregard the skills of users, resulting in a diminished overall quality of the work experience[131]. It is important to note, however, that the industry must consider several conditions and needs before developing, upgrading, or adopting human-centred technology. Specifically, these industry needs include:

- Replacing existing tools and machines with advanced manufacturing technologies such as robotics and IoT.
- Seeking consultation and advice on the development and adoption of human-centred technology.
- Ensuring access to a skilled workforce capable of effectively using human-centred technology.
- Allocating investments dedicated to the purchase, development, or upgrade of human-centred technologies.
- Complying with regulations, addressing ethical issues associated with new technologies, and leveraging the opportunities presented by human-centred technology to address societal challenges.

The aforementioned needs are not comprehensive, not presented in a prioritised order, and are derived from workshops and interviews with HCT ecosystem key stakeholders.

**Technology adoption as an opportunity for a more human-centric industry**

A fundamental assumption for the adoption of Industry 5.0 and a human-centric approach is the replacement of current tools and machines with advanced manufacturing technologies such as robotics and IoT. To gain a better understanding of whether companies in the manufacturing industries are indeed acquiring new or up- graded machinery, equipment, or software, we can analyse data from the Community Innovation Survey (as shown in Figure 2). Although this data is available for only 17 European Union Member States (EU-MS), it provides valuable insights into the sectors where the adoption of new technologies has taken place or not.

One of the most striking observations is that in nearly all industries and countries, the emphasis appears to be on acquiring existing (i.e., the same) or improved equipment rather

[131] Gasson, S. (2003). Human-centred vs. user-centred approaches to information system design. Journal of Information Technology The- ory and Application (JITTA), 5(2), 5.

than entirely new technology. This trend is depicted by the predominant blue areas in the lower section of Figure 7. In contrast, in the upper part, where industries are categorised under 'Purchase... of new technology,' we notice that the lowest adoption rates (in darker red) are most noticeable in Romania, Spain, and Poland. On the other hand, Greece and Cyprus demonstrate relatively high rates of adopting new technology. It is worth noting that Spain, Poland, Romania, and Slovakia exhibit relatively low levels of investment in both existing and new machinery and equipment.

Upon closer examination of the data by industry sector, we find that the acquisition of new technology is mainly concentrated in a few sectors, including pharmaceuticals, chemicals, machinery and equipment, and computer, electronic, and optical products.

What do these indicators say about a potential wider diffusion and implementation of Industry 5.0 principles? If we take the technological basis, it seems that the choice of existing or improved technology over entirely new technology can be attributed to several factors. These include organisational factors such as a lower level of digitalisation, as well as a limited capacity to incorporate new (especially critical or high-tech) solutions in workplace environments. This is linked to established industrial structures. In industries traditionally labelled as low-tech, the cost-effectiveness of high-tech machinery and advanced manufacturing technologies might be overshadowed by the advantages of manual labour. Beside efficiency factors that render labour simply cheaper than capital, the available workforce may also not possess the requisite skills to effectively adopt new technology.

## Figure 33 Shares of enterprises that purchased machinery, equipment or software

| | Manufacture of... | Bulgaria | Czechia | Estonia | Greece | Spain | Croatia | Italy | Cyprus | Latvia | Lithuania | Hungary | Malta | Poland | Portugal | Romania | Slovenia | Slovakia |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Purchase of machinery, equipment or software based on new technology | **Manufacturing** | 16,2 | 21,0 | 22,1 | 49,2 | | 30,0 | 29,6 | 57,7 | 24,7 | 21,1 | 24,7 | 31,8 | 18,8 | 34,0 | 7,5 | 28,3 | 25,2 |
| | food products; beverages and tobacco products | 14,1 | 22,0 | 20,4 | 49,9 | 10,9 | 22,2 | 40,2 | 65,2 | 22,1 | 24,9 | 24,0 | 20,0 | 16,2 | 33,7 | 2,2 | 23,6 | 25,6 |
| | textiles, wearing apparel, leather and related products | 7,8 | 13,8 | 11,0 | 39,1 | 7,5 | 25,7 | 17,9 | 50,0 | 10,4 | 21,9 | 9,8 | | 9,0 | 26,8 | 4,6 | 29,4 | 28,5 |
| | wood, paper, printing and reproduction | 17,5 | 20,4 | 21,7 | 50,2 | | 29,3 | 32,1 | 47,9 | 24,6 | 17,2 | 22,2 | 46,4 | 20,7 | 31,7 | 6,0 | 24,3 | 31,5 |
| | chemicals and chemical products | 28,9 | 33,7 | 20,6 | 60,7 | 19,5 | 40,0 | 35,9 | | 39,5 | | 30,5 | 0,0 | 19,1 | 48,0 | 12,4 | 38,1 | |
| | basic pharmaceutical products and pharmaceutical preparations | 34,5 | | 14,3 | 75,0 | | 43,1 | 54,0 | 83,3 | 54,5 | | 51,6 | 63,6 | 22,0 | 65,2 | 19,7 | 62,5 | 67,5 |
| | rubber and plastic products and other non-metallic mineral products | 17,8 | 18,3 | 17,0 | 47,9 | 10,4 | 33,4 | 33,1 | | 29,9 | 17,4 | 24,7 | 28,8 | 21,4 | 35,3 | 9,2 | | 22,2 |
| | basic metals and fabricated metal products, except machinery and equipment | 17,8 | 18,4 | 28,8 | 53,7 | 10,1 | 28,5 | 27,6 | | 33,1 | 18,6 | 24,9 | | 19,7 | 38,4 | 12,3 | | 21,1 |
| | computer, electronic and optical products | 26,8 | 31,8 | 40,0 | 53,3 | 18,6 | 37,5 | 44,2 | | 32,5 | 40,0 | 38,9 | 62,5 | 23,0 | 55,6 | 15,4 | 43,6 | 23,9 |
| | electrical equipment | 24,6 | 30,8 | | 61,6 | 16,8 | 52,5 | 33,8 | | 29,2 | 32,1 | 26,5 | 41,7 | 26,9 | 30,2 | 14,0 | 47,3 | 33,0 |
| | machinery and equipment n.e.c. | 29,9 | 21,3 | | 46,6 | 13,4 | 43,5 | 27,9 | 61,5 | 23,2 | 28,2 | 31,6 | 36,4 | 19,8 | 40,6 | 12,5 | 28,6 | 20,0 |
| | motor vehicles, trailers and semi-trailers | 21,3 | 29,9 | | 48,4 | 14,6 | 34,3 | 44,7 | | 27,8 | | 36,3 | 66,7 | 28,5 | 41,4 | 13,2 | | 37,0 |
| | other transport equipment | 28,0 | 25,3 | | 62,9 | 12,5 | 32,3 | 27,2 | | 11,1 | | 20,7 | | 23,6 | 74,4 | 6,7 | | 16,1 |
| | furniture; jewellery, musical instruments, toys; repair and installation of machin | 16,2 | 18,6 | 26,1 | 45,4 | 7,8 | 29,9 | 27,6 | 67,6 | 22,6 | 18,4 | 22,0 | 25,5 | 18,0 | 37,3 | 8,9 | 23,5 | 22,4 |
| | Other manufacturing | 18,7 | 24,3 | | 56,0 | 10,3 | 47,0 | 33,6 | 83,3 | 22,7 | | 20,1 | 53,8 | 19,4 | 34,8 | 5,8 | | 19,4 |
| Purchase of machinery, equipment or software based on the same or improved technology | **Manufacturing** | 37,6 | 50,9 | 72,0 | 67,1 | | 59,0 | 69,1 | 53,8 | 42,7 | 50,9 | 56,8 | 81,3 | 33,7 | 57,9 | 29,3 | 75,0 | 39,3 |
| | food products; beverages and tobacco products | 35,6 | 48,8 | 68,0 | 64,3 | 31,2 | 59,1 | 68,4 | 55,4 | 37,5 | 50,4 | 51,5 | 89,2 | 33,4 | 54,9 | 32,7 | 74,4 | 45,6 |
| | textiles, wearing apparel, leather and related products | 23,7 | 42,6 | 63,7 | 55,9 | 26,9 | 53,5 | 60,3 | 43,8 | 34,3 | 43,8 | 40,4 | | 23,0 | 46,9 | 18,4 | 67,8 | 34,6 |
| | wood, paper, printing and reproduction | 41,1 | 49,2 | 78,0 | 61,8 | | 61,6 | 64,4 | 49,2 | 34,5 | 49,0 | 55,7 | 75,0 | 34,7 | 52,1 | 21,1 | 67,2 | 35,6 |
| | chemicals and chemical products | 57,2 | 71,8 | 82,4 | 76,5 | 42,8 | 70,3 | 77,6 | | 67,4 | 76,5 | 59,5 | 71,4 | 38,2 | 68,4 | | 88,0 | |
| | basic pharmaceutical products and pharmaceutical preparations | 72,4 | | 100,0 | 80,4 | | 62,0 | 84,3 | 83,3 | 45,5 | 71,4 | 81,0 | 100,0 | 35,5 | 71,0 | 42,1 | 75,0 | 80,5 |
| | rubber and plastic products and other non-metallic mineral products | 39,7 | 48,0 | 74,5 | 74,3 | 33,1 | 65,5 | 73,5 | | 50,8 | 53,1 | 62,8 | 83,1 | 38,6 | 70,2 | 35,3 | | 41,9 |
| | basic metals and fabricated metal products, except machinery and equipment | 42,9 | 51,9 | 72,4 | 76,4 | 32,4 | 51,4 | 71,8 | | 50,1 | 53,0 | 56,8 | | 34,4 | 62,8 | 35,6 | | 37,7 |
| | computer, electronic and optical products | 55,9 | 60,5 | 80,0 | 80,0 | 40,6 | 50,1 | 76,0 | | 52,5 | 80,0 | 72,6 | 87,5 | 33,9 | 96,4 | 29,2 | 83,2 | 33,7 |
| | electrical equipment | 49,2 | 58,0 | | 69,6 | 38,3 | 66,0 | 74,3 | | 70,8 | 73,2 | 63,3 | 83,3 | 40,8 | 57,2 | 35,9 | 87,2 | 38,7 |
| | machinery and equipment n.e.c. | 56,0 | 50,5 | | 73,3 | 32,1 | 69,8 | 70,7 | 53,8 | 55,6 | 56,5 | 69,7 | 90,9 | 31,4 | 65,1 | 40,9 | 79,3 | 36,9 |
| | motor vehicles, trailers and semi-trailers | 42,6 | 63,4 | | 58,1 | 42,5 | 59,1 | 77,8 | | 61,1 | | 70,6 | 100,0 | 44,3 | 65,1 | 37,3 | | 46,9 |
| | other transport equipment | 68,0 | 53,6 | | 80,0 | 32,2 | 52,2 | 69,2 | | 44,4 | | 52,7 | | 44,2 | 80,5 | 31,4 | | 38,1 |
| | furniture; jewellery, musical instruments, toys; repair and installation of machin | 33,6 | 46,1 | 64,4 | 69,1 | 26,5 | 58,5 | 67,2 | 59,2 | 48,8 | 44,8 | 51,5 | 76,5 | 30,3 | 67,9 | 27,2 | 68,8 | 37,8 |
| | Other manufacturing | 43,1 | 56,2 | | 68,8 | 32,0 | 68,1 | 69,6 | 41,7 | 37,4 | | 48,0 | 84,6 | 32,7 | 58,0 | 23,5 | | 51,6 |

Data: Eurostat, CIS 2020 (inn_cis12_purmes), Figure: Authors

The 2022 EU Survey on Industrial R&D Investment Trends results indicate that companies in the high-tech sectors consider ICT software, services and hardware and adaptation to Industry 4.0 to be of most relevance for their future competitiveness. The medium- and low-tech companies consider that environmental sustainability is absolutely crucial and, as noted above, in conjunction with Industry 4.0. The differences in the relevance of certain forms of capital investment appear to be determined by the technology classes rather than by company size.[132]

The EU Survey on Industrial R&D Investment Trends also captured the opinion of companies on whether they produced new goods or provided new services in 2021 using one or more of a list of technologies. The table provides and overview of technologies related to industry 5.0 that are already used and are being tested, thus potentially adopted in future.

**Table 40 Share of companies that have already adopted advanced technologies or are testing their application in goods and services (table sorted by share of companies that are testing technologies)**

| Technologies related to I 5.0 | Already implemented | Tested |
|---|---|---|
| Augmented reality | 34.8% | 22.8% |
| Additive manufacturing, including prototyping | 40.2% | 21.7% |
| Machine learning | 66.7% | 20.4% |
| Machine vision | 41.3% | 18.5% |
| Robotics | 65.2% | 12% |
| Touchscreens/kiosks for customer interface | 46.2% | 3.3% |
| | | |

Source: Nindl, E., The 2022 EU Survey on Industrial R&D Investment Trends, Publications Office of the European Union, Luxembourg, 2022, doi:10.2760/579174, JRC131984

Machine learning and robotics are already used by two thirds of the responding companies and they are in testing in another 20% and 12% respectively. The most widely tested technologies for producing goods and services include augmented reality, additive manufacturing and machine learning.

The study team further investigated technological uptake within the launched survey. Results show that programmable logic controllers (PLCs) lead in adoption among, with 41% currently using them. Industrial robots follow, with a current usage of 26% and an additional 18% planning to implement them within two years. The use of wearable devices is also notable, with 31% of organisations engaging with these technologies. Artificial intelligence (AI) and big data collaborative robots (Cobots) and extended reality (XR) technologies show less current use but have potential growth, as indicated by the percentage of companies planning to adopt them in the near future. Exoskeletons and automated guided vehicles are currently the least utilised technologies in manufacturing processes amongst the respondents.

According to the survey commissioned for this study, organisations also reported that the most significant costs associated with implementing technologies were incurred in workflow and machinery adjustments. This was particularly the case in larger companies, with those having 50-249 employees and more than 249 employees indicating 25.6% and 21.4% respectively as having high costs in this area. Training and upskilling also represented a notable expense,

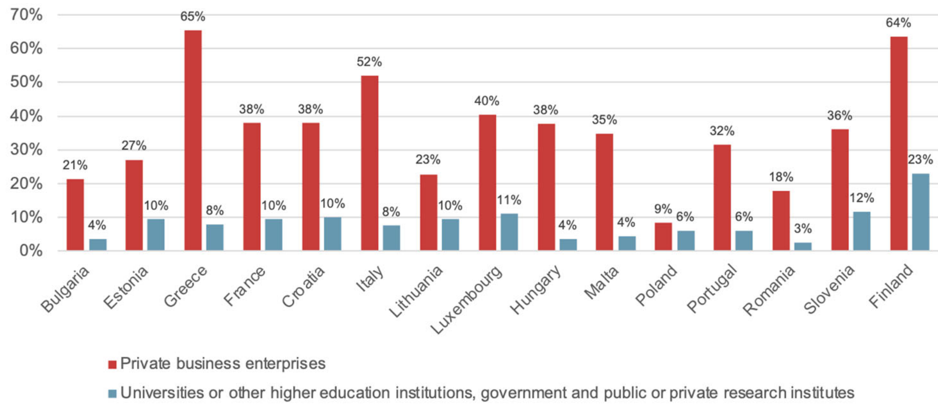
[132] Nindl, E., The 2022 EU Survey on Industrial R&D Investment Trends, Publications Office of the European Union, Luxembourg, 2022, doi:10.2760/579174, JRC131984

especially for firms with 10-49 employees, where 20.9% reported it as a costly aspect. Downtime due to new technology integration and organisational adjustments, such as setting up new teams or job functions, were also identified as significant cost factors across different company sizes.

**Consulting/advisory services**

The figure below illustrates the acquisition of technical services, including consulting, measurement and testing, certification, as well as installation, refitting, or retrofitting services by companies. The data reveals that across the EU-27, the vast majority of enterprises in all industrial sectors predominantly rely on technical services provided by other private businesses. In comparison, universities, research institutes, and other public or private research institutions account for a significantly smaller portion of these services. Only in Finland does this latter group constitute more than 20% of the total. Finland and Greece stand out as the countries with the highest proportions of procured technical services.

**Figure 34 Share of enterprises that purchased technical services by cooperation partner (2018)**




Source: Eurostat: inn_cis11_purts

This was also highlighted in the interviews conducted in the scope of this study with technology providers, where they described that they do not act as only technology providers but are there for the whole process. Where they design and update the technology together with the company as well as train the workers and conduct validations studies to customise the application to worker needs. In some cases, a customer service agreement is set up to ensure the continuity of the relationship with the provider after the technology is purchased and representatives from the manufacturing industry interviewed argued that this is essential to ensure trust in the procedure and overall process as well as to make the application accurate for the needs of the company.

This ongoing relationship with the provider was however described as costly since it requires more resources than if they would develop the technology in-house or buy an off-the shelf product. This challenge was also highlighted in the E&E case study (in annex) where they opted to develop a solution in-house due to the lack of an accurate off-the shelf solution for emerging technologies and use cases. However, the interviewee in the case study reflected that it is often difficult to scale such self-developed solutions as the company grows, thus requiring continuous investments into adapting and improving the solutions down the line.[133]

**Skilled workforce**

The effectiveness and efficiency of technologies deployed with human-centric outcomes in mind depend on a highly skilled workforce. Consequently, it is crucial for companies to invest in the training and education of employees in specialised areas, such as artificial intelligence. Without a well-trained workforce, industries cannot effectively harness the potential of HCT. For a more comprehensive understanding of the necessary skills, the 2019 World Manufacturing Forum Report titled "Skills for the Future of Manufacturing" offers an in-depth analysis. This report extensively explores the prevalent skills gap in the manufacturing sector, identifies the essential skills required by manufacturing workers, outlines the primary methods for assessing and developing these skills, and provides key recommendations to promote a knowledgeable and skilled manufacturing workforce. The table below outlines the critical skills required for the future of the manufacturing industry.

**Figure 35 Overview of skills for the future of manufacturing industry**

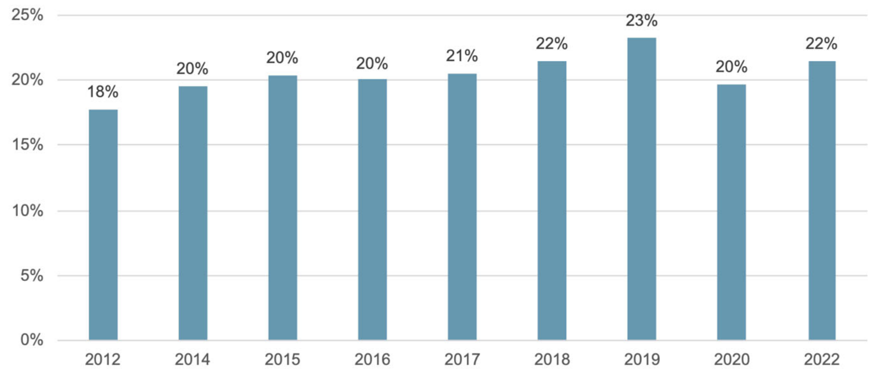
| **Skills for future of manufacturing** |
| --- |
| Digital literacy as a holistic skill to interact with, understand, enable, and even develop new digital manufacturing systems, technologies, applications, and tools |
| Ability to use and design new AI and data analytics solutions while critically interpreting results |
| Creative problem solving in times of abundant data and technological opportunities in smart manufacturing systems |
| A strong entrepreneurial mindset including proactiveness and the ability to think outside the box |
| Ability to work physically and psychologically safely and effectively with new technologies |
| Inter-cultural and -disciplinary, inclusive, and diversity oriented mindset to address new challenges arising from a more diverse manufacturing workforce |
| Cybersecurity, privacy, and data/information mindfulness to reflect the rapidly increasing digital footprint of the manufacturing value chain |
| Ability to handle increasing complexity of multiple requirements and simultaneous tasks |
| Effective communication skills with humans, IT, and AI systems through different platforms and technologies |
| Open-mindedness towards constant change, and transformation skills that constantly question the status quo and initiate knowledge transfer from other domains |

Source: 2019 World Manufacturing Forum Report, Skills for the Future of Manufacturing

[133] Interviews conducted between 16-10-2023 and 3-11-2023 and E&E Case study.

Reflecting this, the figure below indicates that the share of manufacturing companies which provide training to upskill their workers in ICT skills increased within a decade from 18% to 22%. A peak of 23% was reached before the pandemic. Since then, training is slowly returning to pre-COVID levels.

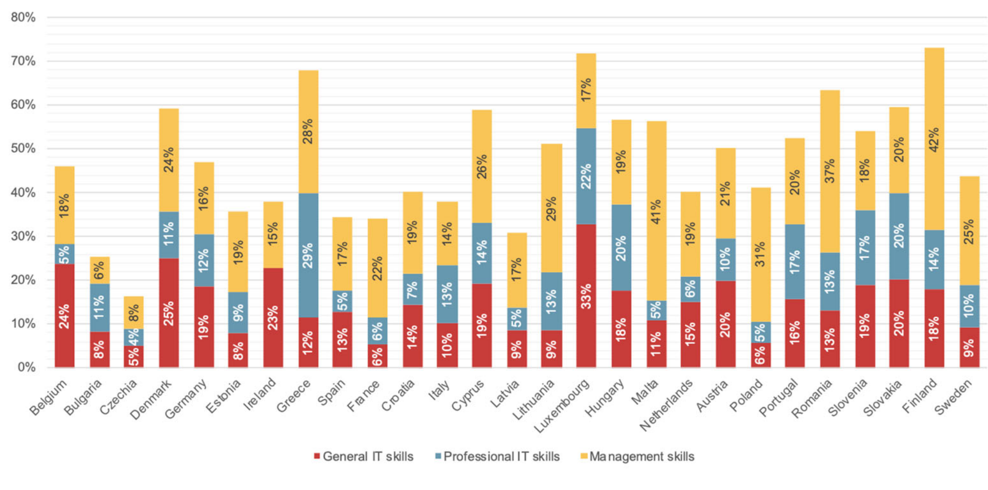
**Figure 36 Share of manufacturing firms that provide training for upgrading ICT skills (2022)**




Source: Eurostat, ISOC_SKE_ITTN2

At the EU level, there is an assessment of Continuing Vocational Training (CVT)[134]. Upon examining the specific skills addressed by these training programmes, it becomes evident that in 2020, the private sector in several EU Member States primarily emphasised the development of management skills, rather than placing a central focus on professional IT skills. However, this situation could be associated with the pandemic, which might have disrupted numerous (physical) industry training courses, while management training could have been more feasible to organise and attend online.

**Figure 37 Main skills targeted by vocational training courses in industry (2020)**



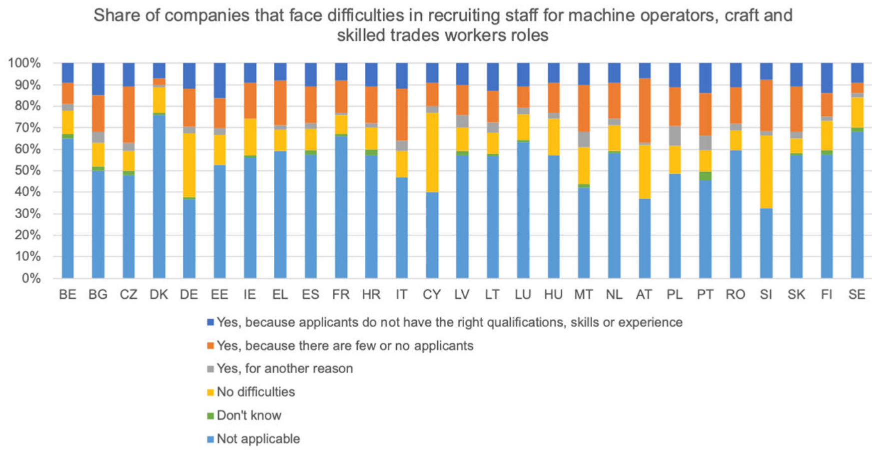

[134] See: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Continuing_Vocational_Training_Survey_(CVTS)_methodology

Data: Eurostat, CVT survey data, see trng_cvt_29n2

The high percentage of companies facing difficulties due to a lack of applicants as shown in the figures above suggests that there may be a need for more targeted recruitment strategies. Companies may need to explore alternative sourcing channels, such as actively engaging with educational institutions, retraining programmes, or even international recruitment to find suitable candidates.

The impact of AI is another important trend that can impact the job quality and skills needed from the employees. A potential mechanism for AI's impact on job quality is that the task composition of jobs changes. To date, AI appears to be automating more tedious, repetitive tasks than it creates, while also broadening the range of tasks performed by workers and aiding them in their decision making[135].

**Figure 38 Share of companies that face difficulties in recruiting staff for machine operators, craft and skilled trades**




Source: Flash Eurobarometer 529 European Year of Skills: Skills shortages, recruitment and retention strategies in small and medium-sized enterprises.

On average, across the EU-27, 16.5% of companies face difficulties as there are few or no applicants, while 11.1% of companies indicated that they face difficulties recruiting for machine operators, craft and skilled trades workers roles because applicants do not have the right qualifications, skills, or experience.

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[135] Green, A., A. Salvi del Pero and A. Verhagen (2023), "Artificial intelligence, job quality and inclusiveness", in OECD Employment Outlook 2023: Artificial Intelligence and the Labour Market, OECD Publishing, Paris, https://doi.org/10.1787/99c4c123-en

# ANNEX 5 HUMAN-CENTRIC DESIGN METHODS

This section outlines in more detail different steps to impelement human-centric design methods.

**Understand and specify the context of use**

When creating a **context specification**, several key elements must be considered. Firstly, the specification should identify the users and other stakeholder groups involved in the system. This includes pinpointing the individuals or groups interacting with the system and having a vested interest in its outcomes. Additionally, understanding user characteristics such as knowledge, capabilities, physical attributes, and experience is crucial. This understanding allows designers to tailor the system to meet the specific needs and abilities of the intended users. Goals and tasks of both users and the organisation also need to be comprehended. This understanding aids in designing a system that aligns with desired outcomes. Lastly, the context specification should encompass various operating environments of the system, including organisational, technical, and physical aspects.

For instance, when customising exoskeletons, the customisation process follows two primary development streams: hardware and software. Hardware development focuses on universality, aiming to create a design adaptable to any body type, irrespective of size, gender, or age. On the other hand, software customisation, leveraging AI technology, addresses inherent differences between for instance male and female body types. Recognising the impossibility of a one-size-fits-all hardware solution, AI-driven software allows the exoskeleton to learn and adapt to individual users over time. This adaptive capability enables continuous customisation to suit various users and settings, enhancing its versatility and effectiveness.[136]

**Specify the user requirements**

To emphasise the importance of user requirements, the HCD process produces an explicit statement of user requirements. The statement should begin by clearly defining the intended context of use for the product or system being designed. This includes considering the specific scenarios, environments, and conditions in which the users will interact with the product. Furthermore, the user requirements should be based on a thorough understanding of the user's needs and the context in which the product will be used. Further, requirements related to relevant ergonomics and user interface knowledge, standards and guidelines, and usability need to be considered. Furthermore, the user requirements should also take into account any requirements derived from the organisational context. This includes aligning the design with the strategic goals, policies, and constraints of the organisation. By doing so, the resulting product will not only meet user needs but also align with the larger objectives of the organisation.

During the process of defining user requirements, it is common to encounter conflicting requirements. In such cases, it is crucial to resolve these conflicts by carefully considering the trade-offs and documenting the rationale behind the decisions made. This allows for transparency and facilitates future decision-making processes.

[136] Interviews conducted between 16-10-2023 and 3-11-2023.

**Produce design solutions to meet user requirements**

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During the process of defining user requirements, it is common to encounter conflicting requirements. In such cases, it is crucial to resolve these conflicts by carefully considering the trade-offs and documenting the rationale behind the decisions made. This allows for transparency and facilitates future decision-making processes.

**Produce design solutions to meet user requirements**

Design solutions are generated by considering the context of use, baseline evaluations, state-of-the-art in the application domain, design and usability standards, and the expertise of a multidisciplinary team. Co-Design and Participatory Design approaches show how to involve non-designers in design activities to ensure that their needs for the future are met. The significance of those approaches was also highlighted during interviews with technology providers specialising in human-centric technologies. Interviewees indicated that the connections with researchers, including social scientists and UX designers play a key role in co-design and/or participatory design. According to the experience of the interviewees, the EU research projects have been crucial to establishing such connections, some of which have later been adopted in industry settings.[137]

Approaches like these provide individuals with a framework to envision and articulate their desires, needs, and concerns for future experiences. This phase not only allows organisations to concentrate on empowering work processes but also emphasizes preserving the cognitive aspect of work throughout the entire company's workforce. However, **the effectiveness of these efforts significantly depends on the organisation's high learning capacity.**

As a result, companies must foster an environment that encourages autonomy in cognitive tasks, intrinsic motivation, social support, supportive supervisory styles, worker training, and direct participation practices.

**Evaluate design against requirements**

User-centred evaluation proves valuable at all stages of a project, from its initial conception to later phases. They serve to gather fresh information about user needs, offer feedback on design solutions, or assess the design against various requirements like user needs, organisational goals, safety, and more.

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[137] Interviews conducted between 2023-10-16 and 2023-10-28.

There are two primary types of evaluation approaches: user-based and inspection-based. User-based evaluations involve directly engaging users in the evaluation process, seeking their feedback and insights on the design. Inspection-based evaluations, on the other hand, rely on established usability or accessibility guidelines to evaluate the design. Both approaches offer their own advantages, providing valuable insights during the evaluation process.

Additionally, evaluations should cover both short-term assessments and long-term monitoring of systems. Short-term evaluations occur during the development process, aiming to gather immediate feedback and pinpoint areas for improvement. On the contrary, long-term monitoring involves continual assessment of the system's performance, usability, and user satisfaction after its deployment. This ongoing evaluation aids in identifying potential issues or areas for enhancement in future updates or iterations.

However, according to the interviewees, conveying the benefits of large-scale user validation studies and similar tools for ensuring human-centric aspects to company's management is challenging. While such studies were seen as pivotal for enhancing user experience, the unclear return-on-investment thanks to the typically high degree of required customisation was often reported as a barrier for the adoption of human-centric approaches to technology implementation. According to interview representatives, every addition made from a human-centred design perspective was associated with increased costs, requiring robust justifications for these expenses.

Implementing studies involving up to 140 participants to replicate real-world scenarios also proved difficult due to regulatory constraints. Despite the complexity and scale of these studies, there was a strong push to complete them within a tight timeframe. Maintaining exceptionally high-quality standards further compounded the complexity of these endeavours.

Moreover, in user experience investigations, comprehensive studies involving up to 140 participants were needed to implement a "real world settings" which also showed difficult due to regulations. Despite the scale and complexity, there was a push to complete these studies and obtain results within a short timeframe. Furthermore, maintaining exceptionally high standards of quality added another layer of complexity.

In the context of advancing the development and adoption of human-centred technologies and the cultivation of more human-centred organisations, companies employ various methods to nurture, implement, and strengthen human-centricity. The human-centred methods are summarised in. To ensure the effective implementation of human-centred design processes, companies can leverage a toolbox of human-centred methods, which serve several key purposes:

**Understanding User Needs**: These methods assist in gaining a deep understanding of user needs through comprehensive user analysis.

**Formalising User Requirements**: They aid in the formalisation of user requirements, ensuring that they are well-documented and clear.

**Engaging Users**: These methods promote active involvement of users throughout the Human-Centred Design process, enhancing the co-creation of solutions.

**Evaluating Design Solutions**: They provide mechanisms for evaluating the design solutions developed to ensure they meet user expectations and needs (see previous section).

The selection of these methods is guided by recommendations put forth by stakeholders during the roadmap scoping workshop. Specifically, two key areas have been identified for improvement:

**Expanding Evaluation Methodologies**: There is a need to expand the range of evaluation methodologies, particularly in the context of a quantitative assessment of human-centricity. This expansion should address the current lack of concrete methodologies for such assessments. Consideration should be given to developing new, context-specific questionnaires, rather than solely relying on potentially outdated ones (e.g., TAM).

**Extending Requirements**: In addition, it was recommended that the scope of requirements should be extended to encompass aspects related to users' physiological and psychological well-being. This broader focus can better align design processes with the holistic needs and well-being of users.

It should be noted that in order to adopt HC methods, **companies need to follow a structured process (e.g., a maturity model)** to ensure that human-centredness is considered and improved upon. In other words, depending on the maturity level of the organisation in question, different methods within the HCD toolbox need to be used to ensure that each phase (analysis, requirements specification, design, evaluation) is conducted. For example, the method set for organisations with little prior knowledge on human-centredness will significantly differ from the method set for organisations with a consolidated human-centred practice.

The analysis carried out for the preparation of the roadmap also revealed that **the processes and methods in human-centred design need to be adapted depending on the context,** including the environment, the organisational structure, as well as the **overarching goals and values** within the process. This assessment is in line with work from May and colleagues (2015) who propose a human-centric factory model and provide a taxonomy of worker (e.g., skills and expertise, functional capabilities), factory (e.g., characteristics of tasks, tools, or workplaces) and context (e.g., social, environmental) aspects to be considered in the design and creation of human-centred workplaces.[138]

In the context of developing, adopting human-centred enabling technologies and creating more human-centred organisations, companies employ different types of methods to **develop, adopt and strengthen human-centricity**.

For HCD methods to be successfully adapted to the I5.0 context, two aspects need to be considered:

First, HCD methods and processes may need to be adapted for the design and development of specific technologies applied in I5.0. For example, to involve all workers as the users of technology into the development process as co-designers, they need to have an understanding of the technology – its possibilities, drawbacks, functionalities, etc. While HCD has always involved people with little technical or designer background, a specific emphasis must be put into supporting the users' understanding of technologies such as AI,

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[138] May, G., Taisch, M., Bettoni, A., Maghazei, O., Matarazzo, A., & Stahl, B. (2015). A new human-centric factory model. *Procedia CIRP*, *26*, 103-108.

blockchain, or Extended Reality where an understanding of its underlying functionalities has not become mainstream yet.

Second, adaptations to HCD methods are needed to achieve the relevant goals and values (e.g., human empowerment) as outcomes of the HCD process. While HCD is inherently focused on the well-being of end-users and aims to empower them, the **I5.0 context requires some adapting to facilitate human empowerment, learning and skills, cognitive and behavioural considerations as well as environmental sustainability and positive societal impacts**. For example, viewing automation through the lens of empowerment puts a focus on investigating in which way human and machine can best contribute to a specific goal while ensuring that the human-in-the-loop is cognitively, physically, and emotionally supported and remains autonomous. Human centricity in the context of I5.0 may also entail finding new ways to measure and evaluate success, considering the changing landscape and the potential for broader societal impacts beyond individual user experiences.

The human-centred AI development process involves active engagement with end users, and, in the context of manufacturing, particularly workers in a factory, to understand and articulate their specific needs for technology. However, to effectively express their requirements, these workers must possess a certain level of AI literacy. This literacy encompasses understanding AI technologies, including their capabilities, limitations, familiarity with machine learning algorithms, knowledge of data sources, and an awareness of potential biases. In essence, the human-centred design of AI mandates that participating users have a foundational understanding of AI technologies.

This AI literacy requirement should be seamlessly integrated into the design process. Furthermore, when evaluating AI systems through a human-centred lens, adaptations to the Human-Centred Design (HCD) process are necessary. While many participatory or human-centric design methods involve users in assessing design outcomes, it is important to recognise that, in the case of AI systems, users may have limitations in the aspects they can evaluate. They can effectively assess aspects like interaction mechanisms and the system's interface design. **However, assessing the quality of machine recognition, including scrutinising statistics and training data quality, often extends beyond the project's scope and may require an extended timeframe**. Additionally, understanding how the AI component of the design evolves over time necessitates a longitudinal testing period, which might not always be feasible. In such situations, simulation or envisioning long-term changes for both the AI system and user interaction may be necessary.

Furthermore, **AI systems often aggregate data from various sources, and this data can be riddled with inaccuracies or gaps. Predicting how the AI will perform in practical use cases beforehand can be a complex challenge. Consequently, the human-centred evaluation of self-learning AI requires ongoing, iterative investment to ensure the quality and safety of the system. This means that a sustained, long-term commitment to refining and enhancing AI systems is essential.**

# ANNEX 6 "ACE CLUSTER" CASE STUDY ON HUMAN-CENTRIC ENABLING TECHNOLOGIES AND PRACTICES IN MANUFACTURING

## Executive Summary

The European Union recognizes the importance of Human-Centricity and has adopted its principles in key policies such as the General Data Protection Regulation (GDPR) and the White Paper on Artificial Intelligence. These policies reflect Europe's commitment to human and fundamental rights in the manufacturing industry and emphasize involving employees in the digital transformation process. Industry 5.0, a vision for the future of European industry, promotes a sustainable and worker-focused approach, complementing Industry 4.0 by prioritizing societal goals and human needs through the use of technology. This paradigm shift underscores the significance of Human-Centricity and Socio-Centricity, making technology serve societal demands rather than the other way around in the evolving manufacturing landscape of Industry 4.0 and 5.0.

This case study explores Human-Centricity in manufacturing, drawing from EU-funded research projects within the HumAnCEntred (ACE) Factories Cluster from 2016 to 2020. The ACE Cluster is a collaborative initiative comprising five EU-funded research projects (2016-2020), namely A4BLUE, Factory2Fit, HUMAN, INCLUSIVE, and MANUWORK. Within this cluster, knowledge and technology providers have teamed up with industrial partners to pioneer innovative solutions aimed at bridging the gap toward the factories of the future. The ACE Factories cluster serves as a networking consortium that unites five distinct Factories of the Future (FoF) projects funded through the European Union's Horizon 2020 research and innovation program. These projects share a common objective: to develop solutions for manufacturing work environments that dynamically adapt to the unique needs of each individual worker. With aligned goals and aspirations, the cluster provides a platform for these projects to exchange knowledge, track progress, and share their results as they collectively contribute to advancing the future of manufacturing (ACE Cluster White Paper 2019).

The case study discusses the shift from historical manufacturing practices, where humans had to adapt to machines, to the era of Industry 5.0, where automation systems are designed to recognize and adapt to individual users, leading to more flexible, inclusive, and safe workplaces. This transformation aims to improve work conditions, productivity, and product quality while enhancing worker satisfaction and making factory work more appealing to the younger generation. It emphasizes the role of Human-Centricity in designing workplaces that prioritize human needs, adapt to evolving requirements, and enhance worker satisfaction and productivity. The integration of new technologies is seen as a means to achieve these goals while emphasizing work satisfaction alongside efficiency and productivity.

Industry 5.0 signifies a shift towards a deeply human-centric approach, prioritizing societal considerations and worker well-being. Among the most important Enablers for fostering this change is collaboration among various stakeholders, including workers, unions, tool providers, and policy makers. Customization of technology to specific workforce needs is also crucial for true Human-Centricity, and smaller companies may require additional support mechanisms. Research in this regard should focus on improving production processes broadly, with long-term field trials and interdisciplinary studies to assess the impact of human-centric changes. Barriers to adoption include cost and productivity prioritization, a lack of innovation, unclear responsibilities, and underdeveloped policy support.

The case study also highlights the challenges companies face in attracting and retaining a skilled workforce, particularly for positions requiring digital skills, as demographic changes impact the composition of the workforce. To fully utilize the workforce's potential, a more human-centric approach and skill development are needed, emphasizing that employees are an investment rather than a cost factor. Collaboration between businesses and educational institutions is equally crucial to identify skills gaps and anticipate future requirements. The EU's Digital Education Action Plan addresses digital education and skills development, but further work is needed in labour and social policies. Awareness and education about human-centric approaches and reskilling need to be increased.

Finally, the case study emphasizes the ongoing evolution of Human-Centricity in manufacturing and the need for continued research. Multidisciplinary teams involving social scientists, engineers, production experts, and IT specialists are essential for a holistic understanding of the subject. Project teams involved in human-centric technology projects should possess a multidisciplinary skill set to integrate new technologies effectively. Participatory design, where workers actively contribute to the design process, is crucial for ensuring that work processes evolve alongside technology adoption. Measuring worker satisfaction and well-being, in addition to traditional KPIs, is essential to demonstrate the advantages of human-centric approaches. Involving workers in the design phase may be challenging but will be beneficial for project success. Virtual reality technology can be used to gather worker feedback for ongoing refinement, and the participatory approach can lead to improved workplace efficiency and worker acceptance and satisfaction.

**Introduction: Human-Centricity as a Policy Focus of the European Union**

The European Union has embraced human-centric and socio-centric principles in several key policies. Examples include the General Data Protection Regulation (GDPR), which safeguards individuals' data rights, and the White Paper on Artificial Intelligence, which outlines protective measures for certain AI technologies. Despite some corporate criticism, these policies underscore Europe's commitment to human and fundamental rights in the manufacturing industry and show that Europe is leading by example globally with its values-based approach. In the industrial context, the human-centric approach aims to ensure that both companies and employees benefit from the digital transformation. In this regard, business models need to be rethought and redesigned - involving employees in every phase of this transformation process is essential (EC 2020). Human-Centricity is closely interwoven with the concept of "Industry 5.0" as a vision for the future of European industry. This emerging paradigm signifies a transformative phase where humans and machines come together in seamless symbiosis (Briken et al. 2023).

Industry 5.0 incorporates various technologies, including human-machine interaction, bio-inspired materials, digital twins, cybersecurity, and AI. However, it places a strong emphasis on values, particularly Human-Centricity and environmental responsibility. The shift towards Industry 5.0 is motivated by the idea that technology should serve societal needs, not the other way around. This paradigm shift underscores the importance of technology supporting and empowering workers rather than replacing them. Furthermore, Industry 5.0 extends the concept of Human-Centricity to socio-centricity, considering the broader needs of society. It highlights the significance of effectively training individuals to use new technologies, making Human-Centricity a two-way process. Socio-centricity integrates the needs of individuals within the larger context of society and the workforce (EC 2021).

**Defining Human-Centricity: the importance of Human-Centricity in industrial settings and the potential of emerging technologies to improve work environments and productivity**

This Case study serves as an exploration of important aspects and dimensions of Human-Centricity in the manufacturing realm and is mainly based on findings from pioneering EU-funded research projects from the HumAnCEntred (ACE) Factories Cluster, which span the period from 2016 to 2020.

Historically, the manufacturing industry required humans to adapt to the rigid requirements of machines. However, in this new era of Industry 5.0, automation systems are being designed to recognize individual users, their capabilities, skills, and preferences, and adapt accordingly. This symbiotic relationship between humans and automation leverages their respective strengths, resulting in more flexible, inclusive, and safe workplaces, improved work conditions, increased productivity, and enhanced product quality. Most importantly, it fosters greater worker satisfaction, well-being, empowerment, and engagement, thus making factory work a more attractive career choice for the younger generation. Industry 5.0 visions also emphasize the potential for a more enriching and autonomous work environment that promotes personal development and initiative among industrial workers.

This vision and development are also taken up by the ACE Cluster, which has developed the so-called "Operator 4.0" concept, where factory workers are seen as strategic decision makers and flexible problem solvers. The factories of the future will not only be qualitatively enriched and flexible but will also demand new qualifications to harness digital technologies. These factories must support existing workers in acquiring new skills and attract digitally-savvy newcomers. Importantly, the success of the Operator 4.0 paradigm hinges on recognizing individual operators' capabilities, skills, and preferences, and fostering their competence development. It calls for reshaping work processes and innovative approaches to training to support continuous skill development. Operators must have a say in designing their work, reflecting a future where Human-Centricity thrives in the manufacturing sector (ACE Cluster White Paper 2019).

An interviewed member of the Manuwork Project explained that Human-Centricity has its roots in the historical evolution of ergonomic workplaces. What sets it apart as an approach is its emphasis on designing workplaces with the human factor in mind right from the inception stage. Traditionally, the goal has been to ensure safety and efficiency in workplaces. However, the paradigm has shifted. Human-Centricity now calls for workplaces that can seamlessly adapt to the ever-evolving needs of their human occupants. This evolution goes beyond merely accommodating digital technology-savvy individuals or the elderly. It encompasses the idea that workplaces should be versatile and capable of accommodating various user groups, ensuring not only safety but also enhancing worker satisfaction and overall usability. Crucially, the adaptation of workplaces to specific human needs emerges as a crucial factor. The symbiotic relationship between human-centric design and worker satisfaction ultimately leads to enhanced productivity, as ACE pilot cases have shown (ACE Cluster White Paper 2019, page 8). Human-centric design should prioritize the transformation process before introducing new technology. The recommendation, as suggested by an interviewed employee of an engineering company collaborating with the ACE Cluster project Factory2Fit, emphasizes the importance of considering work satisfaction as a crucial aspect, not just focusing on efficiency and productivity.

**Enablers and Barriers for the Implementation of Human-Centricity on the shop floor: The importance of considering multiple stakeholders, customization of technology, and ongoing research efforts to promote Human-Centricity in industrial settings**

One of the central shifts defining Industry 5.0 is a profound change in perspective, moving away from a technology-driven advancement to a commitment to a human-centric approach. This shift underscores the industry's responsibility to carefully consider societal constraints, with the primary goal of ensuring that no employee is marginalized or excluded. This transformation carries significant implications, particularly when it comes to prioritizing the creation of a work environment that is not only secure but also highly conducive to the well-being of workers (EC 2020).

During an interview, a project member of the Manuwork project emphasized the importance of internal enablers within organizations as critical drivers for promoting Human-Centricity and the emerging concept of Industry 5.0. These enablers are characterized by maintaining an open mindset that actively seeks solutions capable of positively impacting various facets of work, such as productivity, worker satisfaction, safety, and stress reduction. It was acknowledged that historically, the focus has predominantly centred on technology, exemplified by the Industry 4.0 era. However, there is a growing recognition that this focus is increasingly shifting toward a more balanced view that places greater emphasis on the human element in the work environment. This shift towards Industry 5.0 and Human-Centricity is also seen as a positive development by the interviewed project member.

Implementing a human-centric approach within a company is a complex undertaking that requires the involvement of various stakeholders. While the decisions made by management are crucial, the engagement of other parties is equally significant. These can encompass input from employees themselves, cooperation with labour unions, and the support of associations dedicated to enhancing working conditions. Collaboration plays a central role in the effort to establish human-centric workplaces, extending to tool providers, machine tool suppliers, and other automation technology providers. These partners are essential elements of the ecosystem, offering their expertise to facilitate the creation of environments where humans and technology coexist harmoniously. Additionally, policy development and regulations can serve as crucial supportive measures for these initiatives, fostering an environment conducive to human-centric practices.

Furthermore, in the realm of manufacturing, customization is often an imperative enabler to ensure that technology aligns seamlessly with the specific needs of the workforce and the company. Ready-made, off-the-shelf solutions frequently fall short, necessitating that each company tailor technology to its unique context and requirements. This approach is key to achieving true Human-Centricity in the manufacturing process. While one company's experiences and solutions can be valuable references for others, a degree of customization is often required. Concepts and interaction models developed in a particular context and for a specific purpose can be generalized and applied to other companies and industries, but fine-tuning may be required to make them seamlessly adaptable to specific production tasks and contexts. This adaptability and customization ensure that the principles of Human-Centricity can be effectively applied across diverse manufacturing landscapes. The challenges faced by small and medium-sized enterprises (SMEs) in accessing and adopting human-centric technologies were also highlighted during the expert interviews, underscoring the need for additional support mechanisms tailored to smaller companies. An interviewed member of an industrial union said that small and medium-sized enterprises may not have dedicated internal human resources management units and lack coordination on education and training programs, as well as a long-term strategy for developing workers' skills; this gap needs to be addressed to promote human-centricity. Considering this fact, the need for external experts to manage the process is highlighted by a member of a cooperating engineering company in the Factory2Fit project. But even in larger companies, there is sometimes a lack of will, communication and responsibility regarding the concrete implementation of HC solutions and the fulfilment of internal and external requirements.

According to a Manuwork project member interviewed, advanced technologies such as augmented and virtual reality, collaborative robots, and nowadays also large language models can play a crucial role in promoting human-centric workplaces on the shop floor enabling better collaboration with automation and enhancing the overall work experience for employees. These tools act as enablers of Human-Centricity, offer diverse methods to enhance worker experiences and productivity as well as serve as valuable knowledge hubs for workers, providing guidance in natural language and alleviating stress. A potential challenge to Human-Centricity, nevertheless, lies in the risk that digital systems and platforms will capture workers' knowledge. This could lead to the erosion of workers' unique expertise and skills, posing a threat to their job satisfaction and well-being. On the other hand, research has shown that such fears can be overcome are unfounded and that better system performance results from the collaborative intelligence that occurs when humans and AI systems work together. In a human-machine environment, human and machine agents can form a partnership that improves overall team outcomes and their respective long-term gains (Lu et al. 2022).

A project member of Factory2Fit further states that research on the matter of Human-Centricity should also focus on improving various aspects of production and work processes broadly, rather than narrowing down to specific technologies. Long-term field trials with continuous feedback from workers are essential for successful implementation, along with the necessity for conducting long-term studies to assess the enduring implications of human-centric changes in the workplace, including their impact on work well-being, productivity, and company image. Future interdisciplinary, incremental, and ongoing research should also consider the need for more comprehensive measurements and key performance indicators (KPIs) to assess employee satisfaction, human-centredness in operations, and the impact of new technologies on the overall work process.

The expert from the cooperating engineering company recognizes that the barriers associated with the adoption of human-centric practices in industry are conspicuous. Frequently, investment decisions tend to give precedence to factors like cost and productivity, relegating the incorporation of human-centric design and worker involvement to a secondary consideration. This challenge is exacerbated when customers prioritize the mere acquisition of a system, often neglecting the crucial human element, despite a company's intent to embrace a human-centric approach.

The interviewed member of the industrial union adds that necessary spending on new equipment and human-centric digital machinery has failed to materialize and that there is too little sense of innovation, of breaking out of traditional, decades-old routines and of the medium- and long-term added value of new types of fully automated, human-centric equipment. Another barrier to the implementation of human-centric solutions in companies is the unclear communication and distribution of tasks as to who exactly is responsible for this implementation - the HR department, the management level or the tool provider. Policy support and guidelines are also still underdeveloped. Another problem is that the potential of human-centric solutions in terms of attraction of talent, job satisfaction, productivity and long-term competitiveness is not widely understood.

**Skills Development as a Prerequisite for the Success of Human-Centricity and the Implementation of Industry 5.0 Visions**

One of the pressing challenges for companies is attracting and retaining a skilled workforce, particularly for positions requiring digital and multi-disciplinary skills (EC 2020). Societal and demographic changes are altering the composition of the workforce, with the aging population bringing valuable experience but potentially reaching physical limits. At the same time, the number of younger workers, especially in manufacturing, is declining. To meet this challenge and realize the full potential of the staff, a more human-centric approach is essential. This approach is based on the concept that employees should be viewed as an investment rather than a cost factor (Briken et al. 2023). Modern technology can support older workers in effectively interacting with complex machinery, leveraging their experience for competitive production.

Analogously, skills development is a fundamental element of the Industry 5.0 vision, including the concept of "learning factories" and vocational training specifically designed to meet the needs of industry, comprising also in-company training. Such initiatives operate under the assumption that smart manufacturing may lead to task and skill replacement/shift, driving the need for employee re-and upskilling. However, it is worth noting that many of such initiatives are still in the strategic planning phase and have not fully materialized in industry practices.

To harness the advantages of both technology and the workforce, companies must make investments in both areas. This requires closer collaboration between businesses, on one hand, and educational and training institutions, on the other. Companies are well-positioned to identify skills gaps and anticipate future skill requirements. To support this endeavour, research should play a role by offering expertise on skills, drawing from wider societal and labour market trends (EC 2020). Adapting to the digital transition in industries necessitates a focus on education, training, and upskilling. However, not everyone can undergo this transformation due to varying skill levels. The EU's Digital Education Action Plan (2021-2027) addresses these challenges by fostering digital education and skills development. Yet, further work is needed in labour and social policies to recognize digital work, rethink social benefits, and revise taxation systems. Society has a responsibility to support and protect those who may not find a place in the transformed industries (EC 2020). Despite these efforts an interviewed project member of Factory2Fit said that awareness and education about the importance of human-centric approaches and reskilling in the workplace need to be increased at both the national and European levels, targeting decision-makers and industry leaders.

A project member of Manuwork acknowledged that skill development approaches are not one-size-fits-all solutions. Various methods are employed, including on-the-job training, vocational training, and the use of online platforms with training materials. Some projects have successfully simplified skill development with the use of online manuals and guides, serving as a reminder that overly complex approaches are not always required.

Supporting infrastructure for skills development was also cited as a critical aspect by this project member, who called for the establishment of teaching and learning factories, open labs, and test beds. These facilities would serve as valuable resources that enable workers and managers to learn about new opportunities and solutions and facilitate the transition to human-centred practices. Regarding the future, the interviewee suggested that follow-up projects to the ACE Factories cluster should aim to elevate ideas and technologies to a more mature and production-ready level. This transformation may involve adapting consortia or including other end-users; however, it was noted that this transition necessitates further research. EIT Manufacturing was identified as a potential catalyst for bringing human-centric solutions to the market, particularly in areas related to training, augmented reality (AR), and virtual reality (VR). These technologies were considered more mature and suitable for reaching end-users effectively. The interviewee viewed EIT Manufacturing as a pivotal player within the ecosystem, contributing significantly to the promotion of human-centric manufacturing practices and solutions.

A representative of a cooperating mechanical engineering company also states that fully automated production lines place new demands on the skills of the operators. As automation continues to increase, the role of machine operators is shifting toward supervision, leading machine tool vendors to offer operator education services to help them adapt and to help bridge the gap between technology adoption and workforce readiness. However, this readiness of customers and factories for this automated transition varies, they said, underscoring the importance of education and communication to help them understand the evolving demands on operators. The responsibility for organizing and managing the transformation process, including training and job redesign lies on both customers (factories) and machine manufacturers. There is a need to provide clearer education and training for workers, especially blue-collar workers, to help them understand their roles in the context of advanced technologies, such as AI, industrial IoT, and automation, adds an interviewed representative from an industrial union. They also underlined that worker unions and work councils also may need to acquire new skills and adapt to new technologies to be fully equipped to address the digital transformation in the interest of the employees.

**The concept of the "Operator 4.0" as a central actor in the ACE Cluster human-centric industrial work processes**

Central to Industry 5.0 is its focus on human-centricity in the context of environmental responsibility, within the ACE Cluster epitomized by the Operator 4.0 concept. Operator 4.0 categories are perceived as skill profiles that mirror the competencies essential for handling various technologies, and these profiles can be customized to suit distinct job roles with varying skill prerequisites. This Operator 4.0 concept, described in the ACE Cluster White Paper, envisions intelligent and skilled human operators supported and empowered by technical devices and tools that reduce physical and mental strain and foster creativity and innovation without compromising production goals. Romero et al. (2016) introduced various Operator 4.0 types, including Super-strength, Augmented, Virtual, Healthy, Smarter, Collaborative, Social, and Analytical Operators. Emerging technologies such as virtual reality, augmented reality, robotics, and wearables offer promising avenues to realize these concepts.

A member from Factory2Fit project elaborates that the incorporation of diverse operator categories, including individuals utilizing virtual and augmented reality or artificial intelligence, is regarded as a proactive response to the impact of emerging technologies on the nature of work. These technologies not only offer novel functionalities but also necessitate fresh skill sets from operators. Technology has the potential to furnish workers with new proficiencies and capacities; for instance, exoskeletons can enhance physical capabilities, while artificial intelligence can enhance cognitive abilities.

In the ACE Cluster White Paper there are five distinct types of operators envisioned for future workplaces, each with its unique focus and objectives. These operators represent a forward-looking approach to the evolving world of work:

***Augmented and Virtual Operators***: These operators are associated with co-design activities within the factories of the future. Workers actively participate in shaping their work environments, including factors such as layout, infrastructure, interaction with technology, and the use of auxiliary devices or tools. Virtual reality technology is employed to engage workers in this process, allowing them to provide feedback for continuous workplace improvement, with AR/VR offering substantial support for various operator tasks, including knowledge sharing and training.

***Social and Collaborative Operators***: This operator category places a strong emphasis on knowledge sharing and social networking within the enterprise. Participatory design, established since the 1980s, involves workers in designing their work and tools, with Virtual Reality aiding collaboration (Bruno & Muzzupappa, 2010). Digital tools and social networking technologies are leveraged to facilitate knowledge exchange and foster social relationships among workers and enhance team performance. The goal is to create a collaborative environment where information flows freely. Collaborative robotics aims to combine human flexibility and dexterity with robot strength in semi-structured environments while ensuring safety (Aromaa et al., 2016).

***Super-strong Operators***: Super-strong Operators are defined by their exceptional skills and capabilities, which enable them to proficiently handle complex tasks and advanced technologies. This concept involves the use of wearable devices, such as exoskeletons, to reduce physical fatigue, enhance strength, bolster safety, and improve productivity. Exoskeleton devices, previously applied in areas like rehabilitation and the military, have been explored for industrial use, particularly in scenarios involving prolonged standing work (Karvouniari et al. 2018; Spada et al. 2018).

***One-of-a-kind Operators*****:** This operator category encompasses workers with unique and specialized skill sets tailored to specific tasks or roles within the manufacturing process. The one-of-a-kind operator concept emphasizes tailoring human-automation integration to individual differences and needs, optimizing the balance between flexibility and productivity cost-effectively. Companies must redesign production systems and implement adaptive strategies, enhancing adaptability, reducing setup efforts, accommodating worker limitations, and improving workforce satisfaction to boost organizational commitment and retention.

***Healthy and Happy Operators*****:** The focus here is on the holistic well-being of workers, encompassing both their physical and mental health. As work becomes more knowledge-based, traditional ergonomics and physical safety challenges diminish, but new challenges related to cognitive ergonomics and mental workload may emerge, especially with the introduction of technologies like virtual and augmented reality devices and exoskeletons. The objective is to create workplaces that contribute to the overall health and happiness of operators. The Healthy and happy operator concept benefits from solutions that monitor physical and mental fatigue and provide motivating feedback to workers. However, measuring these aspects can be challenging, potentially necessitating the involvement of social sciences to develop appropriate metrics.

Conclusion: The concept of "Operator 4.0" stands as a central element in the human-centric industrial work processes within the ACE Cluster. Numerous innovative technologies have been proposed and developed to cater to the diverse needs of these operators. The evaluation of these concepts and technologies in ACE industrial cases has provided robust evidence supporting their positive impact on industrial practices. The concept of Operator 4.0 facilitates the comprehension of the transformative capacity of (digital) production technologies for workers and employees, while placing humans at the centre of industrial practices.

### The Involvement of Social Sciences and Humanities in the Process of Co-Designing the industrial Workspace

The field of Human-Centricity in manufacturing is still evolving, and ongoing research is necessary. There is a particular need for comprehensive investigations into how the adoption of new technologies impacts users and their perceptions of improved working conditions. To undertake this research effectively, multidisciplinary teams encompassing social scientists, engineers, production experts, and IT specialists must collaborate, ensuring a holistic understanding of the subject matter. As stated by the European Union and leading technology companies, the promotion of this multidisciplinary socio-technological research should be a priority from the outset. This integration is essential to address the potential complexities that could impact security, safety, acceptance, and the timely implementation of these advancements. While engineering, technology, life sciences, and environmental sciences have long collaborated, the inclusion of social sciences and humanities in research and discussions is an area that is still evolving and requires establishment (Briken et al. 2023).

The role of management in the implementation of new, human-centric technologies was also discussed during the expert interviews. It was suggested by a member of the Manuwork project that management staff involved in projects dealing with human-robot collaboration or shop floor skills development should possess a multidisciplinary skill set encompassing aspects related to production, technology, and social sciences (like sociology, psychology, cognitive sciences). This comprehensive understanding is essential for the successful integration of new technologies within manufacturing processes. The challenge at hand revolves around identifying individuals capable of bridging the divide between technical expertise and a deep comprehension of human behaviour, manufacturing processes, and the production environment. The engineering company representative adds that these individuals could act in a "transformer" role that would require unique skills and an interest in learning the required knowledge in multiple disciplines such as social sciences and engineering. The Factory 2 Fit member also underscores that collaboration with companies that have both Social Sciences and Humanities Project groups, and industry-focused expertise is crucial for effectively implementing human-centric changes in the manufacturing sector of the future.

Co-designing the workplace by involving workers in the process can yield win-win situations. Both the company and workers benefit from improved work environments and more worker-centric practices. A project member of Factory 2 Fit states in this regard that the central focus should shift towards the thoughtful design and management of work processes, going beyond mere instruction in the use of specific digital tools. They advocate for the concept of participatory design, where workers actively contribute to the design process to ensure that work processes evolve alongside technology adoption. Additionally, the importance of actively engaging the work community is highlighted, particularly in workplaces struggling with outdated machinery and inadequate support for employees transitioning to modern technologies. To facilitate this transition, it is essential to first analyse the evolving workplace needs and shifts before selecting the appropriate technology for implementation. Looking ahead, the focus should shift from individual technologies and workers towards the holistic design of sociotechnical systems, guided by a human-centric approach. A member of an industrial union adds that participatory approaches play a central role in crafting and executing human-centric solutions. These approaches necessitate the involvement of diverse stakeholders, encompassing workers from various levels (first floor and second floor) and also management (third or fourth floor) who collectively facilitate the requisite changes.

Measuring worker satisfaction and well-being, along with traditional key performance indicators like quality, efficiency, productivity, and costs, is crucial to demonstrating the advantages of human-centric approaches. A project member from Manuwork highlighted the project's efforts in monitoring worker satisfaction. They specifically mentioned the development of a worker satisfaction assessment method, involving the creation of questionnaires to gather worker feedback and subsequent statistical analyses of the collected data. The project member also stressed the need for more examples showcasing the potential of technologies for human-centred solutions. In the Manuwork project, particular attention is given to people with disabilities, aiming to develop solutions that include them in the production process.

While involving workers in the design phase was acknowledged as a challenge, it was also deemed beneficial for project success. In addition, it was stated that there is currently no established guideline or best practice for involving workers in the initial design and development phases of such projects.

A project member of Factory 2 Fit specifies that when introducing new technologies to the factory floor, the paramount importance of planning and designing work roles and jobs is evident. It is not solely about enhancing workers' skill sets but also about crafting roles that are purposeful, captivating, and fulfilling. This recognition becomes even more crucial considering that automation can lead to workplace transformations where certain tasks may become repetitive, while others could become excessively taxing and stressful, especially in the event of issues arising with automation systems.

The interviewee from the Manuwork project highlighted the role of virtual reality technology in gathering worker feedback for ongoing refinement. One example provided was a project that utilized virtual reality to enable workers to explore a preliminary workplace design and provide feedback. This approach incorporated both quantitative measurements, such as tracking workers' daily distances and repetitive task execution, and qualitative assessments through questionnaires administered to workers. They further emphasized that workers could play a crucial role also in the testing and evaluation phases, contributing to the refinement and success of the Human-Centricity initiatives.

**Conclusions**

The conclusions and recommendations presented in this case study derive mainly from the insights gained through the ACE Cluster projects and interviews with their project members and associates. While scientific sources were also referenced, the primary emphasis of the case study was on the experiential knowledge and practices cultivated within the ACE Cluster. It is important to acknowledge that the findings and suggestions offered in this case study are closely tied to the specific context and experiences of these projects and may not be generalisable to all situations or industries.

In the realm of modern manufacturing, the concept of Human-Centricity is gaining momentum and importance recognizing the pivotal role of human operators in shaping the future of factories. This marks a noticeable shift from the traditional technology-centric approach to a more balanced perspective, denoted as Industry 5.0, where greater emphasis is placed on the human element in work environments, as well as on environmental considerations. This shift entails the evolution of automation systems that are now to be designed to recognize and adapt to individual user capabilities, skills, and preferences. This symbiotic relationship aims to foster more flexible, inclusive, and safe workplaces, significantly enhancing worker satisfaction, well-being, empowerment, and engagement. To achieve these human-centric workplaces, a variety of strategies come into play. Industry 5.0 factories of the future should support the upskilling of existing and new workers by involving them into the design of their workplaces and redesigning work processes. Societal and demographic changes, such as an aging workforce with valuable experience but potential physical limitations, and a decline in the younger manufacturing workforce, must be considered in this regard and are changing the workforce landscape. Workplaces should therefore be adaptable and able to accommodate various user groups, enhancing safety, worker satisfaction, and usability beyond technology or demographic considerations.

Management decisions are crucial for the implementation of human-centric solutions, but the involvement of various other actors, including workers, labour unions, advocacy associations, policy makers, and regulatory bodies, is also essential. These collaborative efforts are integral for the successful promotion of Human-Centricity. Customization is key to achieving true Human-Centricity, as technology should align with the specific needs of the workforce and the company. Off-the-shelf solutions often fall short in this regard. Collaboration with technology providers, alongside with innovation managers and R&I advisors is fundamental, as these partners contribute their expertise to creating harmonious human-centric workplaces.

The importance of worker skills and training cannot be overstated in the context of human-centred solutions, especially with the introduction of advanced technologies, digital tools, and automation. Skill development approaches vary, encompassing on-the-job training, vocational training, and online platforms with training materials. However, simplified approaches such as online manuals and guides have also proven effective.

Management staff involved in projects related to human-robot collaboration or shop floor skills development should possess multidisciplinary skills, including production, technology, and social sciences knowledge.

This comprehensive understanding is essential for the successful integration of innovative technologies into manufacturing processes. Social scientists are particularly valuable contributors to such change projects, bridging the gap between worker perspectives and design processes, aligning technology with human needs, and developing measurements for worker satisfaction and well-being in the workplace. Engaging workers in co-designing their work environments is a crucial component of the future of work. This participatory approach empowers management and workers to create better-suited workplaces, leading to improved efficiency, less stranded investments, higher attractiveness of manufacturing jobs, alongside with worker satisfaction and acceptance.

Lastly, supportive technologies, such as augmented and virtual reality, collaborative robots, and large language models hold the potential to enhance human-centric workplaces.

**Recommendations**

**Stakeholder Engagement and Collaboration:**

Foster collaboration between government entities, industry stakeholders, and educational institutions to create and fund initiatives that promote digitally enabled upskilling and qualification in manufacturing. Encourage joint efforts to develop training materials and curricula.

Support worker unions and work councils in acquiring the skills and knowledge needed to effectively address digital transformation and advocate for worker well-being.

Policy makers and regulatory bodies should create a supportive environment for human-centric practices. Awareness and education about the importance of human-centric approaches in the workplace need to be increased at both the national and European levels, targeting decision-makers and industry leaders.

Emphasize and support collaboration with technology providers, including tool providers, machine tool providers, and automation technology providers.

Collaborate with organisations like EIT Manufacturing and DIH to bring human-centric solutions to the market, especially in training, and more mature technologies like augmented reality or virtual reality.

**Customization of Technology for work environments:**

- Implement initiatives to expedite the uptake of technologies like VR, AR or HMI and drive change within the manufacturing sector, with a specific focus on transforming work processes.

- Adapting technology to the specific needs of employees is a priority, and off-the-shelf solutions should be avoided in order to put people first and adapt technology to the context of the company.

- Companies should learn from other companies' solutions, but without sacrificing the need for customization and fine-tuning tailored to specific work processes. This can ensure that concepts are seamlessly aligned with specific production tasks and contexts.

- The potential of technologies such as augmented and virtual reality, collaborative robots, and large language models should be leveraged to increase productivity and support workers and management. Also, in terms of monitoring workers' physical and mental health and addressing challenges related to cognitive ergonomics and mental workload.

- Establish mechanisms to monitor and analyse how technology is transforming various manufacturing practices, including job roles, equipment operation, planning, quality control, maintenance, engineering, etc., and assess its impact on workplace dynamics, job profiles, collaboration, and overall workplace attractiveness. Identify areas for improvement and implement changes accordingly.

- Develop more comprehensive measurements and key performance indicators (KPIs) to evaluate worker satisfaction and Human-Centricity on the shop floor, reflecting the impact of technology adoption.

- Connect human-centred innovations in manufacturing to industrial competitiveness and excellence by showcasing how these innovations improve worker well-being while reducing non-value-added time, enhancing quality, productivity, and efficiency. Allocate more space to demonstrate the benefits of human-centred approaches for broader industry-wide implementation.

- Establish support mechanisms, potentially through government incentives or industry partnerships, to aid smaller companies and startups in adopting advanced technologies, offering upskilling opportunities for their workforce, and addressing the absence of in-house human resource managers to coordinate education and training programs for workers.

- Create increased incentive systems that reward companies for promoting HC in their business and help them implement it.

**Future Research and Best Practices:**

- Support long-term studies to assess the enduring implications of human-centric changes in the workplace, including their effects on work well-being, productivity, and company image, and allocate funds and resources to research and development initiatives aimed at human-centric manufacturing technologies and practices.

- The formation of multidisciplinary project teams involving Social Sciences and Humanities (SSH) should be pursued to achieve a holistic understanding of the challenges surrounding the implementation of human-centric solutions.

- The focus should be on developing examples that demonstrate the economic potential of human-centred technologies and their positive impact on worker well-being.

- Successful projects and their learnings and approaches must be highlighted and serve as a model for other projects. In general, it is important to promote communication, exchange and symbiosis between projects and initiatives with a similar focus.

**Skills Development and Investment in Infrastructure:**

- Recognize the need for re- and upskilling in view of the impending shortage of skilled workers and the demographic developments of the coming decades.

- Provide clear education and training for both blue-collar workers and management, emphasizing the roles of advanced technologies like AI, robotics, industrial IoT, and flexible automation in manufacturing.

- Develop and fund comprehensive upskilling and reskilling programs for workers and decision makers in collaboration with industry and educational institutions, ensuring accessibility regardless of background or location. Diversify skill development methods based on individual needs.

- Implement mechanisms to monitor and evaluate the effectiveness of upskilling and qualification programs. Regularly assess the impact of digital tools on workers' career development and job transformation.

- Promote a culture of continuous learning within the manufacturing sector. Encourage employers to invest in their employees' development and provide incentives for workers to engage in upskilling and qualification activities.

- Encourage workers to acquire new skills to adapt to advanced technologies and alleviate their fear of change and technology-induced job loss through real and serious participation.

- Advocate for fair compensation policies that reward workers for improving their skills and job performance, thereby linking competence development to increased earnings.

- Support and increase focus on establishing teaching and learning factories, open labs, and test beds.

**Promote Co-Design Activities and Worker Well-being:**

- Encourage a human-centric design approach by emphasizing the transformation of work roles and job designs alongside technology integration. Promote the creation of meaningful, engaging, and satisfying jobs. Promote participatory design practices where workers are involved in co-design of work and shop floor processes to improve workplace efficiency and satisfaction.

- Emphasize the importance of improving the well-being of factory workers. Focus on making manufacturing workplaces more attractive and inclusive. Promote developments that increase factory throughput, energy efficiency, and resource utilization.

- Support the development and adoption of physical augmentation technologies that reduce the physical strain on workers when cooperating with machines. This can include advanced mechatronics, robotics, and wearable devices.

- Shift the focus from individual technologies and workers to designing entire sociotechnical systems with a human-centric approach. Ensure that technology interacts effectively with workers, considering work well-being and satisfaction.

- Strengthen the formation of multidisciplinary teams comprising experts in engineering, social sciences, human behaviour, process development, and technical knowledge to design, implement and evaluate human-centric approaches.

- Recognize the role of "transformation" or “change management” experts who can guide companies through the adoption of promising/new technologies and workplace innovation. Consider whether machine and tool providers can offer transformation services as well.

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# ANNEX 7 CASE STUDY : CASE STUDY. HUMAN CENTRICITY IN THE MANUFACTURING INDUSTRY – A PERSPECTIVE FROM THE INDUSTRY

**Executive Summary**

Recognising the importance of Human-Centricity, the European Union has integrated its principles into crucial policies, including the General Data Protection Regulation (GDPR) and the White Paper on Artificial Intelligence [1]. Such policies reflect the EU's commitment to human and fundamental rights in the manufacturing industry and emphasise the importance of involvement of employees in the digital transformation process. In addition, Industry 5.0, envisioning the future of European industry, advocates for a sustainable and worker-centric approach, complements Industry 4.0 by prioritising societal goals and human needs through technological utilisation. This paradigm shift highlights the importance of human centricity, reshaping the manufacturing landscape of Industry 4.0 and 5.0 to ensure that technology aligns with societal demands.

The case study presents insights on human centricity in the context of manufacturing industry. An industrial setting related to human centricity in E+E Elektronik Ges.m.b.H., an Austrian manufacturing company focusing on the production of sensor technology, is analysed. Drawing on the insights gained from E+E Electronics' experience, the case study offers an industry perspective on what human-centricity may involve and examines how it is currently ensured within the sector.

E+E Elektronik develops and produces sensors and transmitters for humidity, temperature, dew point, moisture in oil, air velocity, flow rate, CO2 and pressure. Data loggers, hand-held measuring devices and calibration systems complete the extensive product portfolio of the Austrian sensor specialist.

The main domains of manufacturing technology applications are in HVAC and building technology, industrial measurement technology, the automotive industry, the pharmaceutical and food industries, clean room technology, meteorology, environmental technology and agricultural technology. E+E Elektronik has its own subsidiaries in China, Germany, France, India, Italy, Korea and the USA and is represented by more than 60 sales partners worldwide.

E+E Elektronik has an established and certified quality management system in accordance with ISO 9001 and IATF 16949. E+E also attaches great importance to environmental protection and is, therefore, certified in accordance with the ISO 14001 environmental standard and has been an Austrian Climate Alliance partner for many years. In addition, E+E Elektronik is a designated institute of the Federal Office of Metrology and Surveying (BEV) and is responsible for providing the national etalons (measurement standards) for humidity, dew point, air flow velocity and $CO_2$ gas concentration in Austria.

Although scientific sources were consulted, the main focus of the case study centred on the experiential knowledge and practices developed with this company. It is crucial to recognise that the insights and recommendations presented in this case study are thus intricately linked to the unique context and experiences of the company under consideration. Therefore, we emphasise that the findings presented in this case study cannot be viewed

as a generalisation of the industry sector, but rather provides specific, context-dependent insights. As such, the recommendations presented in the following are also not generalisable.

**The Meaning of Human Centricity in the Manufacturing Context**

While researchers and policy makers have presented and worked with various definitions of human centricity in general and specifically for Industry 5.0 (I5.0) [2,3], the current literature is lacking key perspectives from industrial stakeholders. The current understanding and implementation of human centricity in the manufacturing context of these stakeholders as well as their perspective towards to future of manufacturing in relation of human centricity is integral to support European industry’s transition towards I5.0.

The following case study provides an overview of human centricity applied in E+E Elektronik. As such, the findings provide relevant insights and indicate potential directions on how human centricity can be further engendered in the manufacturing context.

*“Independence, the ability to think and act independently, to intervene – this must be preserved.” – Head of Production at E+E Elektronik*

During an interview with the Head of Production at E+E Elektronik, the importance of maintaining employees' empowerment was emphasised as a crucial aspect when integrating new technologies into shop floor workflows. It was deemed essential to uphold employees' autonomy—their capacity to think and act independently. This imperative not only reflected the company's values concerning worker autonomy and empowerment but also derived from practical experience.

The interviewee highlighted that deviating from this principle, such as directing employees to strictly "do as they are told," can result in low workplace acceptance. For instance, a recommendation system that removes decision-making from workers can prompt resistance towards such automated systems. Workers can reject suggested work steps, seek better ways to optimise processes, leading to increased errors. Therefore, the interviewee stressed that integrating a technical solution into the workflow is insufficient if workers are instructed not to think, but merely to follow instructions.

At E+E Elektronik, anecdotal evidence revealed that when workflow adaptations were implemented without consulting or involving employees in decision-making, the outcomes included decreased productivity, a rise in errors, increased rework requirements, and heightened dissatisfaction amongst workers. This industrial illustration highlights the importance of prioritising consultation and collaborative decision-making with employees, emphasising the autonomy of employees. Such strategies are crucial for achieving heightened productivity, fostering employee acceptance and satisfaction, and minimising occurrences of errors.

**Factors Ensuring the Necessity of human-centric approaches to technology**

Technologies are often regarded as a pivotal point to ensure more human-centredness in the manufacturing sector, for example, by supporting workers’ cognitive [4] and physical potential [5] or by enhancing hybrid collaboration [6]. Several technologies are discussed in current research and trend reports as providing high potential to support human centricity.

The Head of Production of E+E Elektronik viewed the question of technology potentials for the shopfloor through two aspects. Primarily, irrespective of the technology employed, maintaining workers' autonomy should be considered the focal point of human-centricity, influencing trust and worker satisfaction. As demonstrated earlier, E+E Elektronik encountered adverse effects when attempting to integrate new technologies without incorporating them into the workflow in a way that preserved workers' autonomy.

*"No one will do it if they don't see the necessity to optimise processes."*

Second, the factors for creating demand for technologies in the manufacturing sector were viewed through the lens of 'need'. In other words, a tangible need of the organisation needs to be fulfilled by the implementation of a technology into the workflow, such as a need for higher productivity, reduced errors of workers on the shopfloor, improved worker acceptance, etc.

When asked about the potential of specific technologies to support human centricity in manufacturing, the interviewee pointed to three variables that had deterred them from using advanced technologies such as those related to automation, artificial intelligence, robots, or industrial wearables: **employee acceptance**, **employee safety and limited benefits** (pertaining to recued costs, increased productivity, increased efficiency, etc). For example, human-robot collaborations were perceived as requiring significant additional safety precautions which would make its application either too slow and complex or too costly to implement.

**Introducing Human-Centred Processes**

In the case of E+E Elektronik, human-centred processes were an integral enabler of human centricity, ensuring employees' acceptance of new technologies into their workflow on the shopfloor. E+E Elektronik involved employees in the implementation process of a new line implementation management. More specifically, the company integrated technological adaptations, using e.g., process simulations to create a common understanding of potential process changes.

The key lesson learned is that the active involvement of employees in the design and decision-making process needs to be iterative. The reason is that the production processes change over time (e.g., through the inclusion of new products or product variants). In addition, new employees' join the company without any prior knowledge about working processes. As such, continuous investment is necessary to train and involve employees regularly.

**Getting the Appropriate Technological Solutions**

Throughout the interview, it became evident that E+E Electronics expressed a keen interest in staying at the forefront of technology and was open to incorporating new technologies into their manufacturing process. This commitment was contingent on ensuring the autonomy and safety of their workers, as well as enhancing key metrics such as profitability or productivity. As a result, E+E Elektronik mostly favoured in-house development of technologies, a common practice in industrial settings. The rationale behind this approach stemmed from the perceived lack of satisfactory off-the-shelf solutions for emerging technologies and use cases. However, the interviewee reflected that it is often difficult to scale such self-developed solutions as the company grows, thus requiring continuous investments into adapting and improving the technological solutions down the line.

## Conclusions and Recommendations

This case study, centred around E+E Elektronik, an Austrian sensor technology manufacturer, informs on use case of implemented human-centred processes at the industrial setting.

E+E Elektronik places a significant emphasis on maintaining the autonomy of human workers while integrating novel technologies. For E+E Elektronik the human centricity is a necessary feature of process and product that allows to ensure that the technological solutions utilised on the shopfloor are accepted by employees and they can maintain their autonomy. Only then can the integration of technologies actually positively affect the performance, productivity, and effectiveness of the shopfloor and company overall. Through the investigation of E+E Elektronik's conceptualisation and implementation of human centricity, several pathways were identified through which human centricity may be further supported in the manufacturing sector.

The recommendations provided below stem from the insights gained and discussions held with the Head of Production at E+E Elektronik.

### Facilitate Exchange, Learning, and Collaboration Between Industry Stakeholders

One aspect that was heavily emphasised by the interviewee was the topic of sharing human-centricity related information and experiences with other stakeholders in the manufacturing sector. Knowledge created in research and in the industry needs to be widely disseminated between industrial stakeholders. This ensures that relevant information about human centricity is easily accessed and human-centricity implementation is facilitated. Currently, information essential to the industry regarding human-centred methods, practices for creating and implementing human-centred technologies in one's organisation are commercialised, e.g., through closed training courses, lectures series, etc. To distribute experiences and knowledge more freely, the manufacturing sector would benefit from a Community of Practice with the central goal of creating a practice-oriented community who share experiences and learn from each other to improve human centricity practices in their own organisations.

### Support Sustained Human-Centred Processes as Part of Organisational Change Management

Sustaining human-centred processes in the manufacturing sector is not a short-term endeavour; it requires a strategic and ongoing commitment. The European Commission having a prominent role in fostering innovation and industry development could contribute significantly by implementing targeted initiatives that support continuous learning, collaboration, ethical considerations, and the long-term commitment of industrial companies to human-centric practices. One of the key challenges faced by E+E Elektronik is related to securing resources necessary for maintaining and sustaining adopted human-centred design (HCD) processes within the company over time and to achieve mature a human-centred organisation.

This need is also reflected in existing maturity models in the literature which aim to guide the process of institutionalising human centricity within organisations [7]. Existing maturity models (e.g., [8]) provide guidance for how to strategically implement human centricity in organisations such as part of organisational change management.

### Customisation of Technological Solutions

The Head of Production of E+E Elektronik reflected that many companies in the industrial sector rely on in-house development of technologies, often due to the lack of off-the-shelf solutions that fully fulfil the requirements and needs of the company. However, these in-house developed solutions are often difficult to scale for growth, requiring more investments. This dilemma reflects the need for easy customisation and personalisation of technological solutions. The ecosystem can address this issue in several ways.

First, technology developers can address the need for customisation in off-the-shelf solutions by providing support for companies to customise for their needs. For example, comprehensive training sessions, tutorials, and documentation could be provided to help companies understand the customization options available in the off-the-shelf solutions. Furthermore, a dedicated support team could be established that can assist companies with any technical issues or challenges their customers during the customisation process. Such a team could also assist in the integration of the customised solutions with their existing workflows, systems, and infrastructure and support scalability considerations by offering insights into how customizations can adapt and grow along with their business requirements. Additionally, user-friendly tools could be developed that allow companies to easily customise the off-the-shelf solutions without requiring extensive technical expertise and templates or pre-configured settings that can be easily applied to meet common customization requirements could be offered.

Second, collaboration between companies and technology providers should be supported, involving innovation managers and R&I advisors as well. This could be done by establishing collaboration platforms (either continuous, online spaces for collaboration as well as individual events such as forums or conferences to foster direct communication between innovation managers, R&I advisors, and relevant stakeholders) or by supporting joint research initiative. Overall, security, interoperability and compatibility between systems need to be considered throughout this process.

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# ANNEX 8 COMPLEMENTARY DATA TO THE PATENT ANALYSIS

**Table 41 Top 10 applicants of patents that potentially enhance human-centricity, main patent offices**

| # | Applicants | Country | # of documents |
|---|---|---|---|
| 1 | Tencent Tech Shenzhen Co Ltd | China | 334 |
| 2 | State Grid Corp China | China | 286 |
| 3 | Ping and Tech Shenzhen Co Ltd | China | 224 |
| 4 | Huawei Tech Co Ltd | China | 194 |
| 5 | Univ South China Tech | China | 155 |
| 6 | Netease Hangzhou Network Co Ltd | China | 142 |
| 7 | Univ Tianjin | China | 115 |
| 8 | Univ Southeast | China | 101 |
| 9 | Univ Tsinghua | China | 99 |
| 10 | Univ Jilin | China | 97 |

Source: EPO

**Table 42 Top 25 applicants of patents that potentially enhance human-centricity, EPO and WO**

| # | Applicants | Country | # of documents |
|---|---|---|---|
| 1 | Huawei Tech Co Ltd | China | 142 |
| 2 | Tencent Tech Shenzhen Co Ltd | China | 101 |
| 3 | Ping AN Tech Shenzhen Co Ltd | China | 77 |
| 4 | Siemens AG | Germany | 52 |
| 5 | Guangdong Oppo Mobile Telecommunications Co Ltd | China | 46 |
| 6 | ZTE Corp | China | 31 |
| 7 | Microsoft Technology Licensing LLC | United States | 30 |

| # | Applicants | Country | # of documents |
|---|---|---|---|
| 8 | ABB Schweiz Ag | Switzerland | 24 |
| 9 | Rockwell Automation Tech Inc | United States | 23 |
| 10 | Oppo guangdong mobile telecommunications Co ltd | China | 21 |
| 11 | Robert Bosch GMBH | Germany | 20 |
| 12 | Honeywell int ICT | United States | 20 |
| 13 | Boe technology group co ltd | China | 19 |
| 14 | Le holdings beijing co ltd | China | 15 |
| 15 | Thales SA | France | 15 |
| 16 | Alibaba group holding ltd | China | 14 |
| 17 | Intel CORP | United States | 14 |
| 18 | Qualcomm inc | United States | 14 |
| 19 | Shenzhen gowild robotics Co ltd | China | 13 |
| 20 | ABB Technology AG | Switzerland | 12 |
| 21 | Continental Automotive GmbH | Germany | 12 |
| 22 | Honor Device Co ltd | China | 12 |
| 23 | Lemobile Information Tech (Beijing) Co ltd | China | 12 |
| 24 | Orange | France | 12 |
| 25 | Shenzhen Mindray Biomedical Electronics Co ltd | China | 12 |

Source: EPO

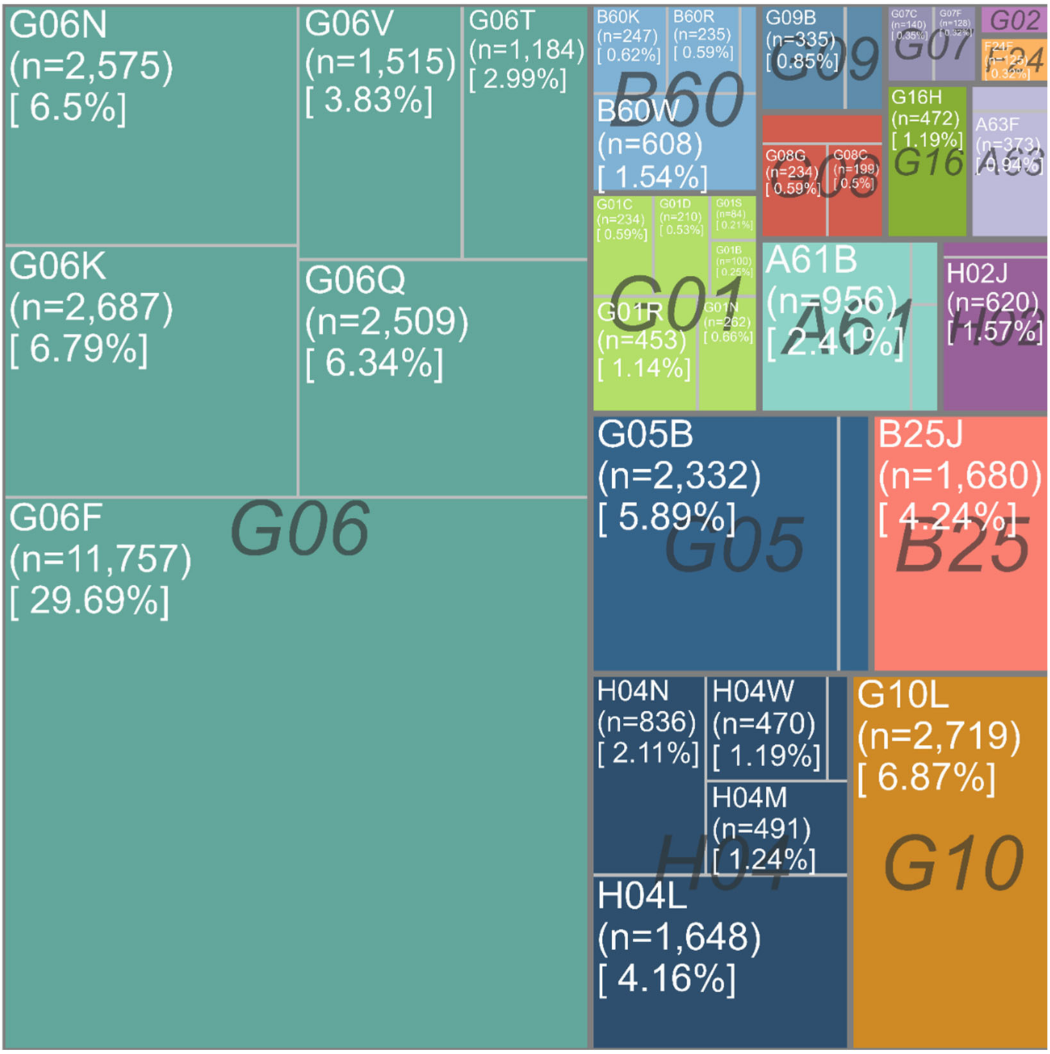
**Table 43 Technology classification (IPC Class) of patents that potentially enhance human-centricity, main patent offices**

| | Class | Name of class | # of documents | Share of class |
|---|---|---|---|---|
| 1 | G06 | Computing; calculating or counting | 22,227 | 56.1 |
| 2 | H04 | Electric communication technique | 3,534 | 8.9 |
| 3 | G10 | Musical instruments; acoustics | 2,719 | 6.9 |
| 4 | G05 | Controlling; regulating | 2,639 | 6.7 |

| | Class | Name of class | # of documents | Share of class |
|---|---|---|---|---|
| 5 | B25 | Hand tools; portable power-driven tools; handles for hand implements; workshop equipment; manipulators | 1,680 | 4.2 |
| 6 | G01 | Measuring; testing | 1,343 | 3.4 |
| 7 | B60 | Vehicles in general | 1,152 | 2.9 |
| 8 | A61 | Medical or veterinary science; hygiene | 1,140 | 2.9 |
| 9 | H02 | Generation, conversion, or distribution of electric power | 692 | 1.7 |
| 10 | G08 | Signalling | 577 | 1.5 |
| 11 | G09 | Educating; cryptography; display; advertising; seals | 491 | 1.2 |
| 12 | G16 | Information and communication technology [ict] specially adapted for specific application fields | 472 | 1.2 |
| 13 | A63 | Sports; games; amusements | 453 | 1.1 |
| 14 | G07 | Checking-devices | 268 | 0.7 |
| 15 | F24 | Heating; ranges; ventilating | 125 | 0.3 |
| 16 | G02 | Optics | 82 | 0.2 |

Source: EPO. Note: IPC Main Groups (5 digit) are aggregated to Classes (3 digit) (double counting). As multiple Main Groups within a Class are often used to specify the detailed technology class of a patent, the sum of figures here exceed the number of total patents.

**Figure 39 Technology class distribution of families of patents; main patent offices**




Note: See table above and below for a list of all technology classes pictured and full names of the classes and subclasses (see also the current IPC technology classification online). Here, the frequency of appearance of detailed technology Main Groups (5 digit), aggregated to Subclass level (4 digit) (double counting) is shown by the area of squares (and n in parenthesis). The relative share of aggregated Subclass technology classes is shown in brackets. Squares are coloured according to the higher-level technology Class (3 digit). Patents from all main patent offices are sourced here.

**Table 44 Technology classification (IPC Subclass) of patents that potentially enhance human-centricity, main patent offices**

| | Subclass | Full name of subclass | # of documents | Share of subclass |
|---|---|---|---|---|
| **1** | G06F | Electric digital data processing (computer systems based on specific computational models G06N) | 11,757 | 29.7 |
| 2 | G10L | Speech analysis or synthesis; speech recognition; speech or voice processing; speech or audio coding or decoding | 2,719 | 6.9 |
| 3 | G06K | Graphical data reading (image or video recognition or understanding G06V); presentation of data; record carriers; handling record carriers | 2,687 | 6.8 |
| 4 | G06N | Computing arrangements based on specific computational models | 2,575 | 6.5 |
| 5 | G06Q | Information and communication technology [ict] specially adapted for administrative, commercial, financial, managerial or supervisory purposes; systems or methods specially adapted for administrative, commercial, financial, managerial or supervisory purposes, not otherwise provided for | 2,509 | 6.3 |
| 6 | G05B | Control or regulating systems in general; functional elements of such systems; monitoring or testing arrangements for such systems or elements (fluid-pressure actuators or systems acting by means of fluids in general F15B; valves per seF16K; characterised by mechanical features only G05G; sensitive elements, see the appropriate subclasses, e.g., G12B, subclasses of G01, H01;correcting units, see the appropriate subclasses, e.g., H02K) | 2,332 | 5.9 |
| 7 | B25J | MANIPULATORS; CHAMBERS PROVIDED WITH MANIPULATION DEVICES (robotic devices for individually picking fruits, vegetables, hops or the like A01D0046300000;needle manipulators for surgery A61B0017062000;manipulators associated with rolling mills B21B0039200000;manipulators associated with forging machines B21J0013100000;means for holding wheels or parts thereof B60B0030000000;cranes B66C;arrangements for handling fuel or other materials which are used within nuclear reactors G21C0019000000;structural combination of manipulators with cells or rooms shielded against radiation G21F0007060000) | 1,680 | 4.2 |
| 8 | H04L | TRANSMISSION OF DIGITAL INFORMATION, e.g., TELEGRAPHIC COMMUNICATION (arrangements common to telegraphic and telephonic communication H04M) | 1,648 | 4.2 |
| 9 | G06V | Image or video recognition or understanding | 1,515 | 3.8 |
| 10 | G06T | Image data processing or generation, in general | 1,184 | 3.0 |
| 11 | A61B | DIAGNOSIS; SURGERY; IDENTIFICATION (analysing biological material G01N, e.g., G01N0033480000) | 956 | 2.4 |

| | Subclass | Full name of subclass | # of documents | Share of subclass |
|---|---|---|---|---|
| 12 | H04N | PICTORIAL COMMUNICATION, e.g., TELEVISION | 836 | 2.1 |
| 13 | H02J | Circuit arrangements or systems for supplying or distributing electric power; systems for storing electric energy | 620 | 1.6 |
| 14 | B60W | Conjoint control of vehicle sub-units of different type or different function; control systems specially adapted for hybrid vehicles; road vehicle drives control systems for purposes not related to the control of a particular sub-unit | 608 | 1.5 |
| 15 | H04M | TELEPHONIC COMMUNICATION (circuits for controlling other apparatus via a telephone cable and not involving telephone switching apparatus G08) | 491 | 1.2 |
| 16 | G16H | HEALTHCARE INFORMATICS, i.e. INFORMATION AND COMMUNICATION TECHNOLOGY [ICT] SPECIALLY ADAPTED FOR THE HANDLING OR PROCESSING OF MEDICAL OR HEALTHCARE DATA | 472 | 1.2 |
| 17 | H04W | WIRELESS COMMUNICATION NETWORKS (broadcast communication H04H; communication systems using wireless links for non-selective communication, e.g., Wireless extensions H04M0001720000) | 470 | 1.2 |
| 18 | G01R | MEASURING ELECTRIC VARIABLES; MEASURING MAGNETIC VARIABLES (indicating correct tuning of resonant circuits H03J0003120000) | 453 | 1.1 |
| 19 | A63F | Card, board or roulette games; indoor games using small moving playing bodies; video games; games not otherwise provided for | 373 | 0.9 |
| 20 | G09B | Educational or demonstration appliances; appliances for teaching, or communicating with, the blind, deaf or mute; models; planetaria; globes; maps; diagrams | 335 | 0.8 |
| 21 | G05D | Systems for controlling or regulating non-electric variables | 307 | 0.8 |
| 22 | G01N | Investigating or analysing materials by determining their chemical or physical properties (measuring or testing processes other than immunoassay, involving enzymes or microorganisms C12M, C12Q) | 262 | 0.7 |
| 23 | B60K | Arrangement or mounting of propulsion units or of transmissions in vehicles; arrangement or mounting of plural diverse prime movers in vehicles; auxiliary drives for vehicles; instrumentation or dashboards for vehicles; arrangements in connection with cooling, air intake, gas exhaust or fuel supply of propulsion units in vehicles | 247 | 0.6 |
| 24 | B60R | VEHICLES, VEHICLE FITTINGS, OR VEHICLE PARTS, NOT OTHERWISE PROVIDED FOR (fire prevention, containment or extinguishing specially adapted for vehicles | 235 | 0.6 |

| | Subclass | Full name of subclass | # of documents | Share of subclass |
|---|---|---|---|---|
| | | A62C0003070000) | | |
| 25 | G01C | MEASURING DISTANCES, LEVELS OR BEARINGS; SURVEYING; NAVIGATION; GYROSCOPIC INSTRUMENTS; PHOTOGRAMMETRY OR VIDEOGRAMMETRY (measuring liquid level G01F; radio navigation, determining distance or velocity by use of propagation effects, e.g., Doppler effect, propagation time, of radio waves, analogous arrangements using other waves G01S) | 234 | 0.6 |
| 26 | G08G | TRAFFIC CONTROL SYSTEMS (guiding railway traffic, ensuring the safety of railway traffic B61L;radar or analogous systems, sonar systems or lidar systems specially adapted for traffic control G01S0013910000, G01S0015880000, G01S0017880000;radar or analogous systems, sonar systems or lidar systems specially adapted for anti-collision purposes G01S0013930000, G01S0015930000, G01S0017930000;control of position, course, altitude or attitude of land, water, air or space vehicles, not being specific to a traffic environment G05D0001000000) | 234 | 0.6 |
| 27 | G01D | Measuring not specially adapted for a specific variable; arrangements for measuring two or more variables not covered by a single other subclass; tariff metering apparatus; transferring or transducing arrangements not specially adapted for a specific variable; measuring or testing not otherwise provided for | 210 | 0.5 |
| 28 | G08C | TRANSMISSION SYSTEMS FOR MEASURED VALUES, CONTROL OR SIMILAR SIGNALS (fluid pressure transmission systems F15B; mechanical means for transferring the output of a sensing member into a different variable G01D0005000000; mechanical control systems G05G) | 199 | 0.5 |
| 29 | G09G | ARRANGEMENTS OR CIRCUITS FOR CONTROL OF INDICATING DEVICES USING STATIC MEANS TO PRESENT VARIABLE INFORMATION (arrangements for transferring data between digital computers and displays G06F0003140000;static indicating arrangements comprising an association of a number of separate sources or light control cells G09F0009000000;static indicating arrangements comprising integral associations of a number of light sources H01J, H01K, H01L, H05B0033120000;scanning, transmission or reproduction of documents or the like, e.g., Facsimile transmission, details thereof H04N0001000000) | 156 | 0.4 |
| 30 | G08B | Signalling or calling systems; order telegraphs; alarm systems | 144 | 0.4 |
| 31 | G07C | Time or attendance registers; registering or indicating the working of machines; generating random numbers; voting or lottery apparatus; arrangements, systems or apparatus for checking not provided for elsewhere | 140 | 0.4 |
| 32 | G07F | COIN-FREED OR LIKE APPARATUS (coin sorting | 128 | 0.3 |

| | Subclass | Full name of subclass | # of documents | Share of subclass |
|---|---|---|---|---|
| | | G07D0003000000; coin testing G07D0005000000) | | |
| 33 | F24F | AIR-CONDITIONING; AIR-HUMIDIFICATION; VENTILATION; USE OF AIR CURRENTS FOR SCREENING (removing dirt or fumes from areas where they are produced B08B0015000000; vertical ducts for carrying away waste gases from buildings E04F0017020000; tops for chimneys or ventilating shafts, terminals for flues F23L0017020000) | 125 | 0.3 |
| 34 | A61H | PHYSICAL THERAPY APPARATUS, e.g., DEVICES FOR LOCATING OR STIMULATING REFLEX POINTS IN THE BODY; ARTIFICIAL RESPIRATION; MASSAGE; BATHING DEVICES FOR SPECIAL THERAPEUTIC OR HYGIENIC PURPOSES OR SPECIFIC PARTS OF THE BODY (electrotherapy, magnetotherapy, radiation therapy, ultrasound therapy A61N) | 115 | 0.3 |
| 35 | G01B | Measuring length, thickness or similar linear dimensions; measuring angles; measuring areas; measuring irregularities of surfaces or contours | 100 | 0.3 |
| 36 | H04B | Transmission | 89 | 0.2 |
| 37 | G01S | Radio direction-finding; radio navigation; determining distance or velocity by use of radio waves; locating or presence-detecting by use of the reflection or reradiation of radio waves; analogous arrangements using other waves | 84 | 0.2 |
| 38 | G02B | Optical elements, systems or apparatus | 82 | 0.2 |
| 39 | A63B | APPARATUS FOR PHYSICAL TRAINING, GYMNASTICS, SWIMMING, CLIMBING, OR FENCING; BALL GAMES; TRAINING EQUIPMENT (apparatus for passive exercising, massage A61H) | 80 | 0.2 |
| 40 | H02H | EMERGENCY PROTECTIVE CIRCUIT ARRANGEMENTS (indicating or signalling undesired working conditions G01R, e.g., G01R0031000000, G08B; locating faults along lines G01R0031080000; emergency protective devices H01H) | 72 | 0.2 |
| 41 | A61N | ELECTROTHERAPY; MAGNETOTHERAPY; RADIATION THERAPY; ULTRASOUND THERAPY (measurement of bioelectric currents A61B; surgical instruments, devices or methods for transferring non-mechanical forms of energy to or from the body A61B0018000000; anaesthetic apparatus in general A61M; incandescent lamps H01K;infra-red radiators for heating H05B) | 69 | 0.2 |
| 42 | B60L | PROPULSION OF ELECTRICALLY-PROPELLED VEHICLES (arrangements or mounting of electrical propulsion units or of plural diverse prime-movers for mutual or common propulsion in vehicles B60K0001000000, B60K0006200000;arrangements or mounting of electrical gearing in vehicles B60K0017120000, B60K0017140000;preventing wheel slip by reducing power in | 62 | 0.2 |

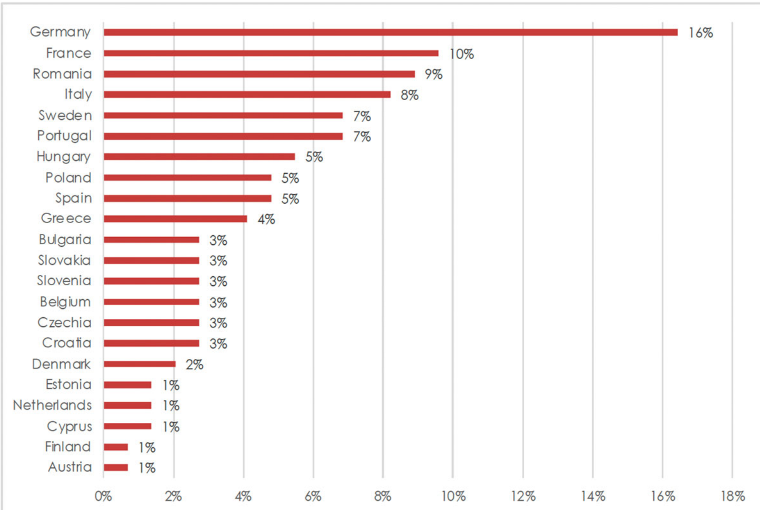
| | Subclass | Full name of subclass | # of documents | Share of subclass |
|---|---|---|---|---|
| | | rail vehicles B61C0015080000;dynamo-electric machines H02K;control or regulation of electric motors H02P); SUPPLYING ELECTRIC POWER FOR AUXILIARY EQUIPMENT OF ELECTRICALLY-PROPELLED VEHICLES (electric coupling devices combined with mechanical couplings of vehicles B60D0001640000;electric heating for vehicles B60H0001000000); ELECTRODYNAMIC BRAKE SYSTEMS FOR VEHICLES IN GENERAL (control or regulation of electric motors H02P); MAGNETIC SUSPENSION OR LEVITATION FOR VEHICLES; MONITORING OPERATING VARIABLES OF ELECTRICALLY-PROPELLED VEHICLES; ELECTRIC SAFETY DEVICES FOR ELECTRICALLY-PROPELLED VEHICLES | | |

Source: EPO. Note: IPC Main Groups (5 digit) are aggregated to Subclasses (4 digit) (double counting). As multiple Main Groups within a Subclass are often used to specify the detailed technology class of a patent, the sum of figures here exceed the number of total patents.

# ANNEX 9 SURVEY SAMPLE OVERVIEW

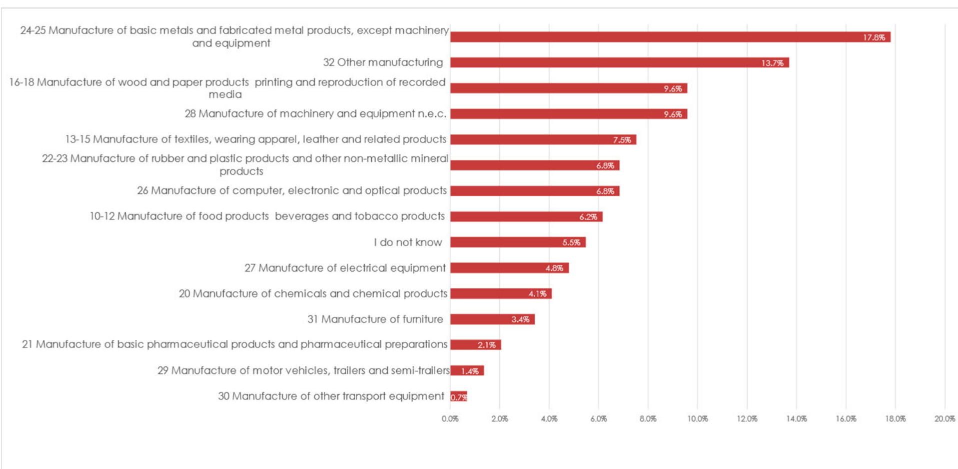
As of the closing day on November 13, 2023, the total number of respondents, including partial respondents, reached 143. Respondents originate from diverse countries, with Germany and France being the most represented, comprising 16.1% and 9.8% of the sample, respectively. Approximately one-third of the sample consists of organisations based in Eastern European countries, with Romanian-based companies accounting for 7.7% of the total sample.

### Figure 40 Country of origin of respondents




Source: Authors based on survey question 1: Please select the country of your organisation (country of residence of operating unit) (N=147)

### Figure 41 Distribution of manufacturing sectors in survey sample

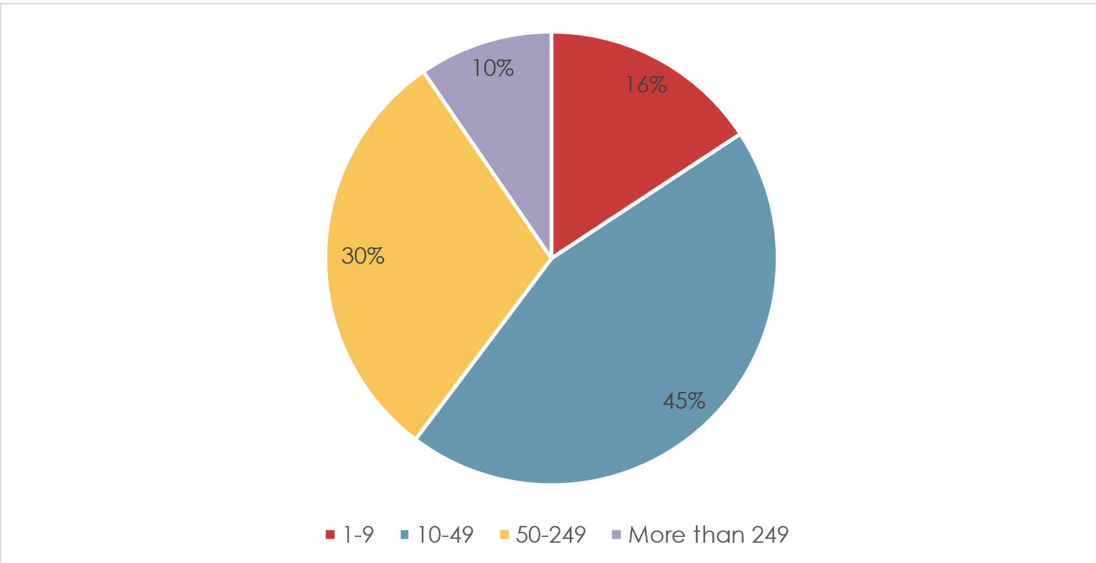



Source: Authors based on survey question 2: Please specify the sectoral code of your primary activity (NACE classification) (N=147)

The distribution of respondents across different manufacturing sectors shows a concentration in specific areas. The largest sector represented is 24-25, which includes the manufacture of basic metals and fabricated metal products (excluding machinery and equipment), accounting for 18.2% (26 respondents). The second most represented is sector 32, encompassing other manufacturing activities, with 14% (20 respondents). Sectors 28 and 16-18, which represent the manufacture of machinery and equipment N.E.C. (not elsewhere classified) and the manufacture of wood and paper products including printing and reproduction of recorded media, also have a notable presence with 9.8% (14 respondents) each. Additionally, sectors 26 and 22-23, covering the manufacture of computer, electronic and optical products, and the manufacture of rubber and plastic products along with other non-metallic mineral products, respectively, are represented by 7% (10 respondents) each.

In terms of size, SMEs make up 90% of the sample, with 38% indicating a workforce of 50 to 249 employees. Micro-enterprises constitute 16% of the sample, while larger SMEs (with 50 to 249 employees) contribute to 30% of the total sample.

**Figure 42 Distribution of companies by size**




Source: Authors based on survey question 3: 3. How many persons (in full-time equivalents) were employed in your organisation in 2022? (N=147)

# LIST OF ABBREVIATIONS

| | |
|---|---|
| AI | Artificial Intelligence |
| AR / VR / XR | Augmented Reality / Virtual Reality / eXtended Reality |
| CIF | Common Industry Format |
| CVT | Continuing Vocational Training |
| DEP | Digital Europe Programme |
| EaSI | EU Programme for Employment and Social Innovation |
| EC | European Commission |
| EDIH | European Digital Innovation Hubs |
| EFFRA | European Factories of the Future Research Association |
| EIC | European Innovation Council |
| EIT | European Institute of Innovation and Technology |
| EIT KICs | European Institute of Innovation and Technology Knowledge & Innovation Communities |
| ELSA / ELSI | Ethical, legal, societal aspects/impacts |
| EPO | European Patent Office |
| ERA | European Research Area |
| ESF+ | European Social Fund+ |
| ESIR | Expert group on the economic and societal impact of research and innovation |
| EU | European Union |
| FP | Framework Programme |
| GDPR | General Data Protection Regulation |
| HC | Human-centric |
| HCD | Human-centric Design |
| HCT | Human-centric Enabling Technologies |

| | |
|---|---|
| HR | Human Resources |
| IEA | International Energy Agency |
| IoT | Internet of Things |
| IT | Information Technology |
| JRC | Joint Research Centre |
| KPI / OKR | Key Performance Indicators / Objective and Key Results |
| MaaS | Manufacturing as a Service |
| MS | Member States |
| PCP | Pre-commercial Procurement |
| PCT | Patent Cooperation Treaty |
| R&I | Research and Innovation |
| RTO | Research Technology Organisation |
| SDG | Sustainable Development Goals |
| SRIA | Strategic Research and Innovation Agendas |
| SSH | Social Sciences and Humanities |
| TEF | Testing and experimentation facilities |
| TRL | Technology Readiness Level |
| VET | Vocational Education and Training |
| WIPO | World Intellectual Property Office |

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Human centricity is one of the three pillars of Industry 5.0.
This Roadmap shows how industrial innovation ecosystem stakeholders can take a leading role in achieving human-centric outcomes in technology development and adoption, such as improving workers' safety and wellbeing, upskilling or learning.
There are significant opportunities to capture the transformative potential of ground-breaking technologies like artificial intelligence and virtual worlds through more human-centric and user-driven design approaches.
The Roadmap recommends that policy makers support integrating human-centricity considerations in education and training, R&I funding and in company training and innovation strategies.

*Research and Innovation policy*

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