European Commission

Enabling Technologies for Industry 5.0

Results of a workshop with Europe's technology leaders

Independent Expert Report

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Research and Innovation

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Results of a workshop with Europe’s technology leaders

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EXECUTIVE SUMMARY

Europe is embarking on a transition towards climate neutrality and digital leadership[1]. The twin green and digital transition, as well as the need for competitiveness on the global stage will transform our industry, support our small and medium-sized enterprises and keep Europe sustainable and competitive. This transition will require the acceptance, trust and the commitment of the public to be successful and strategies for industrial modernisation must put people and societal needs in the centre.

The vision of an innovative, resilient, socio-centred and competitive industry, which respects planetary boundaries and minimises its negative environmental impact, has been labelled Industry 5.0. It opens up many new challenges related to technology, socio-economy, regulation and governance.

Against this background, the concept of Industry 5.0 was discussed among participants from research and technology organisations (RTOs) and funding agencies across Europe in two virtual workshops on 2 and 9 July 2020. The goal was to get feedback on the general concept, and to discuss the enabling technologies and possible challenges. While the nomenclature of the concept was debated among participants, there was a consensus that social and environmental needs must be better integrated into technology development. Furthermore, participants agreed that the complexity of the challenges could not be solved by individual technologies, but need a systemic approach.

The technologies supporting the concept of Industry 5.0 include:

- **Human-centric solutions and human-machine-interaction** technologies that interconnect and combine the strengths of humans and machines.
- **Bio-inspired technologies and smart materials** that allow materials with embedded sensors and enhanced features while being recyclable.
- **Real time based digital twins and simulation** to model entire systems.
- **Cyber safe data transmission, storage, and analysis technologies** that are able to handle data and system interoperability.
- **Artificial Intelligence** e.g**.** to detect causalities in complex, dynamic systems, leading to actionable intelligence.
- **Technologies for energy efficiency and trustworthy autonomy** as the above-named technologies will require large amounts of energy.

For a systemic approach, several challenges must be regarded that can be addressed with respective enablers:

- 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.

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[1] https://ec.europa.eu/info/strategy/priorities-2019-2024/europe-fit-digital-age/european-industrial-strategy_en

- The high speed of transformation requires measures in the **governmental and political dimension**. This includes 'agile government' approaches, understanding complex, interrelated systems of industrial ecosystems and labour markets

- **Interdisciplinarity and transdisciplinarity,** the requirement to integrate different research disciplines (e.g., life sciences, engineering, social sciences and humanities) is complex and must be understood in a systems approach.

- In the **economic dimension**, solutions for maintaining economic profitability and competitiveness and the funds required must be found, e.g., through developing respective business models that value ecological and social aspects.

- **Scalability** in the sense of ensuring a broad-scale implementation of technologies across value chains and ecosystems, including SMEs.

1 Introduction

1.1 *The concept of Industry 5.0*

Industry is the single biggest contributor to the European economy, providing jobs and prosperity across the continent. European industry is strong, but faces constant challenges. It is highly competitive, but operates in an increasingly complex globalised economy. It is a solid exporter, but is exposed to a fast-changing geopolitical landscape. It is efficient and cost-effective, but vulnerable to hick-ups in long supply and distribution chains. Between 2008 and 2018, industry accounts constantly for 20 % of EU GDP[2] and more particularly, manufacturing provides around 14.5% of added-value to the EU economy[3].

In order for industry to continue to bring prosperity to Europe, it needs to adapt to tackle these ever-changing challenges, which is only possible through ongoing innovation. European industry can improve its efficiency at different places in the value chain even further, increase flexibility, agility and leanness of its production systems to cater to the quickly changing demands of the global consumer, and continue to be a global reference for quality.

The fourth industrial revolution is based on the idea of merging the physical and virtual worlds through cyber-physical systems, and interconnecting humans, machines and devices through the Internet of Things. This horizontal and vertical interconnection across entire value chains, from customer to supplier, across the entire product lifecycle, and across different functional departments forms new value networks and ecosystems. The creation of added value can be made more efficient, personalised, of higher quality, service-oriented, traceable, resilient and flexible. Maintenance will be connected to production in a different way than before, resulting in an integrated chain that covers the entire life cycle. It will generate benefits in economic, ecological and social regards, relating to the Triple Bottom Line of sustainable development.

The four industrial revolutions are centred around general-purpose technologies, in the first industrial revolution mechanization through water and steam power, electrification, labour division and mass production in the second industrial revolution, and IT, electronics and automation in the third industrial revolution. Industry 4.0 focuses on cyber-physical-systems and the Internet of Things, as well as further technologies mentioned when referring to the concept. Instead, Industry 5.0 shall base on supporting and fostering socially and ecologically relevant values.

Two virtual workshops with representatives from Research and Technology Organisations from across Europe were held to discuss the concept of Industry 5.0, based on the preliminary definition: *Industry 5.0 recognises the power of industry to achieve societal goals beyond jobs and growth to become a provider of prosperity, by making production respect the boundaries of our planet and placing the wellbeing of the industry worker at the centre of the production process.*'

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[2] Eurostat (2019) National accounts and GDP, https://ec.europa.eu/eurostat/statistics-explained/index.php/National_accounts_and_GDP#Gross_value_added_in_the_EU_by_economic_activity

[3] The World Bank (2019) Manufacturing, value added (% of GDP) – European Union, https://data.worldbank.org/indicator/NV.IND.MANF.ZS?locations=EU

1.2 Comments on the term and concept of Industry 5.0

The discussion among participants started with doubts about the suitability of the term and the concept of Industry 5.0.

First, if Industry 5.0 covers the technologies relevant for Industry 4.0, this could lead to a potential confusion when coining a result or development associated with the fourth industrial revolution as a fifth industrial revolution. Previous industrial revolutions' developments took decades to unfold, while Industry 4.0 was first described in 2011. Industry 4.0 as a concept is already described as rather marketing-driven, so using the nomenclature once again after such a short time could amplify this perception. For instance, a truly technology-driven development in the field of biological transformation or quantum technologies[4] would be a separate industrial revolution, posing the question if this would then not be centred around societal and ecological values.

Second, creating the concept of Industry 5.0 around societal and ecological values instead of technologies, disrupting the concept of industrial revolutions in general, could lead to a misperception. This could drive the developments from a technological capability perspective to a political one. The concept of values and, more importantly, which values are seen as important and how they are understood, are perceived in several different ways around the world.

Third, many thoughts and concepts of Industry 5.0 can already be found in Industry 4.0. For instance, in its initial concept, Industry 4.0 was centred around values for humans, society, and ecology. Further, highly individualized products, often referred to as 'batch size one' as a catchphrase of mass customization, represent a central characteristic of Industry 4.0.[5] Since the introduction of the term, several technologies have been labelled 'Industry 4.0' without referring to a broader purpose outside economic benefits. Nevertheless, technologies allowing human-machine-interaction such as Augmented and Virtual Reality and collaborative robotics, are part of the concept of Industry 4.0, and used across continents to support humans and generate value.

Fourth, and this is particularly relevant, Industry 4.0 is still unfolding to a large extent. Especially small and medium-sized enterprises, craft manufacturers, or traditional industries are still far from a wide-scale implementation of Industry 4.0 technologies. Further, while several technologies can be seen in isolated solutions, the full horizontal and vertical integration across the supply chain, as aimed for in Industry 4.0, is still far from reality in most industrial value chains. Therefore, the nomenclature of Industry 5.0 might indicate an even newer set of technologies than in Industry 4.0, but several of Industry 4.0 ideas are even further far away from implementation than proposed for Industry 5.0.

To summarise, several of the ideas of Industry 4.0 seem to be revitalised under a new terminology. The concept of Industry 5.0 could also be described as re-introducing the lost dimension of a 'human/value-centred Industry 4.0', or as one participant put it,

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[4] Müller, J. & Potters, L. (2019) Future technology for prosperity. Horizon scanning by Europe's technology leaders. https://op.europa.eu/en/publication-detail/-/publication/ae785b63-dba9-11e9-9c4e-01aa75ed71a1/language-en/format-PDF/source-107509475

[5] Kagermann et al. (2013) Recommendations for implementing the strategic initiative INDUSTRIE 4.0. https://en.acatech.de/publication/recommendations-for-implementing-the-strategic-initiative-industrie-4-0-final-report-of-the-industrie-4-0-working-group/

'Industry 4.1'. At the end of the two workshops, however, there was a clear consensus that there is a need for adding a value dimension to the concept of Industry 4.0.

Participants agreed that Industry 5.0 should not be understood as a replacement nor an alternative to, but an evolution and logical continuation of the existing Industry 4.0 paradigm. As such, the concept of Industry 5.0 is not based on technologies, but is centred around values, such as human-centricity, ecological or social benefits. This paradigm shift is based on the idea that technologies can be shaped towards supporting values, while the technological transformation can be designed according to the societal needs, not vice versa. This is especially important as ongoing societal developments in the fourth industrial revolution change the way value is created, exchanged and distributed. Further, technologies in Industry 5.0 must be regarded as part of systems that are actively designed towards empowering societal and ecological values, not technologies that determine societal developments. For example, the primary focus of technologies used should not be to replace the worker on the shop floor, but to support the workers' abilities and lead to safer and more satisfying working environments. The technologies at the core of Industry 5.0 are largely congruent with Industry 4.0, while a stronger focus on human-centred technologies forms the basis for Industry 5.0. The term is further associated with the Japanese concept of Society 5.0, describing societal developments following or accompanying Industry 4.0 technologies. Industry 5.0 complements and extends the hallmark features of Industry 4.0. Its key dimension is the inclusion of a broader set of values, especially extending a human-centric towards a socio-centric perspective. This also increases the complexity and requirement for governance, as explained further in section 3.

According to the discussions in the two workshops, the following features of Industry 5.0 were emphasised in particular: Merging human and technological skills and strengths to the mutual benefit of industry and industry workers not technology replacing, but complementing humans. This allows safer, more satisfying and more ergonomic working environments, in which humans can use their creativity in problem-solving, adopt new roles, and enhance their skills. The core idea behind Industry 5.0 is to choose technologies based on an ethical rationale of how those support human values and needs, and not only based on what they can achieve from a purely technical or economic perspective. Technologies such as human-machine-interfaces, merging human brain capacities with Artificial Intelligence or collaboration with robots and machines are used to generate products and services. These products and services can be further customised to customer needs, reduce environmental impact and allow concept such as closed loops, energy self-sufficiency, emission-neutrality, or the Circular Economy.

While the development of the concept of Industry 5.0 started before Covid-19, it can be regarded as exemplary challenge that highlights the need to consider or reconsider concepts such as local generation of added value and reshoring, increased focus on resilience, optimisation, return of stock and introducing the notion of sovereign capability in contrast to lean principles and productivity-driven rationales. Policy plays a crucial role in reshoring; it must create attractive framework conditions to stimulate companies to place their businesses in Europe. Innovation and value creation must be oriented towards demands and needs, requiring organisational and societal change towards converging disciplines, mind-sets, leadership and decision-making, and organisational silos, advancing concepts such as the shared economy. Further, trust in technologies, cybersecurity and data protection must be enhanced by encouraging customers to make informed decisions on the technologies and products they use. Moreover, individual trust in new technologies increases with the level of competence in manoeuvring those, so substantial trainings and upskilling are needed across supply chains. Finally, developing the currently dominating techno-deterministic rationale into a human-deterministic rationale, based on joint values, is the first step towards the concept of Industry 5.0.

2 Enabling technologies

The enabling technologies of Industry 5.0 are a set of complex systems that combine technologies, such as smart materials, with embedded, bio-inspired sensors. Therefore, each of the following categories can only unfold its potential when combined with others, as a part of systems and technological frameworks.

2.1 Individualised Human-machine-interaction

To link humans with technologies, support humans and combine human innovation and machines capabilities. The following technologies support humans in physical and cognitive tasks:

- 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

2.2 Bio-inspired technologies and smart materials

Bio-inspired technologies and processes stemming from the concept of Biological Transformation can be integrated with, for instance, the following properties:

- Self-healing or self-repairing
- Lightweight
- Recyclable
- Raw material generation from waste
- Integration of living materials
- Embedded sensor technologies and biosensors
- Adaptive/responsive ergonomics and surface properties
- Materials with intrinsic traceability

2.3 Digital twins and simulation

Digital twins and simulation technologies optimise production, test products and processes and detect possible harmful effects, for instance:

- Digital twins of products and processes
- Virtual simulation and testing of products and processes (e.g., for human-centricity, working and operational safety)
- Multi-scale dynamic modelling and simulation

- Simulation and measurement of environmental and social impact
- Cyber-physical systems and digital twins of entire systems
- Planned maintenance

2.4 Data transmission, storage, and analysis technologies

Energy-efficient and secure data transmission, storage, and analysis technologies are required, with properties such as:

- Networked sensors
- Data and system interoperability
- Scalable, multi-level cyber security
- Cyber security/safe cloud IT-infrastructure
- Big data management
- Traceability (e.g., data origin and fulfilment of specifications)
- Data processing for learning processes
- Edge computing

2.5 Artificial Intelligence

Artificial intelligence, nowadays often still referring to advanced correlation analysis technologies, must be developed further in several regards:

- Causality-based and not only correlation-based artificial intelligence
- Show relations and network effects outside of correlations
- Ability to respond to new or unexpected conditions without human support
- Swarm intelligence
- Brain-machine interfaces
- Individual, person-centric Artificial Intelligence
- Informed deep learning (expert knowledge combined with Artificial Intelligence)
- Skill matching of humans and tasks
- Secure and energy-efficient Artificial Intelligence
- Ability to handle and find correlations among complex, interrelated data of different origin and scales in dynamic systems within a system of systems

2.6 Technologies for energy efficiency, renewables, storage and autonomy

As the majority of technologies mentioned requires large amounts of energy to operate, the following technologies and properties are required to achieve emission neutrality:

- Integration of renewable energy sources

- Support of Hydrogen and Power-to-X technologies
- Smart dust and energy-autonomous sensors
- Low energy data transmission and data analysis

3 Challenges and Enablers

In general, the challenges and enablers discussed encompass a complex system across technological and organisational aspects, political and public factors, and the Triple Bottom Line of sustainability (economic, ecological and social dimensions). Therefore, the following categories of challenges and enablers represent a complex system and must be regarded as strongly interlinked and interrelated.

3.1 Social dimension

- Technology acceptance and trust in technologies is crucial. Therefore, initiatives must highlight the support, not determination of humans, while maintaining the right for society to participate in the ideation and application of technologies and the respective purpose. In addition, new technologies such as Artificial Intelligence need to be understandable and transparent.
- Adapting technology to humans must coincide with training people how to use new technologies. Human-centricity should not be a one-way road. Otherwise, technologies will not unfold their full potential.
- Upcoming labour and skills shortages through demographic developments must be envisioned as well as changing requirements of skills across generations, while future skills required are not known yet. Retraining and lifelong learning concepts must be implemented, supported by policy makers.
- Current challenges such as youth unemployment, ageing society or gender and societal inequality must be integrated better to achieve a wide acceptance, forging a 'new deal' between society and industry.
- Heterogeneity of society leads to disagreement on which values and needs should be prioritised. Different parts of society focus on different values and have distinct needs. Age, gender, sex, cultural background and diversity aspects must be integrated.
- Full integration of customers across the entire value chains is required to inform them about social or environmental value created and include this in their choice and willingness to pay.
- Traditional Corporate Social Responsibility approaches are rather a marketing concept and implemented as showcases, but not implemented to full scale yet. Regulatory incentives must complement public opinions here to stimulate companies to drive Corporate Social Responsibility further, especially in SMEs.
- Socio-centricity describes a concept that extends the concept of human-centricity, complementing the needs of individuals to those of a society. The needs of individual employees must be integrated within the needs of an entire workforce of employees, employers, the society as a whole.
- In the long run, society cannot ignore planetary boundaries. Hence, socio-centricity must take into account the ecological perspective. Environmental targets such as CO_2 neutrality must not be forgotten and require research in the domain of e.g., nanotechnologies or smart materials. To develop approaches such

as the Circular Economy further, corresponding business models, approaches such as CO_2 taxation and platform-based technologies for traceability, reusing and recycling are required. One option is a CO2 footprint label on all products to make it possible to compare and get a personal or a company footprint.

- Environmental impact is hard to measure, social impact is even harder to quantify. Technological approaches must be found to measure and quantify environmental and social value generated.

3.2 Governmental and political dimension

- Social and governmental change often cannot keep up with the speed of technological change. This requires an 'agile government' approach with issues such as responsiveness, collaboration, participation, experimentation, adaptability, and outcome-orientation based on intrinsic, extrinsic and market motivations.

- European industries and ecosystems should become more sovereign to facilitate compliance with European values, e.g. concerning resources, skills, raw materials, or energy. Regional value chains can help to ensure resilience and secure ecological and social values.

- There is a risk of protectionism of individual countries and industries in which there is a support to single industries rather than dynamic ecosystems, and certain technologies are selected not because of the values they contribute to, but for protectionist motives. Therefore, national or regional strategies must be widened regarding innovation policy design and implementation, for which RTOs and SMEs can take an active role.

- System-oriented innovation policies are required that focus on supporting ecosystems, not single technologies or sectors. In addition, policies must be evaluated based on their (possibly negative) interrelations with other policies or companies being overwhelmed with complexity. There is a clear need to strengthen capacity in the EU for system oriented innovation policy evaluation because it is the cornerstone for evidence-based and distributed intelligence in innovation policy-making.

- The complex ecosystem of technologies, industries and labour markets must be regarded from a holistic perspective and require a governance approach that integrates and balances the different requirements. For instance, social sciences and humanities (especially ethics) and the observation of labour markets must complement technological perspectives in order to support values.

- The economic perspective on productivity, that is dominant for many companies, must be balanced with a long-term, sustainability perspective on increasing productivity through generating ecological and social value. The need to be productive and competitive in a short to medium-term perspective in comparison to regions outside Europe, that might be mainly productivity-oriented and technology-driven, must not be forgotten in this context.

3.3 Interdisciplinarity

- An interdisciplinary approach is required related to engineering, technology, life sciences, and environmental and social sciences and humanities. One possible approach is to support interdisciplinarity of research from early on, e.g., the inclusion of social sciences in technological research. High complexity might otherwise have negative impacts on security, safety or acceptance and might slow down implementation, but fast actions are required.

- The interdisciplinarity and complexity requires a system approach, such as 'cyber-physical systems of systems'. Such a System of Systems approach must model the interrelations at various scales of systems that dynamically interact. Such a modelling approach is challenging from various angles, as there is a wide variety of systems, scales and data involved as well as path dependencies arising from different industries and research disciplines.

- It is important to highlight that Industry 5.0 also includes sectors outside the manufacturing industry, such as life sciences, healthcare, agriculture, food or energy. Further, the inclusion of governments, consumers, and society is key to gain acceptance. Especially a biological transformation might lead to new values, but might not be associated to the term 'industry'.

- Artificial Intelligence needs to be included in research and design processes while integrating the requirements of different research disciplines in complex systems. In particular, the interrelations and cause-effect relations between multiple variables must be understood as dynamic networks that constantly change.

3.4 Economic dimension

- Business models need to be developed that make ecological and social value approachable, e.g. through benefitting from social and environmental value created as the customer is willing to pay for it, or through legislation, such as CO_2 certificates. Companies are required to make money. Such business models can be complemented with digital platform approaches and ecosystems that allow the integration of multiple stakeholders, such as companies, public institutions, and customers.

- Productivity is still required to maintain competitiveness. Economic and social value generated is becoming an increased competitiveness factor. Therefore, the economic dimension must not be neglected and economic targets should not be left out of the concept for companies. Otherwise, only marketing-driven showcases might be implemented while many firms could be discouraged from the concept.

- Large investments are required that follow a new rationale in contrast to purely economic considerations. Solutions must be found to, for instance, guide private equity funds towards generating social and environmental added value.

- In this context, public-private-partnerships may be a suitable instrument to institutionalise the dialogue between business and policy in specific areas.

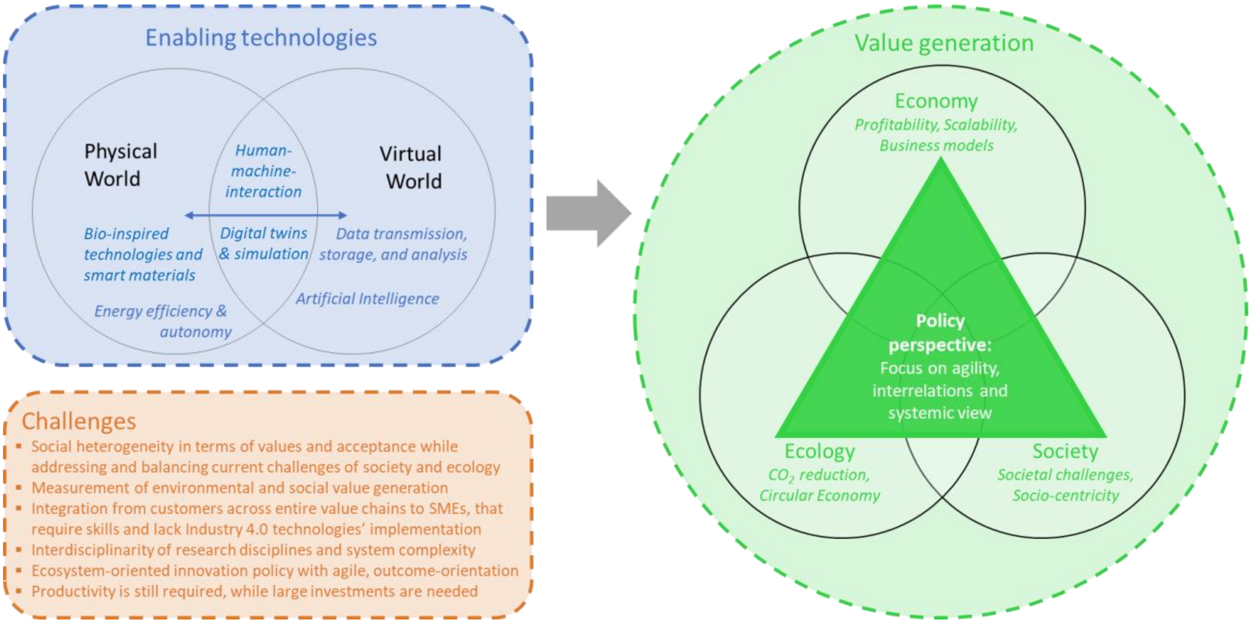
3.5 Scalability

- Many Industry 4.0 technologies are not fully implemented yet, especially in SMEs or across entire value chains. Further, innovation management and R&D investments are underdeveloped and not standardised, particularly in SMEs or traditional industry sectors. The policies should also support broad implementation in entire industries or in SMEs, not only High-Tech for a small proportion of firms. For this, a wider integration of industry associations and representatives from industry is required for the further design of the concept. Skills in leadership and management alongside workers' skills must be further developed

- Entire industries and ecosystems must be addressed with a systematic approach to new technologies. Entire ecosystems must be understood and supported accordingly, including leading players, followers, SMEs, RTOs and universities as well as legislation and policy makers. A full-scale implementation at a lower technology level can bring more benefits in comparison to single pillars that can be leading examples, but must be followed by broad implementation.

4 Conclusion

The framework below highlights the main features of goals, technological enablers, and challenges associated with the concept of Industry 5.0.



Participants agreed on the requirement of a better integration of social and ecological needs while contributing to European values through new technologies. However, such an approach must respect the heterogeneous perception of values and needs in society, while measuring and quantifying environmental and especially social value remains difficult.

When technologies that stem from life sciences are combined with engineering and information technology disciplines, this will require a more systematic innovation approach that integrates different perspectives and takes a systemic view on entire ecosystems. Further, the systems generated will be highly complex, interrelated, interdependent and will have to cope with inhomogeneous data sets.

Economic targets such as productivity and competitiveness must not be neglected but set within agreed ecological and social values. This can be achieved through business models which value ecological and social value creation or incentives from legislation.

Apart from nomenclature and challenges arising from complexity or technological considerations, society and the bulk of the industrial landscape must be integrated in such a concept. Therefore, customers and entire supply chains, up to SMEs must be better integrated to ensure a broad-scale implementation and value generation towards prosperity.

ANNEX

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The concept of Industry 5.0 was discussed among participants from research and technology organisations as well as funding agencies across Europe in two virtual workshops on 2 and 9 July 2020. The goal was to get feedback by participants on the general concept, and to discuss the enabling technologies and possible challenges. While participants had different views on the nomenclature of the concept, they agreed on the requirement to better integrate social and environmental needs into technological innovation and to shift the focus from individual technologies to a system approach. In line with this objective, several technologies that must be combined to coherent systems and associated challenges were discussed.

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