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Report with recommendations on the future of the Industrial digitalisation roadmap

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Summary

This deliverable presents the final version of the recommendations on the future of the Industrial digitalisation roadmap in order to define next ECSEL MASP and help shaping the Lighthouse Initiative.

Team involved in deliverable writing: MGEP, S2i, VTT.

1 Introduction

This deliverable presents the final results of the recommendations for the next ECSEL MASP. The deliverable has been developed in the “Task 1.3 Recommendations for next steps (M7-24)” and results are based on previous tasks and resultant deliverables of Work Package 1.

- *D1.1: Report on programmes and project’s complementarities and synergies of “Task 1.1 Identify overlaps, complementarity and added value regarding relevant roadmaps, programmes, activities and projects”*
- *D1.2: Report on Industrial digitalisation roadmap gaps identification of “Task 1.2 Identification of gaps and emerging themes”*

After an analysis of other roadmaps and programmes and gaps identification, final recommendations for the next ECSEL MASP are presented in this deliverable.

The tasks in WP1 was carried out in two iterations. The first iteration had the goal of delivering preliminary results for June 2019, to give inputs in time to the 2019 Strategic Research Agenda writing. The intermediate deliverables (D1.1, D1.2 and D1.3-intermediate one) were part of the first iteration. Tasks 1.1, 1.2 and 1.3 continued in the second iteration. During the second iteration, results were refined, a deeper analysis of the projects in the lighthouse was performed and new projects incorporated to the lighthouse were also analyzed.

2 Followed methodology

This section presents the methodology followed to draw the recommendations for the future of the Industrial digitalisation roadmap.

The methodology has consisted of six main phases (see Figure 1):

1. **Selection of relevant roadmaps:** In this phase, the roadmaps, research agendas and visions that are relevant were identified. The output of this phase was a list of roadmaps to be analysed.
2. **Roadmap analysis:** In this phase, the selected roadmaps were analysed. The output of this phase was a report with the analysis of the roadmaps.
3. **Identification of initial gaps and emerging themes:** In this phase, the gaps and emerging themes were identified comparing the analysed roadmaps and the ECS SRA (Strategic Research Agenda) of ECSEL. The output was a list of emerging themes and gaps
4. **Project mapping:** In this phase, the projects of the Industry 4.E lighthouse were mapped and assessed. The output was the mapping.
5. **Update of gaps and emerging themes:** Once the project mapping was ready, an update of emerging themes and gaps was performed. Interviews with coordinators of the projects and the “Shaping the Future Lighthouse Industry 4.E” workshop in Bucharest were used to get information and feedback from coordinators.
6. **Draw recommendations:** Finally in this phase, the recommendations were drawn. During all the phases but especially for drawing recommendations, the interaction with the SRA writing team has been continuous. In the second iteration, a “Roadmapping” workshop has been used to get further feedback from experts.

Two iterations of these five phases have been performed. In the second iteration, new roadmaps and projects have been included; and more feedback from experts have been gathered.

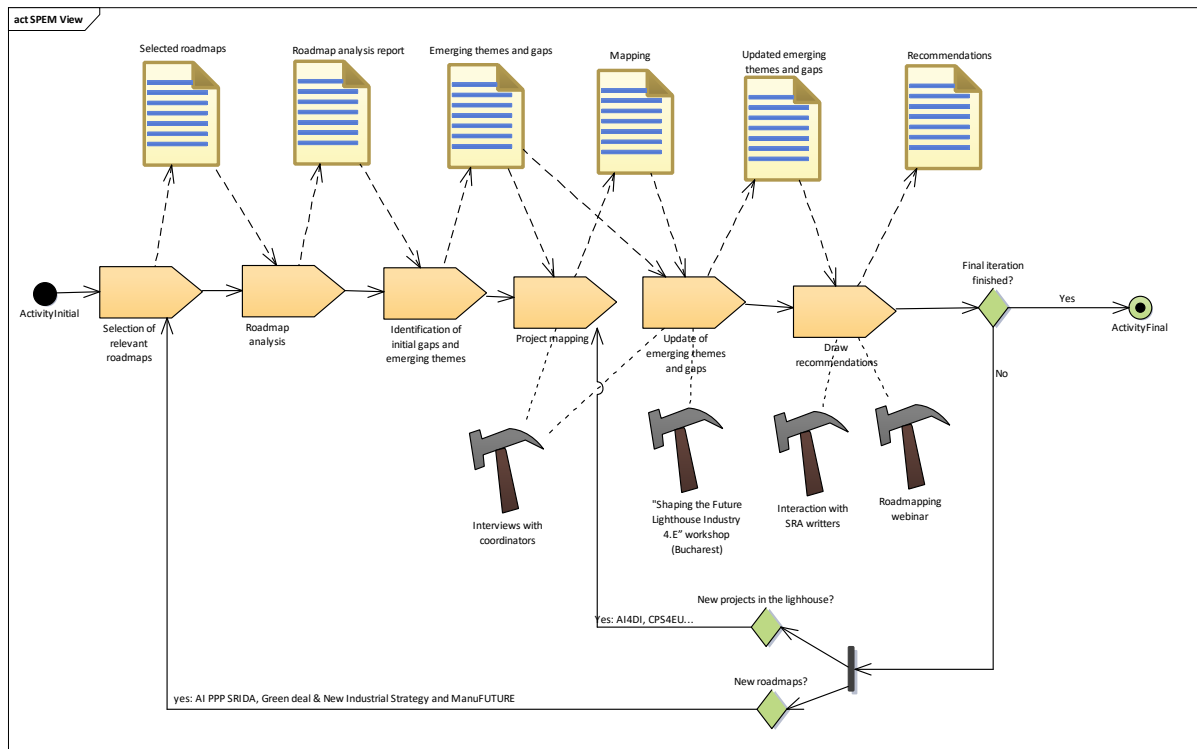


Figure 1: SPeM diagram showing the followed methodology

2.1 Selection of relevant roadmaps

For the selection of relevant roadmaps, three criteria were defined:

- Date of the documents: Only recent roadmaps (2017-2020) were selected.
- Topics: Roadmaps with focus on manufacturing plus roadmaps with focus on technological topics related to the challenges of Digital industry (data analysis, IoT/CPS, HPC, etc.) were selected.
- Geographical scope: European roadmaps and a national initiative: German national industry 4.0 roadmap. Only the German roadmap were selected as is the precursor of other national initiatives in Europe.

In the first iteration, these were the roadmaps analysed:

- EFFRA Roadmaps + Factories of the Future in Horizon Europe (2021-2027): Preparing the next multi-annual roadmap for Framework Programme 9, FoF in Horizon Europe – confidential – 12/2018
- European Roadmap for Industrial Process Automation, 2nd version (2018)
- Eureka Smart Advanced manufacturing Technology Roadmap (2018)
- Manufuture Vision 2030
- CPS Roadmaps (Platforms4CPS, Road2CPS and CPSoS)

- Big data: European Big Data Value Strategic Research and Innovation Agenda, BDVA, 2017 + “Big data challenges in smart manufacturing: A discussion paper on big data challenges for BDVA and EFFRA Research & Innovation roadmaps alignment” (March 2018)
- HiPEAC Vision
- The Industrie 4.0 (national/German) Roadmap/Guidelines and the associated Working Group Documents
- 2018 World manufacturing forum report: Recommendations for the future of manufacturing

In the second iteration, four new roadmaps or strategies were selected and analysed. Three of them aligned with two very relevant movements in Europe: The hype about AI and the European Green Deal. And a specific roadmap of the Manufacturing sector.

- AI PPP SRIDA [1]: Strategic Research, Innovation and Deployment Agenda for an AI PPP: A focal point for collaboration on Artificial Intelligence, Data and Robotics, June 2019
- The European Green Deal [2]
- New Industrial Strategy for Europe [3]
- ManuFUTURE Vision for 2030 [6]

2.2 Roadmap analysis

During this phase, roadmaps have been analysed in order to find synergies and complementarities with ECS SRA of ECSEL. Comparisons have been done using the challenges identified for the Digital Industry and the subtopics highlighted in the ECS SRA of ECSEL, plus cross-cutting aspects and other topics relevant in ECSEL: Digital twin, Machine learning, Condition monitoring, digital platforms and cross-cutting aspects present in ECSEL. This way, common priorities/challenges/topics has been identified and also emerging trends and potential gaps not present in the ECSEL SRA.

2.3 Identification of initial gaps and emerging themes

In this phase, the initial results of the previous phase (roadmap analysis) have been used to further identify emerging trends and gaps.

2.4 Project mapping

All the projects in the Industry 4.E lighthouse have been mapped. Three items from the ECSEL’s SRA 2019 were used to assess the projects:

- The key application areas: Transport and Smart Mobility, Health and Well-being, Energy, Digital Industry and Digital Life.
- The essential capabilities: Systems and Components: Architecture, Design and Integration; Connectivity and Interoperability; Safety, Security and Reliability; Computing and Storage; and Process Technology, Equipment, Materials & Manufacturing for ECS.
- The challenges identified for the Digital Industry:
 - Major Challenge 1: Developing digital twins, simulation models for the evaluation of industrial assets at all factory levels and over system or product life cycles.

- Major Challenge 2: Implementing AI and machine learning to detect anomalies or similarities and to optimize parameters.
- Major challenge 3: Generalizing condition monitoring, to pre-damage warning online decision-making support.
- Major challenge 4: Developing digital platforms, application development frameworks that integrate sensors and systems.

During the first iteration, “**Mantis**: Cyber Physical System based Proactive Collaborative Maintenance”, “**SWARMS**: Smart and Networking Underwater Robots in Cooperation Meshes”, “**Semi40**: Power Semiconductor and Electronics Manufacturing 4.0”, “**Delphi4Led**: From Measurements to Standardized Multi-Domain Compact Models of LEDs”, “**Productive 4.0**: Electronics and ICT as enabler for digital industry and optimized supply chain management covering the entire product lifecycle”, “**SCOTT**: Secure Connected Trustable Things”, “**I-MECH**: Intelligent Motion Control Platform for Smart Mechatronic Systems”, “**AFarCloud**: Aggregate Farming in the Cloud”, “**iDev40**: Integrated Development 4.0”, “**MADEin4**: Metrology Advances for Digitized ECS industry 4.0” and “**Arrowhead Tools**: Arrowhead Tools for Engineering of Digitalisation Solutions” projects were mapped. And during the second iteration, two new inclusions to the lighthouse were mapped: “**Ai4Di**: Artificial Intelligence for Digitizing Industry” and “**CPS4EU**: Cyber Physical Systems for Europe” projects.

2.5 Update of gaps and emerging themes

In this phase, the initial gaps and emerging themes were updated. The project mapping helped to identify which areas already in the ECS SRA of ECSEL are more covered or less. In addition, project mapping was enlarged with new items: technical & non-technical emerging themes that were not yet included in the ECSEL. Projects were assessed against these emerging themes.

Interviews with coordinators of the projects and the “Shaping the Future Lighthouse Industry 4.E” workshop in Bucharest were used to get information and feedback from coordinators.

2.6 Draw recommendations

Finally, recommendations were drawn. The more technical recommendations about new challenges or changes in the challenges (results of the first iteration) were already included in the SRA of 2020 (due to the continuous interaction with the SRA writing team). And to draw final recommendations a “Roadmapping” workshop was used to get further feedback from experts.

3 First iteration (intermediate version)

3.1 Approach

One of the success factors identified in the “Task 1.3 Recommendations for next steps” is getting the feedback of key stakeholders such as relevant experts from academia and industry from the ECSEL community. With this purpose:

- The preliminary results of gap analysis has been shared with the writing groups of the Strategic Research Agenda of ECSEL. And the writing group of the “Digital Industry” chapter has used the information to reshape the challenges of the chapter.
- The feedback of the Coordinators of Industry 4.E lighthouse projects has been also obtained. During the “Shaping the Future Lighthouse Industry 4.E” workshop held in Bucharest the 19th of June 2019 co-located with the ECSEL Symposium, coordinators have presented the future topics of their projects. Moreover, a roadmap session was organized with presentation of results of project mapping and roadmap analysis and discussion on gaps, obstacles and urgent challenges to be tackled in next calls.

3.1.1 Involvement of stakeholders: SRA writing group

The Strategic Research Agenda Writing group has been working in the SRA for 2019 and has taken into consideration our initial gap analyses for reshaping the Challenges of the “Digital Industry” Chapter of the SRA. The “Identified Emerging Topics and Possible Gaps” taken into consideration are explained in D1.2 and are related to the following topics:

- **Topic 1:** Human centred manufacturing
- **Topic 2:** Sustainable manufacturing in a Circular Economy
- **Topic 3:** AI enabled cognitive, resilient, adaptable factories
- **Topic 4:** Multi-technology co-engineering enabled by digitalization
- **Topic 5:** Innovation Accelerators / Business models / Skills

In the Figure 1, the changes proposed for the SRA 2019 could be seen. The challenges of “Digital Twins” and “Digital Platforms” are maintained, three new challenges are proposed: “Human centred manufacturing”, “Sustainable manufacturing in a Circular Economy” and “Multi-technology co-engineering enabled by digitalization” in order to address the gaps identified. And a new challenge related to AI is proposed “AI enabled cognitive, resilient, adaptable manufacturing” replacing two challenges (AI and condition monitoring) of SRA 2018 and broadening the scope of AI applied to industry 4.0 and inspired by the gaps identified.

Major Challenges

Mainly based on the initial gap analyses of the CSA-Industry4.E

ECS SRA 2018

- **MC1:** 'Developing **digital twins**, simulation models for the evaluation of industrial assets at all factory levels and over system or product life-cycles'
- **MC2:** 'Implementing **AI** and machine learning to detect anomalies or similarities and to optimize parameters'
- **MC3:** 'Generalising **condition monitoring**, to pre-damage warning on-line decision-making support and standardisation of communication scenarii to enable big data collection across huge (remote) sites'
- **MC4:** 'Developing **digital platforms**, application development frameworks that integrate sensors/actuators and systems'

ECS SRA 2019

- **MC1:** 'Developing **digital twins**, simulation models for the evaluation of industrial assets at all factory levels and over system or product life-cycles'
- **MC2:** **AI enabled cognitive, resilient, adaptable manufacturing**
- **MC3:** 'Developing **digital platforms**, application development frameworks that integrate sensors/actuators and systems'
- **MC4:** **Human centred manufacturing**
- **MC5:** **Sustainable manufacturing in a Circular Economy**
- **MC6:** **Multi-technology co-engineering enabled by digitalization**

19/06/2019 VTT – beyond the obvious

Figure 2: Slide of the SRA writing group

The SRA writing group has developed a draft version of the Digital Industry chapter implementing the six major challenges of the figure.

3.1.2 Involvement of stakeholders: Feedback from Coordinators of Lighthouse projects

During the “Shaping the Future Lighthouse Industry 4.E” workshop held in Bucharest the 19th of June 2019 co-located with the ECSEL Symposium, coordinators presented the future topics (two steps ahead) of their projects. The topics mentioned by each of the projects are the following:

- Delphi4LED
 - Standardized LED electronics datasheets from LED vendors
 - Implementation of the Multi-domain LED compact model in the commercial CFD, FEM Tools or interfacing to the Delphi4LED model
- Productive 4.0
 - AI in production: Combination of data
- Mantis
 - Bring the Intelligent Functions from the Cloud to the Edge
 - Improve HMIs
- I-MECH
 - Full machine digital twins living parallel live used for predictive maintenance
 - Combining AI with information from the machine (nobody knows the machine better than the control system which controls it – edge computing)
 - New principle sensors (even self-powered) namely for vibration measurement
 - New principle actuators

- From machine level to system level
- Collaborative robots – elastics joints
- IDev40
 - AI algorithms have the potential to support and automate many processes and combine information from different sources
 - Consistent IT security throughout the value chain bears the potential for dramatic increase in trust and efficiency
 - Autonomous production systems by digital twins
 - SSoT enables seamless data and information re-use across the hierarchical levels of each system and between systems, concerning the whole product lifecycle
 - Socio-economic aspects are crucial for the upcoming digital transformation, Human aspects
- MADEIn4
 - HiFIVE “Heterogeneous integration for 5G deployment and Industry 4.0 data growth Viability supported by ECS developments” project (2019 ECSEL IA submission)
- SCOTT
 - Safety and security of IoT:
 - Must be defined by each domain and use case.
 - Define model of evaluation of safety and security. Flexible, adjustable...
 - Application of AI
- Arrowhead tools
 - Integrate Development and Operation of SoS and IoT

As a summary, topics such as standardization, Interoperability, Artificial Intelligence (AI), AI and Edge computing, HMLs, Digital Twins, Security and Safety, Human aspects, 5G and Wireless manufacturing and Co-engineering are mentioned.

In the discussion of the Roadmap session after presenting the recommendations in section 3, participants agree that the new topics proposed are relevant, especially Human centred manufacturing and Circular economy topics. During the discussion, Artificial Intelligence was also mentioned, as is a trending topic mentioned in almost all the projects.

The importance of non-technical and cross-cutting topics was mentioned, even if they are not so highlighted in the SRA of ECSEL, they are of great importance. For example, the skills and education is mentioned as something that ECSEL projects should address (Arrowhead tools is mentioned as example of Lighthouse project addressing education). The lighthouse should also address education and skills topics.

3.2 Recommendations

This section presents the recommendations about topics and themes for the SRA, special topics and other kinds of recommendations.

3.2.1 Recommendations about Challenges and Topics

The recommendations proposed in this section are based on the gaps and initial recommendations identified in D1.2 and the feedback of stakeholders explained in section 2. The recommendations are subdivided into proposals for

- refinements/extensions of the current 4 major challenges
- additions in terms of new technological topics in the current challenges
- additions in terms of new non-tech / innovation related topics in the current challenges
- addition of new 3 challenges

Refinements/adaptions/extensions to the current major challenges:

The current ‘major challenges’ of the ‘Digital Industry’ Chapter are:

- **Major Challenge 1:** ‘Developing digital twins, simulation models for the evaluation of industrial assets at all factory levels and over system or product life-cycles’
- **Major Challenge 2:** ‘Implementing AI and machine learning to detect anomalies or similarities and to optimise parameters’
- **Major challenge 3:** ‘Generalising condition monitoring, to pre-damage warning on-line decision-making support and standardisation of communication scenario to enable big data collection across huge (remote) sites’
- **Major challenge 4:** ‘Developing digital platforms, application development frameworks that integrate sensors/actuators and systems’

All ‘major challenges’ have been assessed to still being very relevant and should indeed be kept in the next iteration of the ECS SRA, but can partly be extended with the evolving trends identified. Major challenge 2 and 3 were found to be very related (even overlapping) and are proposed to be fused to one new major challenge for ‘AI enabled/optimised manufacturing’. New trends, especially ‘Circular Economy’ and ‘Human-centred manufacturing’ have become very prominent and are proposed to be added as new major challenges. The topic of “Multi-technology co-engineering enabled by digitalization” could be also a candidate for a new challenge.

Major Challenge 1: ‘Developing digital twins, simulation models for the evaluation of industrial assets at all factory levels and over system or product life-cycles’

In major challenge 1, the digital twin is comprehensively described and specifically elaborated for ‘virtual commissioning’. Moreover ‘machining process simulation’ and is described and the wider context for modelling and simulation, digital design and documentation mentioned. (Other) priority areas include multi-simulation, tracking mode simulation, model adaption, simulator-based design. There is a link to major challenge 4, as digital platforms can provide the infrastructure to automate background processes. Interoperability is a barrier to be overcome, possibly by a standard to make

13 (98)

digital twins ‘communicate’. As indicated in the headline, digital twins are to be developed for the evaluation of industrial assets at all factory levels and over the system or product life-cycle.

The analysis of different roadmaps (and discussions with experts) revealed, that on the one hand, the ‘digital twins’ referred to within the ECS SRA could be extended toward ‘other twins’, the methods for modelling and simulation could be extended and detailed and the scope of applying the digital twin/methods for modelling and simulation could be widened towards including the human in the loop, and the product life-cycle towards a circular economy approach (from cradle-to-cradle). Moreover, the digital twin can support new business models. In addition, coordinators of ongoing lighthouse projects mentioned topics such as Autonomous production systems by digital twins and full machine digital twins living parallel live used for predictive maintenance.

Gaps in regards to other roadmaps include the following topics, which should be taken into account in ECSEL SRA:

- Further methods for modelling and simulation
- Human in the loop
- Circular Economy
- Standardisation
- Business models
- Skills

Major Challenge 2: ‘Implementing AI and machine learning to detect anomalies or similarities and to optimise parameters’ and **Major challenge 3:** ‘Generalising condition monitoring, to pre-damage warning on-line decision-making support and standardisation of communication scenario to enable big data collection across huge (remote) sites’

Major challenge 2 focuses on deep learning and mentions CPS/ Industrial Internet, big data, machine learning, AI, which today are not yet transparent nor practical to use. Local edge-based intelligence is seen as an opportunity for Europe. Major challenges 3 refers to advanced condition monitoring (towards 5G condition monitoring), which can be supported by AI and is also very linked to MC1, modelling and simulation/digital twin, as key priority areas include (automated) modelling and analytics tools and multi-variant and multi objective-simulation and optimisation. Increased efficiency, flexibility and robustness of the production process is expected.

As major challenge 2 and 3 were found to be very related they are proposed to be fused to one new major challenge for ‘AI enabled/optimised/cognitive manufacturing’. This ‘new major challenge would then build on the former two, and would be extended towards AI enabled, adaptable, resilient factories including the human as a part of the ‘socio-technical’ system. AI in combination with (predictive) condition monitoring and maintenance will be applied to not only support reconfigurable first time right / zero defect manufacturing, but also support human decision making (considering uncertainties) as well as enable resilient manufacturing ecosystems based on new business models.

Gaps in regards to other roadmaps include the following topics, which should be taken into account in ECSEL SRA:

- (Big) Data Analytics, AI / machine learning
- AI/Condition monitoring for high quality outcomes
- Cognitive, resilient factories, supply chains, value creation networks
- AI and Human in the Loop, Human as part of the resilient factory
- AI, condition monitoring for Circular Economy
- AI and Business
- AI and skills

Major challenge 4: ‘Developing digital platforms, application development frameworks that integrate sensors/actuators and systems’

Major challenge 4 focuses on digital platforms providing computing, storage and networking services between (edge) devices and data centres with AI capabilities. The platform landscape is still very heterogeneous on supply and demand side. To support interoperability, the IICF and RAMI is mentioned as standardisation will be key. Questions about meta-platforms, integrating AI, performance, security and impact on the environment are raised. Priorities are on future industrial and engineering applications, prepare for 5G, low power consumption, (semi)autonomy, and trusted (safe and secure by design) platforms.

The analysis of different roadmaps confirms, that the platform landscape is still very fragmented, with open and closed, vertical and horizontal platforms in different developments stages and for various applications. There is a strong need for interoperability / standardisation and orchestration / federation of platforms. The trend heads towards agile, composable, plug and play platforms (also usable for SMEs) and more decentralised, dynamic platforms supporting AI at the edge. Future (ledger based) could provide common services on trusted multisided markets / ecosystems.

Gaps in regards to other roadmaps include the following topics, which should be taken into account in ECSEL SRA:

- Digital Platforms Technology
- Digital Platforms Standardisation
- Digital Platforms Economy / Business / Society

Proposed new challenges:

Major challenge 5: ‘Sustainable manufacturing in a Circular Economy’

The analysis of different roadmaps shows a new trend related to the Circular Economy that is very relevant. The underlying topics include:

- Responsible value creation in a Circular Economy, sustainable manufacturing
- Sustainable manufacturing: innovative processes and systems for sustainability in terms of energy and resource consumption and impact in the environment.

Electronic Components and Systems (ECSs) could have a great impact in reducing the impact in the environment through sustainable manufacturing including energy and resource efficiency and applying circular economy strategies: eco-design, repair, reuse, refurbishment, remanufacture, recycle, waste prevention and waste recycling, etc. This impact is from two perspectives: From one side, the ECS as the product itself to repair, reuse, recycle... and from the other side, the ECS as enablers to improve sustainability and support circular economy in manufacturing. This challenge includes:

- Techniques, methods and tools for adoption of circular economy with ECS products
- Methods, tools, components and cyber physical systems to improve reuse, refurbishment and recycling of ECS products giving support to traceability management and support decision through the use of cyber physical systems, simulation, data analysis and AI techniques.
- Techniques, methods, tools and systems to improve energy and resource efficiency in manufacturing by sensors, components and systems. The challenge is the reduction of energy consumption in the manufacturing process, either by the reuse of wasted energy or by optimizing the processes and agents involved.
- New business models
- Skills

Major challenge 6: 'Human-centred manufacturing'

Another new trend related to Human factors in manufacturing is also very relevant. Gaps in regards to other roadmaps include the following topics:

- Human machine relation, interaction, collaboration, complementarity
- Human-in-the-loop, human as part of the system and HMI including intuitive systems, wearable and implantable systems, virtual and augmented reality as well as human machine collaboration and collaborative decision making
- New engineering tools considering humans as part of the systems
- Human machine / human robot collaboration, enhanced role of workers and customers in manufacturing
- Manufacturing as networked, dynamic socio-technical systems, HUMANufacturing as a new era of automation and human interaction, customer-centric value creation networks
- Human driven innovation, co-creation through manufacturing ecosystems, customer driven manufacturing value networks, social innovation
- Hyper-personalised manufacturing, human in the loop, inclusive manufacturing

Human and social aspects in manufacturing are of vital importance for addressing inclusive manufacturing and obtaining secure and safe workplaces. ECS and CPS Human Centric Cyber Physical Systems are needed to improve the involvement of humans and facilitate the human machine collaboration. Humans are involved in Digital Industry from different perspectives: 1. Systems designers and developers; 2. Systems users, workers; and 3. Systems clients and society in general.

These challenges include:

- New methods and tools to **incorporate humans and end-users** in the design process of Human Centric Cyber Physical Systems; possibly based on co-creation and user-driven techniques.
- Integration, test and experimentation of innovative systems (sensors, components, systems such as human centric Cyber Physical Systems) that will improve human-machine collaboration in training, operation and decision making in production plants assuring **ergonomics, safety and security**, while guaranteeing **interoperability** between learning and production systems. Based on diverse technologies such as
 - Adaptable Human Machine Interfaces (HMI)
 - Interactive learning systems
 - Augmented Reality (AR) and/or Virtual Reality (VR) systems
 - Enriched and enhanced technologies (wearable devices)
 - AI-based Human centric CPSs
 - Visualization technologies: dashboards...
- Didactic and pedagogic methods and systems for training of workers based on CPSs
- Methods and simulations for **Human in the loop simulations** and integration of digital twins in learning systems for workers
- Ethics

Major challenge 7: 'Multi-technology co-engineering enabled by digitalization'

By digital twin it is commonly referred to modelling and simulation (FEM, CFD, etc.) or virtual or mixed reality techniques, and their multitude applications. The product processes, manufacturing design, management of the operative lifetime of a product or factory is very much wider, however. Typical examples of such are: managing the multi-technologies (mechanical, electronics, electrical, software), safety, security and reliability engineering, managing the interactions with the contexts of the target (humans, environment), managing testing, quality, the many kinds of discharges or footprints, managing projects, logistics, supply chains, etc. These tasks are ever more managed by software tools and systems, with high involvement of standards, regulations and engineering handbooks, and in general require extensive domain knowledge and experience.

The respective engineering disciplines are well distinguished, developed and understood. Examples e.g. factory design, electronics design, engine design, car design are well-known and significant for success. These disciplines undergo today a tremendous and demanding digitalization, and they are sometimes called “the other twins” to underline their importance and high value. The so-called narrow focus “digital twin” certainly play a growing role in implementing the growing kinds of the “other twin”.

There is also a notable discipline called “systems engineering”, describing aspects end the whole of the instantiated subfields like factory design, engine design, etc. Similarly, many notable software tools, like PLM, SCM or CAD, are families of tools with significant versions for the actual subdomains.

- Parallel joint engineering of products, processes, safety, security, cybersecurity, human factors, sustainability, circular factors, etc.
- Mastering the deep linkage and complexities about multiple engineering domains and technologies, along with product and process lifecycles. In the digital domain.

- Multiplying the engineering extent, efficiency and quality in the digital world.

3.2.2 General recommendations related to non-technical topics

Several non-technical, innovation related topics and challenges have been mentioned to be incorporated or enhanced in the ECS SRA (digital industry or cross-cutting chapters). The most mentioned topics are the following ones:

- **Business models, innovation and value creation:** The Digitalization is revolutionizing the Business models, innovation and value creation processes. To address this revolution, project should address this challenge in the ECSEL projects.
- **Standardisation and Interoperability:** Standards to ensure full interoperability of data, applications, etc. are needed.
- **Skills and education:** Competences and skills gap for digital industry is one of the most important non-technical challenge that must be addressed as Industry needs more skilled workers for new types of jobs, especially important are the Digital skills in the Industry 4.0 era.

3.2.3 Recommendation for Special Topics

In addition to the recommendations for the future MASP, ECSEL requested to prepare recommendations for Special topics to be included in the work programme. Based on the results of the WP1, the consortium proposed three special topics (all of them could be found in D1.2) and one of them was selected to be presented to the ECSEL Governing Board, see the Special topic below.

The special topic was presented by the LIASE in the ECSEL Governing Board the 19th of June during the ECSEL Symposium.

Proposed Special topic:

Artificial intelligence (AI) enabled inclusive and resilient manufacturing – The Human in the Loop

- AI methods are revolutionary in many industrial areas, but in most cases, their **autonomy is limited specifically** where robustness and resilience is required
- **Participation of humans in the control loops** remains necessary to ensure **maximum performance**
- The difficulty that intelligent algorithms must communicate appropriately the reasons of their decisions. '**Explainable AI**' that humans build trust
- **AI for adaptable/resilient factories:** AI enables the creation of (semi)autonomous but still dependable factories/CPPS (Cyber Physical Production Systems) that can react to unforeseen, unpredictable, evolving behaviors. This also includes humans (e.g. the work force)

Proposal should cover some of the listed aspects but are not limited to:

- **Integration of AI in optimization processes** such as Condition monitoring, predictive maintenance, (predictive) process optimization
- **Combination of data and model-driven AI**
- Socio-CyberPhysical Systems (where humans play a role either as part of the plant, as part of the controller and/or as part of the environment) in manufacturing. **Joint cognitive systems.**
- Developing and demonstrating how AI-related computations are implemented in distributed architectures, modern embedded-**edge/fog-cloud** architectures

3.2.4 Other kinds of recommendation

Apart from recommendations more related to the SRA and roadmap of ECSEL. The importance of increasing the participation of SMEs in ECSEL has been observed. For this purpose, new instruments such as Open calls and Cascade Funding could be interesting. As well as other kind of instruments apart from IA, RIA and CSAs that could be focused on SMEs could be analysed.

4 Analysis of more roadmaps

In the second iteration, four new roadmaps or strategies were selected and analysed. Three of them aligned with two very relevant movements in Europe: The hype about AI and the European Green Deal. And a specific roadmap of the Manufacturing sector has been also analysed:

- AI PPP SRIDA roadmap [1] was selected, very aligned with the importance AI is getting in Europe and European strategy recently. Europe is currently involved in a hype about AI and the combination of Industrial data and AI could lead to great impact in the improvement of products and processes in manufacturing.
- Another important movement in Europe is the tackling of climate and environmental-related challenges. In this sense, the European commission delivered a communication in December 2019: The European Green deal [2]. And related to this the New Industrial Strategy for Europe [3] to address the twin challenge of the green and the digital transformation was delivered in March 2020.
- ManuFUTURE Vision for 2030 [6], relevant roadmap of the manufacturing sector.

4.1 AI PPP SRIDA

4.1.1 Summary

The Big Data Value Association (BDVA) and the European Robotics Association (euRobotics) present a SRIDA (Strategic Research, Innovation and Deployment Agenda) [1] towards a European AI PPP.

Global investment in AI is increasing, and according to IDC¹ worldwide spending in digitally based AI will reach \$35.8 billion in 2019, an increase of 44% over the amount spent in 2018. By 2022, this amount is projected to more than double to \$79.2 billion. The European share of industrial investments for this market is estimated at \$5 billion, with a forecast growth to 2022 to \$13 billion. IDC expects financial investment in all markets (see Figure 2).

¹ International Data Corporation (IDC), 'Worldwide Semi-annual Artificial Intelligence Systems Spending Guide, February 2019.

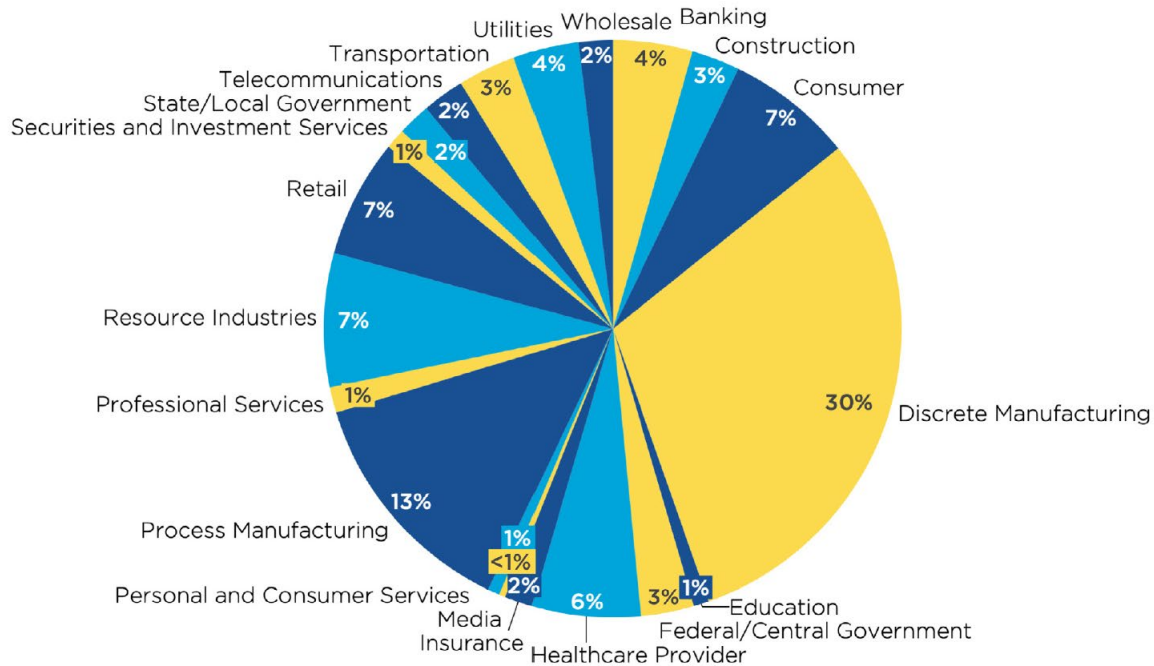


Figure 3: Expected distribution of financial investments in Artificial Intelligence systems, Robotics and Drones in Western Europe in 2019 (from [1])

Regarding [1], the deployment of AI will impact several main areas:

- By weaving AI into the design, manufacturing, production and deployment processes, productivity can be raised.
- By using AI to increase autonomy, higher operational flexibility can be achieved.
- By using AI to improve usability of products and services (e.g. by allowing greater variations in the human-machine interaction), the user value can be increased and new customer segments addressed, therefore creating new markets.
- By using AI for supporting complex decision-making processes in dynamic environments, people can get help in situations of rising complexity (e.g. technical complexity, increasing volatility in markets).

These fundamental impacts are felt at all areas in every market sector. **In manufacturing and production AI delivers productivity gains through more efficient resource, energy and material use, through better design and manufacturing processes and inside products and services, enhancing their operation with more refined contextual knowledge.**

Regarding [1], the challenges for the adoption of AI are the following:

- Fragmented Research Landscape
- Higher Complexity of AI in Industry and Public domain
- Lack of Skills and Know-How
- AI Policy and Regulation Uncertainty
- Societal Trust in AI
- Building a Digital Single Market

- Access to AI Infrastructure
- Technological Barriers
- EU private investment environment

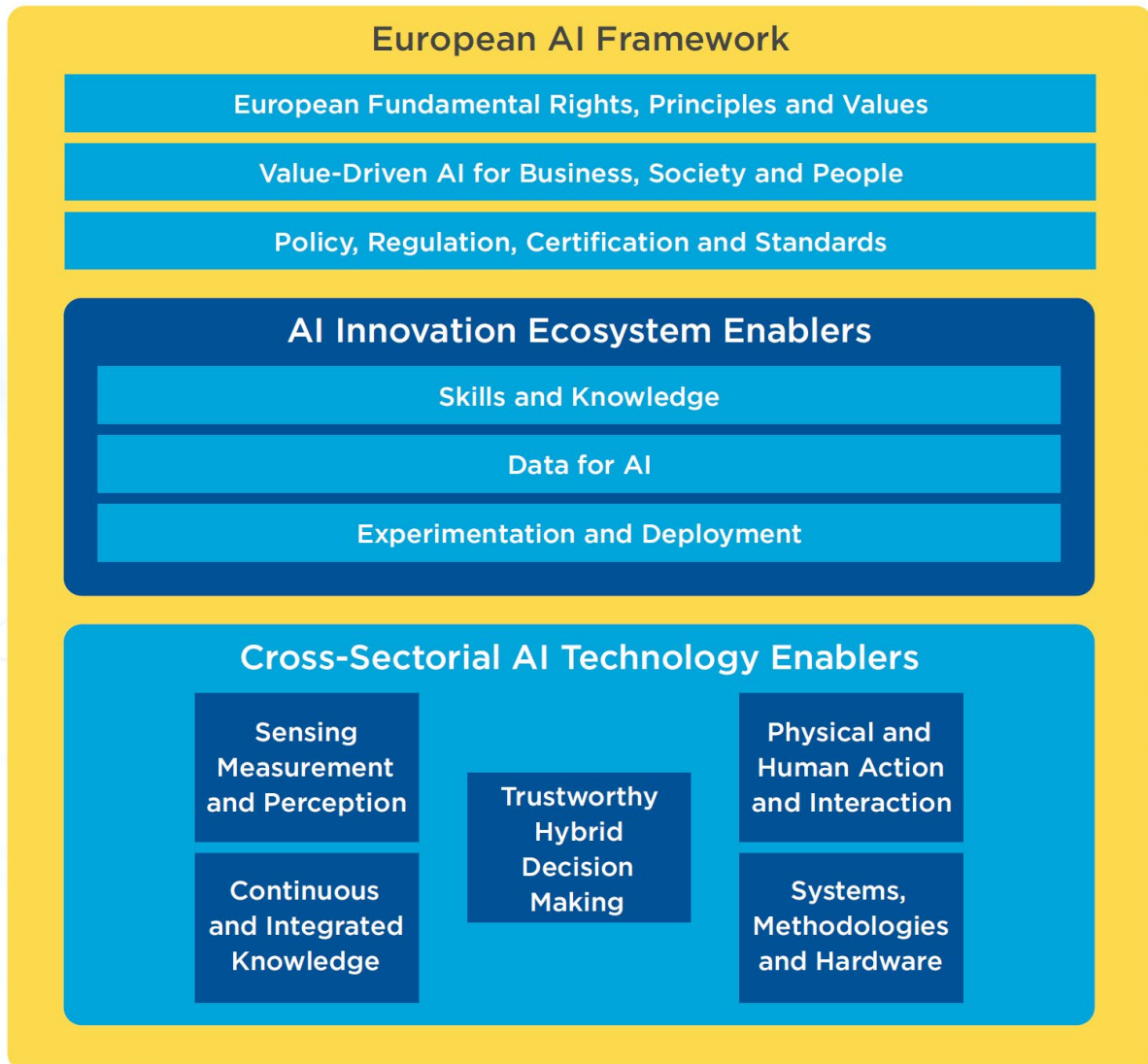


Figure 4: European AI Framework and Enablers

Figure 3 sets out the context for the operation of the AI PPP. It clusters the primary areas of importance for AI research, innovation and deployment into three overarching areas of interest. The European AI Framework represents the legal and societal fabric that underpins the impact of AI on stakeholders and users of the products and services that businesses will provide. The AI Innovation Ecosystem Enablers represent essential ingredients for effective innovation and deployment to take place. Finally, the Cross-Sectorial AI Technology Enablers represent the core technical competencies that are essential for the development of AI systems.

Products and services based on AI must be based on values that are compatible with European rights principles and values. Critical to deploying AI is its acceptance by users and citizens, and this acceptance can only come when they can assign trust. Three elements must be considered:

- **European Fundamental Rights, Principles, and Values:** The AI PPP has a unique ability to facilitate a multi-stakeholder dialogue that can expose challenges and define approaches to be explored and tested to make fundamental rights, principles and values actionable in practice.
- **Capturing Value for Business, Society, and People:** The role of the AI PPP is to mobilise industry and stakeholders in identifying how to build value from AI. With the main focus on application areas and sectors that: Are crucial for the European economy; Relate to critical infrastructure; Have a social or environmental impact or can increase European competitiveness in AI.
- **Policy, Regulation, Certification, and Standards (PRCS):** The adoption of AI depends on a legal framework of approval built on regulation, partly driven by policy, and an array of certification processes and standards driven by industry. As AI is deployed successfully in new market areas, regulation and certification can lag behind thereby creating barriers to adoption.

The AI Innovation Ecosystem Enablers are essential ingredients for success in the innovation system.

- **Skills and Knowledge:** AI will affect skills needed by both industry and wider society. As traditional industry sectors undergo an AI transformation, so too must their workforces
- **Data for AI.** For AI technology to develop further and meet expectations, large volumes of crosssectoral, unbiased, high-quality and trustworthy data need to be made available. Data spaces, platforms and marketplaces are enablers, the key to unleashing the potential of such data. There are however important business, organisational and legal constraints that can block this scenario such as the lack of motivation to share data due to ownership concerns; loss of control; lack of trust; the lack of foresight in not understanding the value of data or its sharing potential; the lack of data valuation standards in marketplaces; the legal blocks to the free-flow of data and the uncertainty around data policies. Additionally, significant technical challenges such as interoperability, data verification and provenance support, quality and accuracy, decentralised data sharing and processing architectures, and maturity and uptake of privacy-preserving technologies for big data have a direct impact on the data made available for sharing.
- **Experimentation and Deployment:** Experimentation is a critical for AI-based innovation because of the need to deploy in complex physical and digital environments. This includes safe environments for experimentation to explore the data value as well as to test the operation of autonomous actors. AI-driven innovations rely on the interplay of different assets, such as data, robotics, algorithms and infrastructure. For that reason, cooperation with other partners is central to gaining access to required assets. This includes access to the AI ecosystem covering AI platform providers, data scientists, data owners, providers, consumers, specialised consultancy, etc.

Cross-Sectorial AI Technology Enablers defined by the framework are the following ones:

- The **Sensing, Measuring and Perception** technology enablers create the data.
- The **Continuous and Integrated Knowledge** technology enablers create the knowledge on which decisions are made.
- The **Trustworthy Hybrid Decision Making** technologies makes the decisions to deliver; edge and cloud-based decision making, planning and decision systems, and the high and low-level decision making that surrounds AI operating in complex environments.
- **Physical and Human Action and Interaction** covers the challenges of human interaction, machine to machine inter-operation and machine interaction with the human environment.

Complex challenges that range from the optimisation of performance to safety and social interaction with humans in unstructured and multilingual environments.

- **The Systems, Methodologies and Hardware** technology enabler provides the technologies that enable the construction and configuring of systems, whether they are based purely on data or based on autonomous robotics. These tools, methods and processes integrate technology into systems and are responsible for ensuring that core system properties and characteristics such as safety, robustness, dependability and trustworthiness can be integrated into the design cycle, tested, validated and ultimately certified for use.

Sensing, Measuring and Perception

Sensing, measuring and perception technologies create information needed for successful decision making, control, and learning. They encompass methods to access, assess, convert and aggregate signals that represent real-world parameters into communicable data assets. They cover the development of sensing and processing methods, and the architecture of sensing systems. They create filtered and managed data streams and fill data stores and provide meta-data contexts. They address the parameters of acquisition, speed, resolution, range and quality and the technologies used to combine and fuse data to deliver an accurate picture of the world, be that from a website, a moving vehicle, **a factory process** or the reactions of people watching a TV advert.

The following high-level application driven challenges exist in this technology enabler:

- The development of faster more accurate methods of perception that cover all types of data modalities (text, video, image, sound, sensor, etc.) and that can operate across a wide range of environmental conditions; different weather, diverse everyday objects, different human emotions and ages, different behaviours and diverse human interactions.
- The development of active perception technologies that use cognition to guide the perceptual process; for example, prior knowledge and expectations can be used to focus sensing, for example, image interpretation may support text understanding, video may contextualise sound processing.
- The modularisation and standardisation of sensor interfaces, meta-information models and data flows; for example interfaces that can adapt to the balance between processing within the sensor (e.g. edge) and processing centrally (e.g. cloud); or handle both local and distributed data capture; or adapt processing methods to changing operating conditions or dynamics.
- The development of novel sensing and sensor systems for AI; for example in challenging environments; low and high temperature, pressure or in corrosive and explosive atmospheres, bio and chemical sensing, bio-compatible sensors and low cost, low energy, high accuracy sensors.
- The development of methods to validate and certify sensor systems for safety, privacy, trustworthiness, etc.; for example, safety certifiable sensors for human robot interaction, body pose detection or in-vivo physical interfaces.
- The development of advanced sensors able to adapt and self-calibrate, zero-energy sensor and sensors that can be embedded in retail packaging, bridges or people.

Continuous and Integrated Knowledge

Continuous and Integrated Knowledge makes the sensing, measurement and perception data assets amenable to use in decision-making. This involves transforming, cleaning, storing, sharing, modelling, simulation, synthesising and extracting insights. By combining data-driven and knowledge-based models, it becomes possible

- to close the loop from data-driven, automated analytics and decision support to fully automated enactment and actuation of decision, a significantly higher level of automation and reliability of processes becomes possible.
- to enable safe and reliable AI functionalities, such as navigation and tracking of autonomous robots in a wide range of applications including autonomous cars, drones, delivery of goods and monitoring.
- **to have a sustainable digital twin along the complete lifecycle (product and production) that provides value to AI data integration.**

The following high-level application driven challenges exist in this technology enabler:

- The scaling and federation of AI systems ensuring that simple AI-models can seamlessly be composed and combined into large scale federated systems.
- The development of data augmentation methods for transforming data assets into high-quality and augmented training data.
- Methods for knowledge modelling and representation that enable the seamless integration of data and connection with the physical world.
- Advanced learning methods to ensure scalability and reusability of analytical outcome. .
- Methods that integrate data-driven and knowledge-based approaches to ensure that AI system use all the available sources of information, and that models trained by data are legible for humans and are compliant to given specifications.
- The development of methods for handling security and privacy concerns.

Trustworthy Hybrid Decision Making

Decision making is at the heart of Artificial Intelligence. Four scenarios can be considered where the different techniques within AI are used:

- Human Decision Making. When people interpret the output of AI-based systems to make decisions and take actions. For example in a manufacturing plant, the supervisor analyses the output of several predictive models in order to immediately stop the plant to repair a single machine or wait until the next scheduled maintenance stop. Here the consequences of the decision are assessed by a person or a team.
- Machine Decision Making. When actions are carried out autonomously by an AI-based system. For example, self-driving cars or drones. The consequences are assessed by the AI-based system.
- Mixed Decision Making and Decision Support. When decisions are agreed balanced between humans and machines. The consequences are evaluated taking into account the criteria of people (one person or a team) and the machine's criteria.
- Sliding or Variable Decision Making. When the balance between human and machine decision making varies during operation depending on machine based confidence levels or human interactions.

All three scenarios face combinations of the following challenges:

- **Timeliness:** ranging from decisions that must be taken immediately, in a matter of milliseconds, because the next steps/actions depend on every single decision (e.g. self-driving cars), to decisions that can be postponed with minimal risks or costs (e.g. predictive maintenance in production plants).
- **Robustness** ensuring that decision making maintains its level of performance under any circumstance.
- **Trustworthiness** increasing users' confidence in an AI System by making it dependable and reliable. To increase trust in AI systems, different aspects, such as transparency, explainability or controllability might be needed to be addressed.

The following high-level challenges exist in this technology enabler:

- **Interpretation of context:** Guiding machine or human to better understand the proposed recommendation / decision. This includes methods for providing explanations as well as methods ensuring interpretability of models.
- **Dealing with uncertainty:** Decisions must be taken in the face of uncertainty in the models, in perceptual data, and the effects of the system's actions. Resilient AI systems must be able to cope with incomplete and contradictory information by combining quantitative and qualitative methods.
- **Transparent anticipation:** Decision making often involves the use of predictive models to forecast possible futures and take anticipatory actions. To ensure trustworthy decisions, it must be possible for both the designers and the users to inspect, understand, validate and possibly challenge these models, as well as the criteria used to make a choice based on their predictions.
- **Reliability:** The challenge is to build decision making systems that prioritise the same option(s) for similar input consistently.
- **Human-centric planning and decision making** requires the incorporation of background knowledge and mental models of human users when deciding the best sequence of action as well as information of related processes, activities or tasks.
- **Augmented decision making** that complements human cognitive capabilities in a supportive way that humans are free to focus on less repetitive and more advanced tasks.

Physical and Human Action and Interaction

The technologies in this enabler embody every aspect of digital and physical AI working together. Interactions occur between machines and objects, between machines, between people and machines and between environments and machines. Interactions are shaped by real-time sensing, by stored information, by long term knowledge acquisition and multiple modalities and languages. At a more abstract level, humans interact, sometimes knowingly and sometimes unknowingly, with embedded AI, for example in financial or telecommunication systems. To achieve the seamless operation of AI digital and physical technologies need to work in harmony to achieve appropriate physical actions and interactions that respect their social, physical and environmental context.

There are a set of core challenges in the interaction technologies that relate to the processing of environmental cues to guide the decisional autonomy that drives the sequences of individual actions

26 (98)

that form an interaction. This can involve multiple sources of data and the interpretation of perceptions within the context of an interaction sequence. For example, interpreting the meaning of the spoken word in the context of an on-going interaction. Or understanding the consequence of detecting liquid in a container and the effect that might have on developing a grasping and movement plan. Within these generic interaction challenges, the following more detailed challenges also exist:

- The development of techniques and methods to achieve seamless and natural interaction in unstructured contexts, including multi-modal interaction and the development of generic interaction models.
- Improved natural language understanding, interaction and dialogue covering all European languages and age ranges.
- Development of verbal and non-verbal interaction models for people and machines, including gesture and emotion based interaction.
- The development of interaction technologies using Virtual Reality (VR) and Augmented Reality (AR) and their relation to human interaction both digital and physical.
- The co-development of technology and regulation to assure safe interaction in safety-critical and unstructured environments. This includes the development of actuators, mechanisms and control strategies for safe operation.
- The development of confidence measures for interaction and the interpretation of actions leading to explanations of interaction decisions and improved decision making.

Systems, Methodologies and Hardware

AI systems are complex. They integrate diverse technologies, from software and hardware to physical structures. They can be distributed or local, large or small scale, they can operate unattended or have complex human interfaces. Designing, developing and deploying these systems has its own technology landscape and methodologies; support tools, system architectures, validation processes and modularity standards etc. These enabling technologies ensure that the designer, integrator and deployer can efficiently deliver AI systems that perform to specification. These enabling technologies cover:

- Software engineering methodologies (for AI, data and robotics).
- Systems engineering and integration science, including Systems of Systems development.
- Hardware systems architecture and design; mechanical, electrical, electronic, computational, sensing, actuation, control etc.
- Tools and processes for; design, deployment, testing, validation and certification, etc.
- Modularity and Interoperability (Standards).

At the core of all challenges in this enabling area is the need to develop, and guarantee that, systems meet a diverse range of system and behavioural design parameters. Parameters such as safety, trustworthiness, dependability; as well as technical parameters such as performance, latency, energy consumption, data use, processor power, communication bandwidth etc.

Achieving these diverse system level requirements requires tools, processes, architectures and standards that can be shown to build confidence that systems are fit for purpose. Efficient design

and development processes lead directly to faster time to market, but the goal of right-first-time development remains a significant challenge for complex AI systems.

This fundamental challenge flows through all parts of the design, development and deployment cycle. The following high-level application driven challenges exist in this technology enabler:

- To develop tools that enable the design, development and deployment of AI systems that achieve their requirements at a behavioural level and a technical level through the design and development process.
- To develop system integration processes and methodologies that are cross domain and allow efficient system design that can deliver against Quality of Service criteria. In particular, these should integrate certification and validation criteria.
- To develop methodologies and processes that ensure that design and development consider the whole life cycle of a product or service, especially where the product learns to alter its behaviour over time and when it operates autonomously in unknowable environments. Existing exhaustive testing regimes are costly and act as a barrier to deployment; design-based autonomy assurance is a critical challenge.
- To develop system architectures and modular standards that encompass all aspects of data and physical systems. Critical to this is the co-development of data and physical standards of modularity, and the development of data standards for exchange and data asset generation that cover real-time, contextual, physical digital contexts and their associated meta-data. Data architectures will have to appropriately balance between cloud functionalities and computing at the edge.
- To develop methods and metrics to evaluate the performance of AI systems, including the development of suitable benchmarks for complex, integrated and evolving systems.

4.1.2 Analysis

The agenda is cross-sectorial, focusing on AI applied in any domain. However, the impact in Digital Industry of Artificial Intelligence is especially important. A Joint BDVA and euRobotics paper has noted that roughly 50% of opportunities for exploitation of AI are in manufacturing [4].

In the Figure 2, the expected distribution of financial investments in AI systems is 30% for Discrete manufacturing, 13% for process manufacturing and 7% for process industries, summing up to 50%.

AI will impact several main areas, *all of them relevant for Digital Industry*:

- By weaving AI into the design, manufacturing, production and deployment processes, **productivity** can be raised.
- By using AI to increase autonomy, higher **operational flexibility** can be achieved.
- By using AI to improve **usability of products and services** (e.g. by allowing greater variations in the human-machine interaction), the user value can be increased and new customer segments addressed, therefore creating new markets.
- By using AI for supporting **complex decision-making processes** in dynamic environments people can get help in situations of rising complexity (e.g. technical complexity, increasing volatility in markets).

Regarding the challenges mentioned for the adoption of AI, *some are also challenges shared by ECS community and Digital Industry sector such as the complexity of Industry domain, the lack of skills, etc.* The agenda mention the technological Barriers: “There is considerable complexity and cost in

creating AI systems with the ability to collect, process, and analyse large quantities of data in order to make robust and trustworthy decisions and implement autonomy”. *These systems are Electronic systems and the ECS (Electronic components and systems) industry has much to say to help in this challenge.* The agenda also mention the Access to AI Infrastructure as challenge: “Both academics and innovators (SME’s and start-ups in particular) need good access to world class innovation infrastructure including access to data and resources such as HPC and test environments, etc.” *This infrastructure such as HPC is part of what is considered “Computing and Storage” in ECS SRA 2019 and 2020.*

Inside the European AI Framework, they mention **Capturing Value for Business, Society, and People** with the main focus on application areas and sectors that: Are crucial for the European economy; Relate to critical infrastructure; Have a social or environmental impact or can increase European competitiveness in AI. *In this sense, digital industry is a very important sector due to the impact on economy, competitiveness as well as social and environmental impact.* **Policy, Regulation, Certification, and Standards (PRCS)** is another of the key elements of the framework. *This is also the case for ECS and Digital Industry domain.*

Regarding the AI Innovation Ecosystems enablers:

- **Skills and Knowledge:** “AI will affect skills needed by both industry and wider society. As traditional industry sectors undergo an AI transformation, so too must their workforces”. *Skilling, upskilling and reskilling are key enablers in Digital Industry.*
- **Data for AI.** In this enabler, they mention “significant technical challenges such as interoperability, data verification and provenance support, quality and accuracy, decentralised data sharing and processing architectures, and maturity and uptake of privacy-preserving technologies for big data have a direct impact on the data made available for sharing”. *ECS community can help with some of the technical challenges such as interoperability, decentralised data sharing and processing architectures, etc.*
- **Experimentation and Deployment.** “Experimentation is a critical for AI-based innovation because of the need to deploy in complex physical and digital environments. This includes safe environments for experimentation to explore the data value as well as to test the operation of autonomous actors. AI-driven innovations rely on the interplay of different assets, such as data, robotics, algorithms and infrastructure. For that reason, cooperation with other partners is central to gaining access to required assets. This includes access to the AI ecosystem covering AI platform providers, data scientists, data owners, providers, consumers, specialised consultancy, etc.” *ECSEL projects with big ecosystems could be a good place for experimentation.*

Regarding, the cross-Sectorial AI Technology Enablers defined by the framework (Sensing, Measuring and Perception; Continuous and Integrated Knowledge; Trustworthy Hybrid Decision Making; Physical and Human Action and Interaction; and Systems, Methodologies and Hardware), *some of these technology enablers are totally aligned with the scope of ECS community. And there is an equivalent in the technology domains in ECS SRA 2019, 2020 and 2021. It is the case of “Systems, Methodologies and Hardware” that is very similar to the “Systems and Components Architecture, Design, and Integration” domain in SRA 2019 and 2020.*

In the Table 1, the AI PPP SRIDA is compared with the SRA 2019, 2020 and 2021 (new domains defined) as well as the challenges in Digital Industry of SRA 2019 and 2020, the emerging themes identified in the first iteration and not included in SRA 2020 and other non-technical issues.

As conclusion, “AI **systems** are complex. They integrate diverse technologies, from **software** and **hardware** to physical structures.” So AI systems could be considered Electronic systems with embedded software and components and modules such as the “Sensing, Measuring and Perception” elements. As stated in the agenda: “Sensing, measurement and perception technologies draw on core technologies from a wide range of industry supply chains related to **semi-conductors**, materials, **embedded systems**, **signal processing** and **metrology**”, all them related to the ECS sector.

Table 1: AI PPP SRIDA compared to ECSEL SRAs

| | | AI PPP SRIDA |
|--------------------------------------|---|---|
| Domains in SRA 2019 and 2020 | Systems and Components Architecture, Design, and Integration | “Systems, Methodologies and Hardware” cross-sectorial AI technology enabler mentioned in the agenda is similar to this domain. |
| | Connectivity and Interoperability | Data exchange and Interoperability are of vital importance for AI. Interoperability and decentralised data sharing are mentioned as significant technical challenges in the “Data for AI” enabler. |
| | Safety, Security, and Reliability | The need to develop and embed trustworthiness, dependability, robustness, safety and privacy in AI systems is mentioned. Data privacy and data security is also important. Policy, Regulation, Certification, and Standards (PRCS) is a key element of the AI framework. |
| | Computing and Storage (Computing and storage now tend to form a continuum between extreme edge devices, edge devices, IoT, Fog, Cloud and HPC) | HPC (as AI infrastructure). Processing architectures is mentioned as significant technical challenges in the “Data for AI” enabler. Edge or cloud processing is also mentioned: “Data architectures will have to appropriately balance between cloud functionalities and computing at the edge.” “Edge and cloud-based decision making” in Trustworthy Hybrid Decision Making , “Relies on edge-based AI” in Physical and Human Action and Interaction. |
| | Process Technology, Equipment, Materials, and Manufacturing for ECS | Not directly mentioned. However, AI could be applied to ECS processes and manufacturing for ECS: AI augmented processes... |
| Technologies as enablers in SRA 2021 | Systems | AI systems are complex. They integrate diverse technologies, from software and hardware to physical structures. |
| | Embedded Software | AI systems have embedded software. AI algorithms. |
| | Components and Modules | The components of AI systems: SW, HW... Components for Sensing, Measuring and Perception. |
| | Process Technology | Not directly mentioned. However, AI could be applied to manufacturing processes: AI augmented processes. |
| | Equipment, Materials & Manufacturing | Not directly mentioned. However, AI could be applied to ECS manufacturing. |

| | | |
|--------------------------------|--|---|
| Transversal topics in SRA 2021 | Edge Computing and Artificial Intelligence | AI is fully covered. The focus of the agenda is AI. Edge processing or computing is also mentioned: “Data architectures will have to appropriately balance between cloud functionalities and computing at the edge.” “Edge and cloud-based decision making” in Trustworthy Hybrid Decision Making, “Relies on edge-based AI” in Physical and Human Action and Interaction. |
| | Connectivity | Data exchange and Interoperability are of vital importance for AI. Interoperability and decentralised data sharing are mentioned as significant technical challenges in the “Data for AI” enabler. |
| | Architecture and Design | “Systems, Methodologies and Hardware” cross-sectorial AI technology enabler mentioned in the agenda is similar to this domain. |
| | Quality, Reliability, Safety & (Cyber-) Security | The need to develop and embed trustworthiness, dependability, robustness, safety and privacy in AI systems is mentioned. Policy, Regulation, Certification, and Standards (PRCS) is a key element of the AI framework. |
| Major Challenges in SRA 2019 | MC1: Developing digital twins, simulation models for the evaluation of industrial assets at all factory levels and over system or product life-cycles | AI could be an enabler of digital twins as mentioned in the “Continuous and Integrated Knowledge”: “By combining data-driven and knowledge-based models, it becomes possible to have a sustainable digital twin along the complete lifecycle (product and production) that provides value to AI data integration”. |
| | MC2: Implementing AI and machine learning to detect anomalies or similarities and to optimise parameters | Totally in line with the agenda of AI and with the productivity raising area: “By weaving AI into the design, manufacturing, production and deployment processes, productivity can be raised”. “In manufacturing and production AI delivers productivity gains through more efficient resource, energy and material use, through better design and manufacturing processes and inside products and services, enhancing their operation with more refined contextual knowledge”. |
| | MC3: Generalizing condition monitoring, to pre-damage warning online decision-making support | “By using AI for supporting complex decision-making processes in dynamic environments, people can get help in situations of rising complexity (e.g. technical complexity, increasing volatility in markets)” is one of the areas where deployment of AI impacts. “Trustworthy Hybrid Decision Marking” is one of the key cross-sectorial technology enablers. Maintenance in digital industry is mentioned in two examples: “For example in a manufacturing plant, the supervisor analyses the output of several predictive models in order to immediately stop the plant to repair a single machine or wait until the next scheduled maintenance stop.” “Timeliness: ranging from decisions that must be taken immediately, in a matter of milliseconds, because the next steps/actions depend on every single decision (e.g. self-driving cars), to decisions that can be postponed with minimal risks or costs (e.g. predictive maintenance in production plants)” |
| | MC4: Developing digital platforms, application development frameworks that integrate sensors and systems | Digital platforms are an enabler for AI. An AI system needs digital platform. AI platform, data platform and platforms for data and algorithm sharing are mentioned. The integration of sensors is also mentioned in the “Sensing, Measuring and Perception” enabler: “The modularisation and standardisation of sensor interfaces, meta-information models and data flows; for example interfaces that can adapt to the balance between processing within the sensor (e.g. edge) and processing centrally (e.g. cloud); or handle both local and distributed data capture; or adapt processing methods to changing operating conditions or dynamics.” |

| | | |
|------------------------------|--|---|
| | | And the architectures of those platforms are mentioned in the “Systems, Methodologies and Hardware” enabler: “To develop system architectures and modular standards that encompass all aspects of data and physical systems. Critical to this is the co-development of data and physical standards of modularity, and the development of data standards for exchange and data asset generation that cover real-time, contextual, physical digital contexts and their associated meta-data. Data architectures will have to appropriately balance between cloud functionalities and computing at the edge.” |
| Major Challenges in SRA 2020 | MC1: Developing digital twins, simulation models for the evaluation of industrial assets at all factory levels and over system or product life-cycles | Same as for SRA 2019 |
| | MC2: AI-enabled cognitive, resilient, adaptable manufacturing | Totally in line with the agenda of AI, covering all the areas: productivity raise, the increase of autonomy and higher operational flexibility. Improve of usability of products and services and supporting complex decision-making processes. Already mentioned items regarding MC2 and MC3 in SRA 2019 are also relevant here. |
| | MC3: Developing digital platforms, application development frameworks that integrate sensors/actuators and systems | Same as for SRA 2019 |
| | MC4: Human-centred manufacturing | “Physical and Human Action and Interaction” enabler covers the challenges of human interaction, machine to machine inter-operation and machine interaction with the human environment. All the challenges of this enabler are relevant for the MC4 (see [1] for more details or summary in section 3.1.1.1). In the rest of technological enablers: <ul style="list-style-type: none"> • In the “Sensing, Measuring and Perception”: “Wearable and embedded sensing will improve human interaction”. • In the “Continuous and Integrated Knowledge” enabler: “ensure that models trained by data are legible for humans” and “Support for human interrogation of AI decision making”. • In the “Trustworthy Hybrid Decision Making” enabler, human decision making or mixed decision making are mentioned and related challenges such as “Augmented decision making that complements human cognitive capabilities in a supportive way that humans are free to focus on less repetitive and more advanced tasks.”, “Improve the human understandability of AI produced decision”, “Human interrogation for decision making” and “Human-centric and compatible decision making by incorporation of social interaction and mental models” • In the “Systems, Methodologies and Hardware” enabler: “Usability and human-machine interaction quality standards” |
| | MC5: Sustainable manufacturing in a circular economy | Not directly addressed, but mentioned in passing. AI could clearly help in improving sustainability, for example: improving efficiency of resource, energy and material use as mentioned: “in manufacturing and production AI delivers productivity gains through more efficient resource, energy and material use ”. Other mentions: |

| | | |
|---|---|--|
| | | <p>Sustainable production is mentioned in the quote of Peter Mohnen, CEO of KUKA. The impact that AI will have on the United Nations' Sustainable Development Goals is also mentioned. In "Capturing Value for Business, Society, and People": "main focus on application areas and sectors that have social or environmental impact".</p> |
| Emerging themes not covered in ECS 2020 | Multi-technology co-engineering enabled by digitalization | <p>Not directly addressed, but in the "Physical and Human Action and Interaction" enabler co-development is mentioned: "The co-development of technology and regulation to assure safe interaction in safety-critical and unstructured environments."</p> <p>Interdisciplinary needs are also mentioned: Regarding skills, interdisciplinary training is needed: "there is also the need to train interdisciplinary experts." "The need for AI practitioners to have multi-disciplinary skills, and the necessity to connect non-technical disciplines that impact on AI and benefit from AI". "Europe must enable and encourage AI researchers to work across disciplines."</p> <p>In the "Sensing, Measuring and Perception" enabler, how many different fields to be considered are mentioned: "Within this technology enabler, the digital and physical become inseparable. This is the crossover point between the physical world and its digital representation. Digital representations of, physical motion, visual images, text, sounds, haptics, chemistry and the human body are all fundamental to AI building a data representation of the world around us."</p> |
| Non-technical themes | Skills development, re-skilling, up-skilling | <p>"Lack of Skills and Know-How" is one of the challenges to be addressed: "Many European organisations lack the skills to manage or deploy AI solutions. A global competition for AI talent is underway. Regions with the most vibrant AI landscape are better positioned to attract skilled professionals".</p> <p>"Skills and Knowledge" is one of the AI Innovation Ecosystem Enablers: AI will affect skills needed by both industry and wider society.</p> |
| | Business models | <p>New business models are mentioned. "AI-based solutions may require innovative business models that redefine the way stakeholders share investments, risk, know-how, data and consequently value." "New business models will help to exploit the value of those data assets through the implementation of AI amongst participating stakeholders including industry, local, national and European authorities and institutions, research entities and even private individuals"</p> |
| | Standardization | <p>Standardization is key, particularly around data exchange and interoperability. Certification also to develop trust.</p> <p>Policy, Regulation, Certification, and Standards (PRCS) is a key element of the AI framework.</p> <p>For the "Data for AI" enabler: standards in relation to tools for data sharing, privacy preservation, quality verification, collaboration and interaction.</p> <p>In the "Sensing, Measuring and Perception" enabler: standardisation of sensor interfaces, meta-information models and data flows.</p> <p>In the "Continuous and Integrated Knowledge" enabler: Knowledge modelling representation in standardised format. And data privacy and data security standards along the data lifecycle which also applies to distributed data and real-time data.</p> <p>In the "Physical and Human Action and Interaction" enabler: Generic standards for multimodal Interaction.</p> <p>In "Systems, Methodologies and Hardware" enabler:</p> |

| | | |
|--|--------|---|
| | | Modularity and Interoperability (Standards), Data standards for exchange and meta data standards Testing and validation processes Standardised Data quality standards, Usability and human-machine interaction quality standards, Standardised trustworthiness, AI architectures standardised, Standardised knowledge models across domains... |
| | Others | <p>Ethics and societal trust in IA</p> <p>The recent advances in AI technology and applications have fundamentally challenged ethical values, human rights and safety in the EU and globally. However, the public trust in AI is prerequisite on it being trustworthy, ethical and secure and without public acceptance the full benefit of AI cannot be realised.</p> <p>The European Commission has already taken action and formulated in its recent communications a vision for an ethical, secure and cutting-edge “AI made in Europe” designed to ensure AI operates within an appropriate ethical and legal framework that embeds European values</p> <p>Capturing Value for Business, Society, and People: Successful adoption of AI solutions requires a flow of knowledge between the different stakeholders to develop a well-balanced and sustainable value network incorporating all stakeholders’ interests, roles and assets that build value.</p> |

4.1.3 Emerging trends and potential gap with the ECSEL SRA

There are two topics that appears in the AI PPP SRIDA agenda, listed as other non-technical themes in the previous section (**Ethics and societal trust in IA** and **Capturing Value for Business, Society, and People**) that are a potential gap in the ECSEL SRAs.

Ethics and societal trust and acceptance are especially important for AI, but are also applicable to Industry 4.0 in general. For successful adoption of Digital Industry, societal acceptance is key; And for getting the societal acceptance: capturing value, showing the benefit of digital industry for the society and creating societal trust is needed.

Misinformation such as that “technology or robots are stealing human jobs” can influence negatively the societal acceptance of Industry 4.0. Societal and worker acceptance is critical for the successful adoption of Digital Industry and this acceptance can only come when they can assign trust. The technology to be fully trusted and accepted by society in Industry context; the research in Digital Industry should foster a research based on European values such as **ethical values, human rights** and **safety**; following **privacy** and ethical norms and safety regulations. Moreover, the value and benefits of this technology for society should be communicated.

“**Skills and Knowledge**” is one of the AI Innovation Ecosystem Enablers. This could be a gap in the ECSEL RIA, the skills are present in SRA 2019 and 2020, but in a general perspective or only briefly mentioned in digital chapter in SRA 2020. *Skilling, upskilling and reskilling are key enablers in Digital Industry.*

4.2 The European Green deal

4.2.1 Summary

The European Green deal communication [2] resets the commission's commitment to tackling climate and environmental-related challenges and it presents an **initial roadmap of the key policies and measures needed to achieve the European Green Deal**. The Figure 2 illustrates the various elements of the Green Deal.

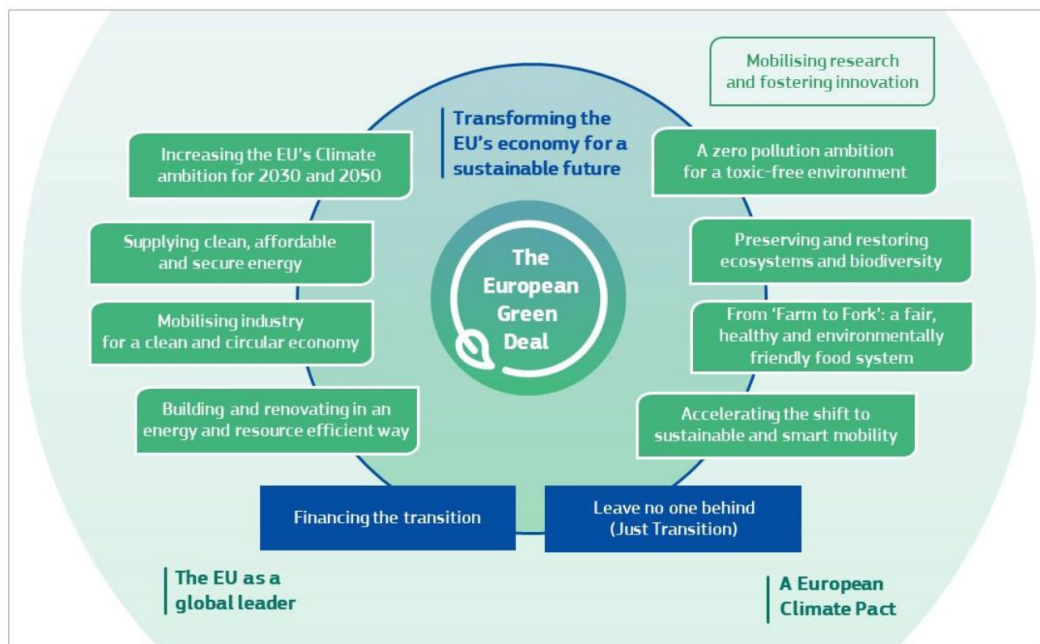


Figure 5: Elements of the European Green Deal (from [2])

“Mobilising industry for a clean and circular economy” is one of the key elements. Inside this element, the following items are mentioned:

- **Achieving a climate neutral and circular economy requires the full mobilisation of industry.**
 - **Resource usage:** From 1970 to 2017, the annual global extraction of materials tripled and it continues to grow¹³, posing a major global risk.
 - **Pollution:** About half of total greenhouse gas emissions and more than 90% of biodiversity loss and water stress come from resource extraction and processing of materials, fuels and food. The EU's industry has started the shift but still accounts for 20% of the EU's greenhouse gas emissions.
 - **Circular economy:** It remains too 'linear', and dependent on a throughput of new materials extracted, traded and processed into goods, and finally disposed of as waste or emissions. Only 12% of the materials it uses come from recycling.
- **The transition is an opportunity to expand sustainable and job-intensive economic activity.**
- **Green and digital transformation.**
 - In March 2020, the Commission adopted an EU industrial strategy [3] to address the twin challenge of the green and the digital transformation.

- Europe must leverage the potential of the digital transformation, which is a key enabler for reaching the Green Deal objectives.
- **New circular economy action plan**
 - This plan will help modernise the EU's economy and draw benefit from the opportunities of the circular economy domestically and globally.
 - It will include a **'sustainable products' policy** to support the circular design of all products based on a common methodology and principles.
 - Action will focus in particular on resource-intensive sectors such as textiles, construction, **electronics** and plastics.
 - It will also include **measures to encourage businesses to offer, and to allow consumers to choose, reusable, durable and repairable products.**
 - It will analyse the need for a 'right to repair', and curb the built-in obsolescence of devices, **in particular for electronics.**
 - Consumer policy will help to empower consumers to make informed choices and play an active role in the ecological transition.
 - New business models based on renting and sharing goods and services will play a role as long as they are truly sustainable and affordable.
- **Energy-intensive industries, such as steel, chemicals and cement, are indispensable to Europe's economy, as they supply several key value chains.**
 - The decarbonisation and modernisation of this sector is essential.
- **Reliable, comparable and verifiable information also plays an important part in enabling buyers to make more sustainable decisions and reduces the risk of 'green washing'.**
 - Digitalisation can also help improve the availability of information on the characteristics of products sold in the EU. For instance, an **electronic product passport** could provide information on a product's origin, composition, repair and dismantling possibilities, and end of life handling.
- **A sustainable product policy also has the potential to reduce waste significantly.**
- **Access to resources is also a strategic security question for Europe's ambition to deliver the Green Deal.**
- **Promoting new forms of collaboration with industry and investments in strategic value chains are essential.**
- **Digital technologies are a critical enabler for attaining the sustainability goals of the Green deal in many different sectors.**
 - The Commission will explore measures to ensure that digital technologies such as artificial intelligence, 5G, cloud and edge computing and the internet of things can accelerate and maximise the impact of policies to deal with climate change and protect the environment.
 - Digitalisation also presents new opportunities for distance monitoring of air and water pollution, or for monitoring and optimising how energy and natural resources are used.
 - At the same time, Europe needs a digital sector that puts sustainability at its heart.
 - The Commission will also consider measures to improve the energy efficiency and circular economy performance of the sector itself, from broadband networks to data centres and ICT devices.
 - The Commission will assess the need for more transparency on the environmental impact of electronic communication services, more stringent measures when deploying new networks and the benefits of supporting 'take-back' schemes to incentivise people to return their unwanted devices such as mobile phones, tablets and chargers.

Another key element is “*Mobilising research and fostering innovation*”. Inside this element, the following items are mentioned:

- **New technologies, sustainable solutions and disruptive innovation are critical to achieve the objectives of the European Green Deal.** To keep its competitive advantage in clean technologies, the EU needs to increase significantly the large-scale deployment and demonstration of new technologies across sectors and across the single market, building new innovative value chains. This challenge is beyond the means of individual Member States. Horizon Europe, in synergy with other EU programmes, will play a pivotal role in leveraging national public and private investments. *At least 35% of the budget of Horizon Europe will fund new solutions for climate, which are relevant for implementing the Green Deal.*
- **The full range of instruments available under the Horizon Europe programme will support the research and innovation efforts needed.** Four ‘Green Deal Missions’ will help deliver large-scale changes in areas such as adaptation to climate change, oceans, cities and soil.
- **Conventional approaches will not be sufficient**
- **Accessible and interoperable data are at the heart of data-driven innovation.** This data, combined with digital infrastructure (e.g. supercomputers, cloud, ultra-fast networks) and artificial intelligence solutions, facilitate evidence-based decisions and expand the capacity to understand and tackle environmental challenges.

Inside another element “*Activating education and training*”, the following item is mentioned:

- **Pro-active re-skilling and upskilling are necessary to reap the benefits of the ecological transition.**

4.3 New Industrial Strategy for Europe

4.3.1 Summary

As stated in the New Industrial Strategy for Europe Communication [3]: “Europe needs an industry that becomes greener and more digital while remaining competitive on the global stage. The twin ecological and digital transitions will affect every part of our economy, society and industry. They will require new technologies, with investment and innovation to match. They will create new products, services, markets and business models. They will shape new types of jobs that do not yet exist which need skills that we do not yet have. And they will entail a shift from linear production to a circular economy.”

The strategy mentions three drivers:

1. *A globally competitive and world-leading industry*
 - Being competitive requires competition – both at home and in the world.
 - EU must leverage the impact, the size and the integration of its single market to set global standards
 - The EU will continue efforts to uphold, update and upgrade the world trading system

2. *An industry that paves the way to climate-neutrality*
 - All industrial value chains, including energy-intensive sectors, will have a key role to play.
 - Industry will need a secure supply of clean and affordable energy and raw materials.
 - Create lead markets in clean technologies
3. *An industry shaping Europe's digital future*
 - The digital sector will also contribute to the European Green Deal, both as a source of clean technology solutions and by reducing its own carbon footprint.
 - Scalability is key in a digitalised economy, strengthening the digital single market will underpin Europe's transition
 - Europe must also speed up investment in research and the deployment of technology, in areas such as artificial intelligence, 5G, data and metadata analytics
 - As set out in the Commission's recent *European Strategy for Data*, Europe needs a framework to allow businesses to create, pool and use data to improve products and compete internationally in a way that upholds our values and respects the rights and privacy of all.
 - The EU must also **enhance its industrial capacity in critical digital infrastructure**
 - The successful roll-out of highly secured and state-of-the-art 5G network will be a major enabler for future digital services and be at the heart of the industrial data wave.
 - Europe must now invest if it wants to be a frontrunner in 6G networks.
 - Europe must pool its strengths to do collectively what no one can do alone.

The strategy also presents a set of fundamentals for Europe's industrial transformation:

1. *Creating certainty for industry: A deeper and more digital single market*
 - Single Market Enforcement Action Plan and Single Market Barriers Report, adopted today.
 - The single market depends on robust, well-functioning systems **for standardisation and certification**. Developing new standards and technical regulations, coupled with increased EU participation in international standardisation bodies, will be essential to boost industry's competitiveness.
 - Setting up a Single Market Enforcement Task-Force, composed of Member States and the Commission.
 - **SME Strategy** for a sustainable and digital Europe, adopted today.
 - Evaluate, review and, if necessary, adapt EU competition rules as of 2021, including the ongoing evaluation of merger control and fitness check of State aid guidelines.
 - Intellectual Property Action Plan to assess the need to upgrade the legal framework, ensure a smart use of IP, better fight IP theft.
 - Follow-up to the **European Data Strategy** to develop an EU data economy, including the launch of common European data spaces in specific sectors and value chains.
 - Digital Services Act to update and strengthen the legal framework for a single market in digital services.
 - Initiative on improving the working conditions for platform workers (Platform work is understood as all labour provided through, on, or mediated by online platforms in a wide range of sectors).
2. *Upholding a global level playing field*
 - White paper on an instrument on foreign subsidies by mid-2020, also looking at foreign access to public procurement and EU funding.

- Strengthening the global rules on industrial subsidies in the World Trade Organization.
- Swift adoption of the International Procurement Instrument.
- Action plan on the Customs Union in 2020 to reinforce customs controls, including a legislative proposal for an EU Single Window to allow for fully digital clearance processes at the border.
- 3. *Supporting industry towards climate neutrality*
 - Strategy for smart sector integration.
 - A Common European Energy data space will exploit the potential of data to enhance the innovative capacity of the energy sector.
 - Launch the Just Transition Platform to offer technical and advisory support for carbon-intensive regions and industries.
 - EU Strategy on Clean Steel and Chemicals Strategy for Sustainability.
 - Review of the Trans-European Network Energy regulation.
 - EU Strategy on Offshore Renewable Energy.
 - Comprehensive Strategy for Sustainable and Smart Mobility.
 - 'Renovation Wave' Initiative and Strategy on the built environment.
 - Carbon Border Adjustment Mechanism to reduce carbon leakage, in full compatibility with WTO rules
- 4. *Building a more circular economy:*
 - **Circular Economy Action Plan** adopted in parallel with this strategy, **including a new sustainable product policy** framework.
 - New Regulatory Framework for Sustainable Batteries.
 - EU Strategy for Textiles.
 - **Circular Electronics Initiative**
 - **Empowering consumers** to play an active role in the circular economy, through better information on products and improved consumer rights.
- 5. *Embedding a spirit of industrial innovation*
 - Communication on the Future of Research and Innovation and the European Research Area to map out a new approach to innovation and ensure the EU budget is used with maximum impact.
 - Launch Public Private Partnerships in the Horizon Europe programme
- 6. *Skilling and reskilling:*
 - An update of the **Skills Agenda for Europe in 2030**, including a recommendation on Vocational Education and Training.
 - Launch of **a European Pact for Skills**.
 - Communication on a European Education Area Strategic Framework.
 - **Digital Education** Action Plan.
 - Implementation of the **EU Gender Strategy**, adopted in March 2020.
- 7. *Investing and financing the transition*
 - Work with Parliament and Council to ensure rapid adoption and implementation of the next long-term budget.
 - Consider scope for coordinated investment by Member States and industry in the form of new IPCEIs and on the possible follow-up to the first IPCEIs on batteries and *microelectronics*.
 - Review State aid rules for IPCEIs, including energy transition projects.
 - A renewed sustainable finance strategy.
 - A new Digital Finance Strategy.

- Action Plan on the Capital Markets Union in 2020, including measures in support of integrated capital markets and more funding opportunities for citizens and businesses.

Reinforcing Europe's industrial and strategic autonomy

Europe's strategic autonomy is about reducing dependence on others for things we need the most: critical materials and technologies, food, infrastructure, security and other strategic areas. They also provide Europe's industry with an opportunity to develop its own markets, products and services which boost competitiveness. Actions:

- Follow-up to the **5G Communication** and the Recommendation on cybersecurity of 5G networks.
- Strategic digital infrastructures and Key enabling technologies:
 - Europe's digital transformation, security and future technological sovereignty depends on our **strategic digital infrastructures**. Beyond the Commission's recent work on 5G and cybersecurity, the EU will develop a critical Quantum Communication Infrastructure, designed to deploy in the next 10 years a certified secure end-to-end infrastructure based on quantum key distribution to protect key digital assets of the EU and its Member States.
 - The EU will also support the development of **key enabling technologies** that are strategically important for Europe's industrial future. These include robotics, microelectronics, high-performance computing and data cloud infrastructure, blockchain, quantum technologies, photonics, industrial biotechnology, biomedicine, nanotechnologies, pharmaceuticals, advanced materials and technologies.
- **Action Plan on synergies between civil, defence and space industries**, including at the level of programmes, technologies, innovation and start-ups.
- A new EU pharmaceutical strategy in 2020, including actions to secure supplies and ensure innovation for patients.
- An Action Plan on **Critical Raw Materials**, including efforts to broaden international partnerships on access to raw materials.

Joining the dots: A partnership approach to governance

Europe's industry must play to its unique features and strengths: its integration across value chains and borders, its diversity, traditions and people. As the twin transitions picks up speed and global competition becomes fiercer, Europe's industry is also transforming. As part of this, there are increasing links between different products and services across sectors. Actions:

- Building on the successful template of industrial alliances (batteries, plastics and microelectronics), a new European Clean Hydrogen Alliance will be launched. Alliances on low-carbon industries, **Industrial Clouds and Platforms** and raw materials should follow when ready.
- The Commission will undertake a thorough screening and analysis of industrial needs and identify ecosystems needing a tailor-made approach.

- An inclusive and open Industrial Forum will be setup by September 2020 to support this work.

4.3.2 Analysis of the European Green deal and the New Industrial Strategy for Europe

Both documents the European Green deal and the New Industrial Strategy for Europe are analysed together.

The European Green deal [2] is not properly a thematic roadmap with focus on manufacturing or technological topics related to the challenges of Digital industry. However, it resets the commission's commitment to tackling climate and environmental-related challenges; and mobilising industry for a clean and circular economy is one of the key elements. Moreover, digital technologies are a critical enabler. In addition, all EU actions will have to contribute to the European Green Deal objectives. Whereas the EU industrial strategy [3] addresses the twin challenge of the green and the digital transformation.

In the Table 2, the European Green deal and the EU industrial strategy are compared with the SRA 2019, 2020 and 2021 (new domains defined) as well as the challenges in Digital Industry of SRA 2019 and 2020, the emerging themes identified in the first iteration and not included in SRA 2020 and other non-technical issues.

Table 2: The European Green deal and the EU industrial strategy compared to ECSEL SRAs

| | | European Green Deal and New Industrial Strategy for Europe |
|------------------------------|---|--|
| Domains in SRA 2019 and 2020 | Systems and Components Architecture, Design, and Integration | - |
| | Connectivity and Interoperability | 5G. European Strategy for Data |
| | Safety, Security, and Reliability | <p>"Single market legislation must also be reviewed and updated to ensure that it is fit for the digital age. This includes the revision of EU rules on product safety, the implementation of the European Data Strategy and the adoption of the Digital Services Act."</p> <p>"Follow-up to the 5G Communication and the Recommendation on cybersecurity of 5G networks"</p> |
| | Computing and Storage (Computing and storage now tend to form a continuum between extreme edge devices, edge devices, IoT, Fog, Cloud and HPC) | <p>Cloud and edge computing and IoT are mentioned in the Green Deal document: "The Commission will explore measures to ensure that digital technologies such as artificial intelligence, 5G, cloud and edge computing and the internet of things can accelerate and maximise the impact of policies to deal with climate change and protect the environment." As well as digital infrastructure: "Accessible and interoperable data are at the heart of data-driven innovation. This data, combined with digital infrastructure (e.g. supercomputers, cloud, ultra-fast networks) and artificial intelligence solutions, facilitate evidence-based decisions and expand the capacity to understand and tackle environmental challenges."</p> <p>And also in the EU Industrial strategy:</p> <p>"These strengths need to be channelled towards gaining leadership in areas where the EU still lags behind, such as on cloud and data applications"; "Europe must also speed up investment in research and</p> |

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| | | the deployment of technology, in areas such as artificial intelligence, 5G, data and metadata analytics. In 2018, only around one in ten EU companies analysed big data, while only one in four used cloud computing services . “The EU will also support the development of key enabling technologies that are strategically important for Europe’s industrial future. These include robotics, microelectronics , high-performance computing and data cloud infrastructure , blockchain, quantum technologies, photonics, industrial biotechnology, biomedicine, nanotechnologies, pharmaceuticals, advanced materials and technologies.” “Alliances on ..., Industrial Clouds and Platforms and ... should follow when ready” |
| | Process Technology, Equipment, Materials, and Manufacturing for ECS | <p>“The Commission will also consider measures to improve the energy efficiency and circular economy performance of the sector itself, from broadband networks to data centres and ICT devices.”</p> <p>“Circular economy action plan with focus in particular on electronics. A new sustainable product policy framework will be established with a circular electronics initiative.”</p> <p>“The Action Plan also includes measures to empower consumers to play a more active role in the circular economy. Reliable, comparable and verifiable information also plays an important part in enabling buyers to make more sustainable decisions and reduces the risk of ‘green washing’. Digitalisation can also help improve the availability of information on the characteristics of products sold in the EU. For instance, an electronic product passport could provide information on a product’s origin, composition, repair and dismantling possibilities, and end of life handling.”</p> |
| Technologies as enablers in SRA 2021 | Systems | - |
| | Embedded Software | - |
| | Components and Modules | - |
| | Process Technology | Same as for Process Technology, Equipment, Materials, and Manufacturing for ECS in SRA 2019 and 2020 |
| | Equipment, Materials & Manufacturing | |
| Transversal topics in SRA 2021 | Edge Computing and Artificial Intelligence | <p>Edge computing and AI are mentioned in the Green Deal document: “The Commission will explore measures to ensure that digital technologies such as artificial intelligence, 5G, cloud and edge computing and the internet of things can accelerate and maximise the impact of policies to deal with climate change and protect the environment.”</p> <p>AI is also mentioned, see MC2 (SRA 2019)</p> |
| | Connectivity | 5G. <i>European Strategy for Data</i> |

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|------------------------------|--|--|
| | <i>Architecture and Design</i> | - |
| | <i>Quality, Reliability, Safety & (Cyber-) Security</i> | Product safety Cybersecurity See Safety, Security, and Reliability in SRA 2019 and 2020 |
| Major Challenges in SRA 2019 | <i>MC1: Developing digital twins, simulation models for the evaluation of industrial assets at all factory levels and over system or product life-cycles</i> | - |
| | <i>MC2: Implementing AI and machine learning to detect anomalies or similarities and to optimise parameters</i> | <p>Artificial intelligence, big data and data are mentioned.</p> <p>Digital technologies are a critical enabler for attaining the sustainability goals of the Green deal in many different sectors. The Commission will explore measures to ensure that digital technologies such as artificial intelligence, 5G, cloud and edge computing and the internet of things can accelerate and maximise the impact of policies to deal with climate change and protect the environment</p> <p>“Accessible and interoperable data are at the heart of data-driven innovation. This data, combined with digital infrastructure (e.g. supercomputers, cloud, ultra-fast networks) and artificial intelligence solutions, facilitate evidence-based decisions and expand the capacity to understand and tackle environmental challenges.”</p> <p>Europe must also speed up investment in research and the deployment of technology, in areas such as artificial intelligence, 5G, data and metadata analytics. In 2018, only around one in ten EU companies analysed big data, while only one in four used cloud computing services.</p> <p>As set out in the Commission’s recent European Strategy for Data, Europe needs a framework to allow businesses to create, pool and use data to improve products and compete internationally in a way that upholds our values and respects the rights and privacy of all.</p> <p>For industry workers, digitisation, automation and advances in artificial intelligence will require an unparalleled shift in their skill set.</p> |
| | <i>MC3: Generalizing condition monitoring, to pre-damage warning online decision-making support</i> | Not explicitly, AI in general is mentioned (see MC2) |
| | <i>MC4: Developing digital platforms, application development frameworks that integrate sensors and systems</i> | <p>“Industrial Clouds and Platforms” are mentioned: “Future alliances should also include low-carbon industries, Industrial Clouds and Platforms and raw materials”</p> <p>Platform economy is also mentioned: “new forms of work must come with modern and improved forms of protections, including for those working on online platforms.” As well as the “Initiative on improving the working conditions for platform workers”</p> |
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| Major Challenges in SRA 2020 | MC1: Developing digital twins, simulation models for the evaluation of industrial assets at all factory levels and over system or product life-cycles | - |
| | MC2: AI-enabled cognitive, resilient, adaptable manufacturing | Same as for SRA 2019 (MC 2 + MC 3) |
| | MC3: Developing digital platforms, application development frameworks that integrate sensors/actuators and systems | Same as for SRA 2019 |
| | MC4: Human-centred manufacturing | Not directly. The Just Transition Mechanism: It will also strive to protect the citizens and workers most vulnerable to the transition. The need for a socially just transition For companies and their workers, an active social dialogue helps to anticipate and successfully manage change. |
| | MC5: Sustainable manufacturing in a circular economy | The circular economy action plan will include a 'sustainable products' policy to support the circular design of all products based on a common methodology and principles. It will prioritise reducing and reusing materials before recycling them. A sustainable product policy also has the potential to reduce waste significantly. While the circular economy action plan will guide the transition of all sectors, action will focus in particular on resource-intensive sectors such as textiles, construction, electronics and plastics. The circular economy action plan will also include measures to encourage businesses to offer, and to allow consumers to choose, reusable, durable and repairable products. It will analyse the need for a 'right to repair', and curb the built-in obsolescence of devices, in particular for electronics. |
| Emerging themes not covered in ECS 2020 | Multi-technology co-engineering enabled by digitalization | - |
| Non-technical themes | Skills development, re-skilling, up-skilling | Pro-active re-skilling and upskilling are necessary to reap the benefits of the ecological transition. The twin ecological and digital transitions will shape new types of jobs that do not yet exist which need skills that we do not yet have. |

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| | | <p>For industry workers, digitisation, automation and advances in artificial intelligence will require an unparalleled shift in their skill set. Retraining and reskilling have to be a major part of our social market economy. Our higher and vocational education and training systems will also need to provide more scientists, engineers and technicians for the labour market. Better attracting skills and talent from abroad will also help to address the EU's labour market needs.</p> <p>Skilling and reskilling:</p> <ul style="list-style-type: none"> • An update of the Skills Agenda for Europe in 2030, including a recommendation on Vocational Education and Training. • Launch of a European Pact for Skills. • Communication on a European Education Area Strategic Framework. • Digital Education Action Plan. • Implementation of the EU Gender Strategy, adopted in March 2020. <p>It is also essential to have a better balance between women and men in industry. This includes encouraging women to study Science, Technology, Engineering and Mathematics, consider a career in technology and invest in digital skills, thus improving the gender balance in creating and leading businesses.</p> |
| | Business models | <p>The circular economy action plan will include a 'sustainable products' policy with new business models to prevent environmentally harmful products from being place on the EU market.</p> <p>Measures to encourage businesses to offer, and to allow consumers to choose, reusable, durable and repairable products.</p> <ul style="list-style-type: none"> • It will analyse the need for a 'right to repair', and curb the built-in obsolescence of devices, in particular for electronics. • Consumer policy will help to empower consumers to make informed choices and play an active role in the ecological transition. • New business models based on renting and sharing goods and services will play a role as long as they are truly sustainable and affordable. <p>Digital technologies are changing the face of industry and the way we do business. They create new business models.</p> <p>The twin ecological and digital transitions will create new products, services, markets and business models.</p> |
| | Standardization | <p>The Green Deal will make consistent use of all policy levers: regulation and standardisation, investment and innovation, national reforms, dialogue with social partners and international cooperation. Air quality, environmental, social and labour standards... are mentioned.</p> <p>The single market depends on robust, well-functioning systems for standardisation and certification. These help to increase the size of markets and provide legal certainty. Developing new standards and technical regulations, coupled with increased EU participation in international standardisation bodies, will be essential to boost industry's competitiveness.</p> |
| | Others | <p>The need for a socially just transition</p> <p>For companies and their workers, an active social dialogue helps to anticipate and successfully manage change.</p> <p>SME Strategy</p> <p>Small and medium sized businesses (SMEs) account for over 99% of all European firms</p> |

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| | | <p>SME strategy for a sustainable and digital Europe .</p> <p>SMEs should be incentivised and support to innovate and bring ideas to market.</p> <p>An “SME to SME approach” will also be essential. The growing number of young, tech-savvy SMEs can help more established industrial firms to adapt their business models and develop new forms of work for the digital age. This has already created new opportunities and start-ups should be supported to help build the platform economy. But new forms of work must come with modern and improved forms of protections, including for those working on online platforms.</p> |
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4.3.3 Emerging trends and potential gap with the ECSEL SRA

ECS sector is a key sector for both the green and digital transitions. However, it is also a sector where sustainability should be fostered: “Europe needs a digital sector that puts sustainability at its heart.” And “the Commission will also consider measures to improve the energy efficiency and circular economy performance of the sector itself, from broadband networks to data centres and ICT devices.”

These are the potential gaps with the ECSEL SRA taking into account the European Green Deal and New Industrial Strategy for Europe:

Sustainability and Circular Economy of the electronics sector

European commission is fostering a sustainable product policy and circular economy action plan; with a special focus on the electronics sector.

The circular economy action plan will also include measures to encourage businesses to offer, and to allow consumers to choose, reusable, durable and repairable products. It will analyse the need for a ‘right to repair’, and curb the built-in obsolescence of devices, in particular for electronics.

The Circular Electronics Initiative: Digitalisation can also help improve the availability of information on the characteristics of products sold in the EU. For example, an *electronic product passport* could provide information on a product’s origin, composition, repair and dismantling possibilities, and end of life handling.

So sustainability and circular economy should be addressed in the ECS sector paying special attention to the “right to repair” and Circular Electronics Initiative (including the electronic product passport).

Regarding non-technical topics, the European Green Deal and New Industrial Strategy for Europe speak about several relevant topics that are not sufficiently addressed in ECS SRA:

Skills, re-skilling and up-skilling

Pro-active re-skilling and upskilling are necessary to reap the benefits of the ecological and digital transition. For industry workers, digitization, automation and advances in artificial intelligence will require an unparalleled shift in their skill set.

The new Industrial Strategy for Europe mentions the following actions related to Skilling and reskilling:

- An update of the Skills Agenda for Europe in 2030, including a recommendation on Vocational Education and Training.
- Launch of a European Pact for Skills.
- Communication on a European Education Area Strategic Framework.
- Digital Education Action Plan.
- Implementation of the EU Gender Strategy, adopted in March 2020.

ECS community should take into account these actions and align with them; in addition of fostering skilling and education in the projects.

Gender gap: “It is also essential to have a better balance between women and men in industry.”

The new Industrial Strategy for Europe mentions the Implementation of the EU Gender Strategy, adopted in March 2020. ECS community should take into account it as the digital Industry or fourth industrial revolution (Industry 4.0) may increase the gender inequalities present in industry or it may be an opportunity to end these inequalities.

The percentage of women in certain industries such as manufacturing is lower than the percentage of men. Factories have been seen as unattractive, dirty workplaces that require strength and demanding physical conditions, where previous experience is required (to take on management positions), etc. All this has meant that women are not attracted to or cannot access these types of jobs; however, with industry 4.0 and the incorporation of technology, these jobs are in theory more attractive and accessible to women. However, women do not leave under the same conditions as men because women are underrepresented in technology fields in general as statistics show: “Women account for 11% of employees in architecture and engineering job families, a lower share than other related STEM industries including 23% of those related to ICT and mathematics, and for less than 30% of world’s science researchers. Women account for 20% of engineering graduates, yet only 11% of the engineering workforce”[5].

In other sectors such as health care or textile factories, the majority of the workforce is female. And digitization and the introduction of technology can make many of the jobs disappear. And again, women are at a disadvantage compared to men. Women are expected to “face five jobs lost for every job gained, versus three jobs lost to one gained for men overall” [5].

In addition, the three past industrial revolutions contributed to the entrenchment of gender stereotypes that place both men and women in restrictive roles. For the revolution to break this trend, steps must be taken to change the structural roots of gender discrimination. The Industrial Revolution can be used to rethink employment structures and forms of work. But this requires policies that can help take steps towards gender equality.

A technological development in Industry 4.0 can have a global impact on gender. This impact needs to be identified. As for technological solutions in Industry 4.0 that will interact with users

(operators, technicians, designers, etc.) These solutions are not gender neutral, it is necessary to incorporate the gender perspective in the design of the solutions, involve users of both sexes in the experiments and evaluations, etc.

To include a gender perspective in all the research and innovation projects regarding Digital Industry or Industry 4.0 could be very beneficial in order to Industry 4.0 to help to decrease gender inequalities in Industry.

New business models

The twin ecological and digital transitions will create new business models. New business models due to digital technologies and sustainability.

New business models related to sustainable products: New business models based on Repairable products, new business models based on renting and sharing goods and services, etc.

SME strategy

“Small and medium sized businesses (SMEs) account for over 99% of all European firms – the vast majority of which are family run companies – and are our economic and social backbone.” Regarding the EU industrial strategy, “an **SME to SME approach** will also be essential. The growing number of young, tech-savvy SMEs can help more established industrial firms to adapt their business models and develop new forms of work for the digital age”. Europe has defined an SME Strategy for a sustainable and digital Europe.

How the ECS community can help SMEs in the twin green and digital transition? To increase the participation of SMEs in the projects could be a first step.

The need for a socially just transition (digital and green)

“The green transition can only succeed if it is conducted in a fair and inclusive way. The most vulnerable are the most exposed to the harmful effects of climate change and environmental degradation. At the same time, managing the transition will lead to significant structural changes in business models, skill requirements and relative prices. Citizens, depending on their social and geographic circumstances, will be affected in different ways. Not all Member States, regions and cities start the transition from the same point or have the same capacity to respond. These challenges require a strong policy response at all levels.” “Europe must ensure the twin (digital and green) transitions are socially fair”.

Digital Industry is an enabler of both transitions, so it is important to assure social fairness and inclusiveness in the adoption of new technology. This will directly impact in the “Societal trust and acceptance” mentioned as gap in the previous roadmap.

4.1 ManuFUTURE Vision for 2030

4.1.1 Summary

The ManuFUTURE Vision for 2030 is presented in the document “ManuFUTURE VISION 2030: Competitive, Sustainable and Resilient European Manufacturing” [6]. This document details the Strategic Research and Innovation Agenda proposed by the ManuFUTURE European Technology Platform.

“Starting with a strong scientific and technical leadership, the ManuFUTURE Vision evolved over time. Moving from being purely focused on ensuring competitiveness in its early days, to the inclusion of sustainability requirements, the 2030’s Vision now also addresses the need for a resilient and adaptive manufacturing ecosystem able to cope with increasing levels of sophistication and environmental and social requirements.”, see Figure 6.

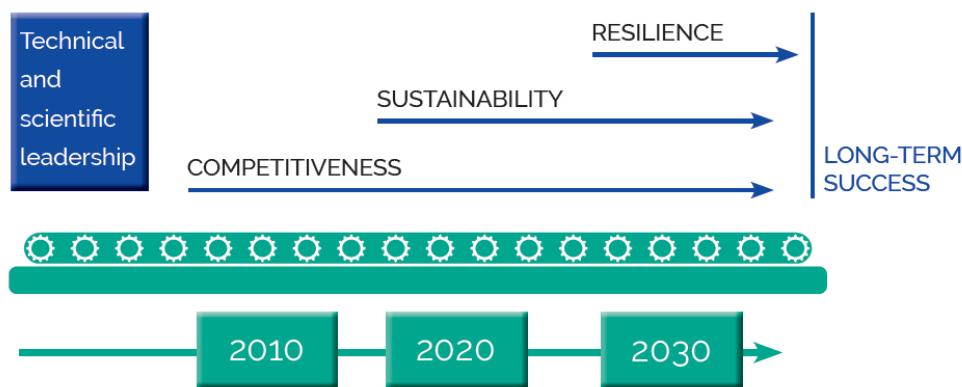


Figure 6: High-level vision for European Manufacturing 2030 (from [6])

In order to achieve its goals, the ManuFUTURE 2030 Vision defines three building blocks: **science and technology, innovation and entrepreneurship, education and training.**

Science and technology challenges:

- Adding value in the manufacturing system: “In the past century, manufacturing was focused on the physical elements for making products via effective usage of resources. Now, this view has to be transformed into manufacturing as a system, strongly supported by digital technologies, aiming at increasing productivity levels in an orchestrated value network to achieve a leading position in the global competition”
- Horizontal and vertical integration: “The new Manufacturing system’s view is multilevel, from technical processes on the factory floor to networking and business operations in the upper level.”
- The Road to Circular Economy: “Manufacturing systems are the driving factors for circular economy and therefore have a specific responsibility for their execution. Circular Economy requires an even more enhanced level of integration along the life cycle and value chain across sectors and system boundaries.”

- **Decentralised Technical Intelligence:** “Decentralised, autonomous systems with embedded intelligence acquire a far greater significance in the digital ecosystems of industrial value creation (B2B) than in the B2C sector.” (2030 Vision for Industry 4.0, German Platform Industrie 4.0). “The implementation of technical intelligence is amongst the most important areas for increasing productivity and efficiency in future manufacturing. Research programmes should boost the competences in manufacturing organisations to achieve solutions for processes, technical components and technical systems in all sectors of manufacturing industries” (See Figure 7). 5 areas are mentioned:
 - ICT Architectures, Platforms and Standards for Industry 4.0
 - High Performance Engineering for Personalised Products
 - Cyber-Physical production systems
 - High Performance Manufacturing Systems
 - Management Systems for Lifecycle Operations

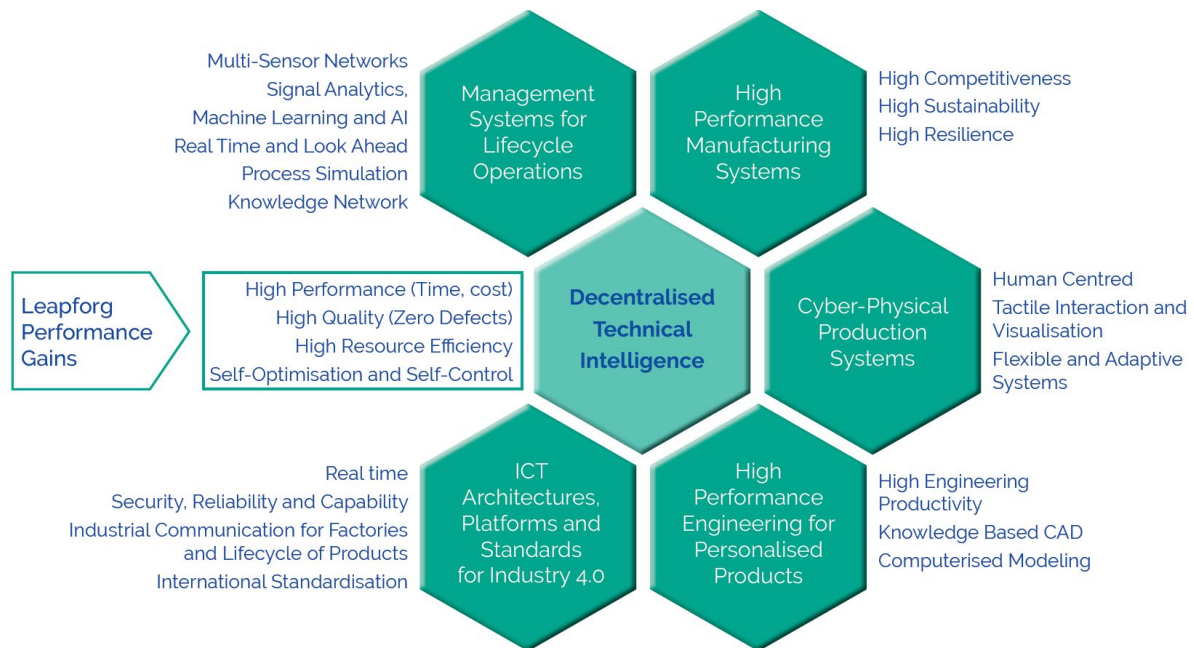


Figure 7: The visionary manufacturing system for adding value over the life cycle with decentralised technical intelligence (from [6])

“The priorities presented are essential crosscutting and enabling competences and promise substantial leverage effects and impact with a view to mastering societal challenges and advancing industrial excellence and competitiveness. They are needed in a broad range of sectors. In particular, however, the relevance and potential impact are evident with regard to the key sectors in manufacturing such as manufacturing equipment and engineering. Bringing these priorities together in a framework for science and technology allows us to define a matrix for research and innovation priority domains as shown in Figure 8 with orientation to decentralised technical intelligence in manufacturing systems.”

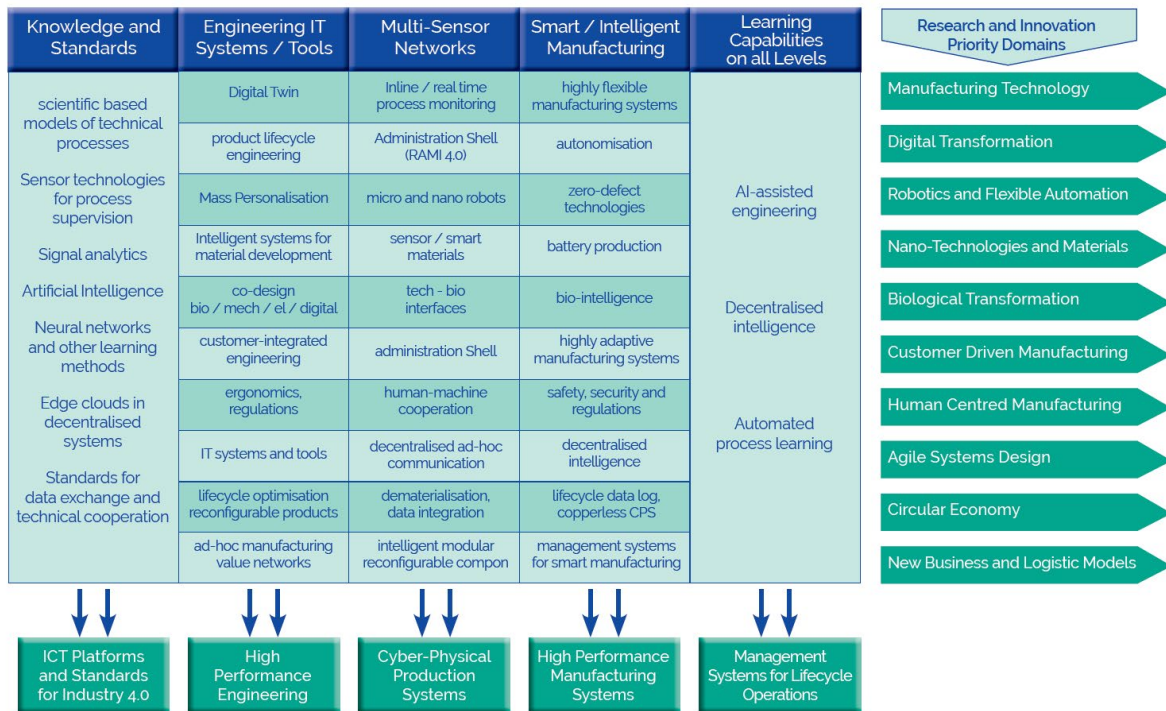


Figure 8: Road towards technical intelligence (from [6])

Research and innovation priority domains

10 research and innovation domains towards 2030 and the respective main research priorities identified are listed.

| Proposed Research and Innovation Priority Domains | |
|--|--|
| Enabling technologies and approaches | Manufacturing strategies |
| 1. Manufacturing technology and processes | 6. Customer driven manufacturing |
| 2. Digital transformation | 7. Human centred manufacturing |
| 3. Robotics and flexible automation | 8. Agile manufacturing systems design and management |
| 4. Nano-technology and new materials | 9. Circular economy, resource and energy efficiency |
| 5. Biological transformation of products, processes and value creation | 10. New business models and logistics networks |

Figure 9: Research and Innovation Priority Domains proposed by the ManuFUTURE Vision 2030 and SRIA (from [6])

For each priority domain the types of research activities that are proposed: (F) Fundamental Research, (A) Applied Research and Technological Development or (P) Pilot implementation and Demonstration.

1. Manufacturing technology and processes. Future manufacturing will move to new paradigms: Nature Inspired Manufacturing, Bionic Manufacturing and Fully circular digital and physical threads.

- Advancement in additive manufacturing (am) (a/p)
- Added-value additive manufacturing for large structural components (f/a/p)
- Competitive composites processing (a)
- High production rate of composite structures (p)
- Surface engineering (a)
- Miniaturisation and functional integration (a)
- Hybrid processes (a/p)
- Effective processing of hybrid materials (a/p)
- Optimised joining for new materials, structures and manufacturing processes (a/t)
- Active, smart and intelligent packaging (a/p)
- Resilient processes (a/p)
- Zero-defect strategies for small-batch manufacturing (f/a)
- Systemic bio-inspired manufacturing platforms (f/a/p)

2. Digital transformation

- Quality in production systems
 - Cloud-based and edge-based cyber-physical systems for efficient in-line root-cause analysis in the manufacturing of complex high added-value products (a)
 - Machine / deep learning for autonomous quality in the smart factory (f)
 - Smart sensors systems for improving quality and use of resources (a)
- Dynamic and flexible production systems
 - Digital and smart manufacturing platforms for mass customised products (p)
 - Digital process pipelines (a)
 - New design and engineering tools and development methods (a/p)
 - Cyber physical systems of systems for dynamic production and logistics (a)
 - Integrating neurocognitive processes with ai in factories and value networks (f/a)
 - Digital tools in manufacturing (a)
 - Knowledge and data fusion for manufacturing (a)
- Digital-real convergence in production systems end ecosystem
 - Digital twin of flexible manufacturing processes (a)
 - Multi-level simulation systems (a)
 - Augmented end-to-end virtual manufacturing systems (a)
 - Digital servitisation (a)
 - Digital marketplace for exchange of qualified resources in dynamic value networks (a/p)
 - Next generation industrial data management (a/p)
 - Cybersecurity and connectivity (p/a)
 - The internet of wearable things in manufacturing (p)

3. Robotics and flexible automation

- Robotics
 - task-based programming of robots (f/a/p)
 - intrinsically safe robots (a)
 - mobile manipulators for logistics (a, p)
 - multi-robot systems - robot swarms (a/p)
 - flying, floating or diving robots for manufacturing (a/p)
 - robot machine tool (a/p)
 - shared autonomy in manufacturing – cobots- cooperative manipulation (f/a/p)
 - robot skill acquisition (f/a/ p)
 - augmenting the human (a/p)
 - handling soft and limp materials (a/p)
 - robots in construction (a/p)
- Flexible automation:
 - reference architectures for flexible manufacturing systems (f/a)
 - autonomic robots and flexible manufacturing systems (a)
 - trust, socially accepted behaviour and cyber security issues in flexible automation – block chain technology (a)
 - reconfigurable manufacturing systems (a)

4. Nano-technology and new materials

- multi-functional multi-material systems (f/a)
- nanomaterials for advanced and high-performance composite materials (a/p)

- novel raw-materials availability for composite materials (a/p)
- smart, hybrid and multiple materials (a/p)
- lightweight structures based on advanced and multifunctional materials (p)
- smart materials and functional printing (f/a/p)
- additive manufacturing with nanoparticles (a/p)
- nanofabrication techniques to control surface properties (f/a/p)
- new non-noble-metal based catalysts (a/p)
- materials design and production for functionality, durability and energy efficiency during use but considering the reuse and recycling phase (a)
- materials, coatings and fluids resistant to high temperature manufacturing systems (p)
- new materials for joining (a)
- nanocellulose-based functional materials and products for multi-sectorial applications (a/p)
- advanced large-scale multi-functional coatings for steel and other metallic substrates (a)
- industrial manufacturing of advanced materials (p)

5. Biological transformation of products, processes and value creation

- bio-inspired structures, mechanisms and principles of the bio-intelligent manufacturing systems (f/a)
- biosensors (f/a)
- bioactuators (f)
- additive manufacturing of bio-intelligent materials (a)
- enzymatic processes (f/a)
- micro-bioreactors (f)
- smart bio-manufacturing devices (f)
- biocoating and bioinoculants (f,a)
- biopackaging (f/a)
- ecology-based manufacturing (f)
- biorefineries (f/a)

6. Customer driven manufacturing

- smart design
 - generative design for personalised production (a/p)
 - factories of the future manufacturing the products of the future: collaborative platforms for value creation (a/p)
 - social media in manufacturing (a)
 - design for additive manufacturing (a)
- customised processes
 - personalised manufacturing (f/a/p)
 - novel solutions for efficient mass customisation via am (f/a)
 - mass personalisation (a/p)
 - mass customisation of composite structures (a/f)
 - new rapid tooling technologies (a)
- data-augmented customisation
 - transfer learning and scaling-up for zero-defect customisation (f/a)
 - process qualification via i4.0 for mass customisation (f/a)
 - zero-defect in personalised production (f)

- i4.0 for customised manufacturing systems (a/p)

7. Human centred manufacturing: The research related to this theme will address four main areas: 1. **Understand** how the human workers behave and reason in a manufacturing environment; 2. **Protect** the workers in manufacturing; 3. **Support** the workers in manufacturing who take care of variable individual skills; and 4. **Empower** human workers in terms of skills, flexibility and adaptability.

- understand
 - advanced behavioural and cognitive models for humans in manufacturing (f/a)
 - behavioural and cognitive human-machine systems (a/p)
 - analytics for data-human interaction (a/p)
 - skills and know-how management (f/a/p)
 - new legal frameworks for human workers
 - knowledge management and sharing (f/a/p)
- protect
 - new materials and new technologies for safety in the workplace (f/a)
 - biosensors and material for humans in manufacturing (f/a)
 - workplace design for health and safety (f/a/p)
 - design of new equipment, interfaces, personal protection devices (f/a/p)
- support
 - training environments (f,a)
 - action-based learning for high added-value manufacturing skills (a/p)
 - human-centric data and information models and tools (a)
- empower
 - augmented humans - unobtrusive assisting technologies for workplace support (f/a)
 - intuitive digital tools for empowered operators (a)
 - new performance management systems for human-centred manufacturing organisation (a)
 - human-machine process and system design (a/p)
 - human-centric work organisation and planning (a/p)

8. Agile manufacturing systems design and management

- global manufacturing networks and dynamic supplier network configuration and management (a)
- decision making tools for flexible assembly lines reconfiguration (a/p)
- adaptive and autonomous production control (a)
- manufacturing systems cognitive digital twins (a)
- novel control and senses based autonomous robotic systems (a/p)
- industrial robotics and dexterous manipulation technologies (a/p)
- hybrid production systems (a/p)
- artificial intelligence (ai) enabled robotic systems for manufacturing (a/p)
- learning processing machines for variable raw materials (a)
- traceability and connectivity to harmonise integrated supply chains (a/p)
- quality planning methods to anticipate the detection
- of non-conformance quality during system design (a)
- dynamic control of production quality targets (a)

- artificial intelligence at the shop floor (a)
- implementation of additive as part of a hybrid process (f/a/p)

9. Circular economy, resource and energy efficiency

- Materials and energy (recovery, recycle, efficiency)
 - secondary material management (f/a)
 - resilient approaches for raw materials (f/a)
 - material resource efficiency (f/a/p)
 - new sustainable materials, processes and bio-products (a)
 - energy-efficient approaches in manufacturing (a/p)
 - industrial symbiosis and eco-efficiency of production processes (f/a)
- Design, Refurbish and Remanufacture
 - product and process design for material reuse and recycling (a/p)
 - process modelling and control in demanufacturing and remanufacturing (f/a)
 - additive-subtractive processes and surface treatments for in-line product repair and remanufacturing (a/p)
 - variant production technologies for manufacturing/ remanufacturing systems (a/f)
 - manufacturing systems for the re-use of secondary raw materials (a/p)
 - digitalising and automating de- and remanufacturing processes and systems (a/p)
 - new technologies for remanufacturing, refurbishment and recycling of products and components (f/a/p)
 - monitoring of the energy footprint of the products (a/p)
 - technologies and tools for intelligent remanufacturing and recycling systems (f/a/p)
 - innovative solutions for sustainable and flexible product packaging (a/p)
- Maintenance and Reuse
 - organisational and business related models for maintenance and reuse and in a circular economy scheme (f/a)
 - lifecycle management technologies and approaches for product maintenance and reuse (a/p)

10. New business models and logistics networks

- industrial product-service systems (ipss) (p/f)
- innovative product design and manufacturing based on the frugal concepts, (functional – robust – user friendly – growing – affordable – local) supported by advanced ict platforms (p)
- development of sustainable business models for industry 4.0 technologies (a)
- manufacturing strategies and business models for circular economy (f/a/p)
- business models for distributed (de-centralised) production and production as service, aiming at commercial availability of pilot lines and specific machinery (a)
- an opportunistic model for integrated maintenance, quality and inventory control (a/p)
- flexible platforms for business process management (a/p)
- end-to-end business process and business model
- optimisation (a/p)

Innovation and entrepreneurship

“The primary objective is to provide a fruitful environment to create start-ups, accelerate technology uptake in SMEs and to support companies with their transformation focusing on enabling technologies with high manufacturing application potential.”

Education and training

“Talented people are crucial to the future leadership of global high-value manufacturing, but our manufacturing industries face both a lack of available employees and increasing skill gaps.

The primary objective is to develop, across Europe, a skilled workforce through education, reskilling and upskilling people of all ages, gender and origin to ensure that the required competences for future manufacturing are available.”

4.1.1 Analysis

ManuFUTURE SRIA is a roadmap focuses on manufacturing. Electronic Components and Systems (ECSs) sector plays specially a key role in the “Decentralised Technical Intelligence” science and technology challenge of ManuFUTURE where areas such as *ICT Architectures, Platforms and Standards for Industry 4.0* and *Cyber-Physical* production systems are mentioned. The “2. Digital transformation” research and innovation domain is also very relevant to ECS domain.

In the Table 3, the ManuFUTURE SRIA is compared with the SRA 2019, 2020 and 2021 (new domains defined) as well as the challenges in Digital Industry of SRA 2019 and 2020, the emerging themes identified in the first iteration and not included in SRA 2020 and other non-technical issues.

Table 3: The ManuFUTURE SRIA compared to ECSEL SRAs

| | | ManuFUTURE SRIA |
|------------------------------|---|---|
| Domains in SRA 2019 and 2020 | Systems and Components Architecture, Design, and Integration | <p>In the “Decentralised Technical Intelligence” Science and technology challenge the following two areas are mentioned:</p> <ul style="list-style-type: none"> • ICT Architectures, Platforms and Standards for Industry 4.0 • Cyber-Physical production systems <p>Production systems, manufacturing systems, smart sensor systems... are mentioned in the “2. Digital transformation” research and innovation domain.</p> <p>Design tools and engineering tools are also mentioned: NEW DESIGN AND ENGINEERING TOOLS AND DEVELOPMENT METHODS; DIGITAL TOOLS IN MANUFACTURING</p> |
| | Connectivity and Interoperability | <p>Inside the “2. Digital transformation” research and innovation domain CYBERSECURITY AND CONNECTIVITY is mentioned.</p> <p>Inside the “8. Agile manufacturing systems design and management” research and innovation domain: TRACEABILITY AND CONNECTIVITY TO HARMONISE INTEGRATED SUPPLY CHAINS is mentioned.</p> |

| | | |
|--------------------------------------|---|---|
| | Safety, Security, and Reliability | <p>Safety, security and regulations are mentioned inside the area ICT Architectures, Platforms and Standards for Industry 4.0</p> <p>Inside the “2. Digital transformation” research and innovation domain CYBERSECURITY AND CONNECTIVITY is mentioned.</p> <p>Inside the “3. Robotics and flexible automation” research and innovation domain: TRUST, SOCIALLY ACCEPTED BEHAVIOUR AND CYBER SECURITY ISSUES IN FLEXIBLE AUTOMATION – BLOCK CHAIN TECHNOLOGY is mentioned.</p> <p>Safety is also mentioned but focused on safety in the workplace (not safety of the devices or electronic components).</p> |
| | Computing and Storage (Computing and storage now tend to form a continuum between extreme edge devices, edge devices, IoT, Fog, Cloud and HPC) | Inside the “2. Digital transformation” research and innovation domain CLOUD-BASED AND EDGE-BASED CYBER-PHYSICAL SYSTEMS FOR EFFICIENT IN-LINE ROOT-CAUSE ANALYSIS IN THE MANUFACTURING OF COMPLEX HIGH ADDED-VALUE PRODUCTS is mentioned. |
| | Process Technology, Equipment, Materials, and Manufacturing for ECS | <p>Manufacturing processes and materials are covered (for example in “1. Manufacturing technology and processes” research and innovation domain.</p> <p>Electronics and microelectronics are explicitly mentioned inside the “3. Robotics and flexible automation” research and innovation domain: TASK-BASED PROGRAMMING OF ROBOTS; Inside the “4. Nano-technology and new materials” research and innovation domain: SMART MATERIALS AND FUNCTIONAL PRINTING; inside the “5. Biological transformation of products, processes and value creation” research and innovation domain: ENZYMATIC PROCESSES. As well as inside the “9. Circular economy, resource and energy efficiency research and innovation domain: MANUFACTURING SYSTEMS FOR THE RE-USE OF SECONDARY RAW MATERIALS and TECHNOLOGIES AND TOOLS FOR INTELLIGENT REMANUFACTURING AND RECYCLING SYSTEMS.</p> |
| Technologies as enablers in SRA 2021 | Systems | <p>In the “Decentralised Technical Intelligence” Science and technology challenge the following area is mentioned:</p> <ul style="list-style-type: none"> • Cyber-Physical production systems <p>Production systems, manufacturing systems, smart sensor systems... are mentioned in the “2. Digital transformation” research and innovation domain.</p> |
| | Embedded Software | Inside the “2. Digital transformation” research and innovation domain: DIGITAL AND SMART MANUFACTURING PLATFORMS FOR MASS CUSTOMISED PRODUCTS: Digitalisation enables the manufacture of customised and smart products (with embedded software , sensors, connectivity and AI). |
| | Components and Modules | Sensors, controls, actuators, etc. are mentioned. |
| | Process Technology | See Process Technology, Equipment, Materials, and Manufacturing for ECS in SRA 2019 and 2020 |
| | Equipment, Materials & Manufacturing | |
| Transversal topics in SRA 2021 | Edge Computing and Artificial Intelligence | <p>See MC2 in SRA 2019 for AI.</p> <p>Inside the “2. Digital transformation” research and innovation domain CLOUD-BASED AND EDGE-BASED CYBER-PHYSICAL SYSTEMS FOR EFFICIENT IN-LINE ROOT-CAUSE ANALYSIS IN THE MANUFACTURING OF COMPLEX HIGH ADDED-VALUE PRODUCTS is mentioned.</p> |
| | Connectivity | See Connectivity and Interoperability in SRA 2019 and 2020 |

| | | |
|------------------------------|--|--|
| | Architecture and Design | In the “Decentralised Technical Intelligence” Science and technology challenge the following area is mentioned: <ul style="list-style-type: none"> ICT Architectures, Platforms and Standards for Industry 4.0 Design tools and engineering tools are also mentioned: NEW DESIGN AND ENGINEERING TOOLS AND DEVELOPMENT METHODS; DIGITAL TOOLS IN MANUFACTURING |
| | Quality, Reliability, Safety & (Cyber-) Security | See Safety, Security, and Reliability in SRA 2019 and 2020 |
| Major Challenges in SRA 2019 | MC1: Developing digital twins, simulation models for the evaluation of industrial assets at all factory levels and over system or product life-cycles | Digital twin concept is explicitly mentioned. Inside the “2. Digital transformation” research and innovation domain: DIGITAL TWIN OF FLEXIBLE MANUFACTURING PROCESSES; MULTI-LEVEL SIMULATION SYSTEMS; KNOWLEDGE AND DATA FUSION FOR MANUFACTURING... Inside the “8. Agile manufacturing systems design and management” research and innovation domain: MANUFACTURING SYSTEMS COGNITIVE DIGITAL TWINS |
| | MC2: Implementing AI and machine learning to detect anomalies or similarities and to optimise parameters | Machine learning and AI are explicitly mentioned. Inside the “2. Digital transformation” research and innovation domain: CLOUD-BASED AND EDGE-BASED CYBER-PHYSICAL SYSTEMS FOR EFFICIENT IN-LINE ROOT-CAUSE ANALYSIS IN THE MANUFACTURING OF COMPLEX HIGH ADDED-VALUE PRODUCTS; MACHINE / DEEP LEARNING FOR AUTONOMOUS QUALITY IN THE SMART FACTORY; INTEGRATING NEUROCOGNITIVE PROCESSES WITH AI IN FACTORIES AND VALUE NETWORKS (F/A) Inside the “1. Manufacturing technology and processes” research and innovation domain: ZERO-DEFECT STRATEGIES FOR SMALL-BATCH MANUFACTURING (F/A) Inside the “8. Agile manufacturing systems design and management” research and innovation domain: ARTIFICIAL INTELLIGENCE (AI) ENABLED ROBOTIC SYSTEMS FOR MANUFACTURING; ARTIFICIAL INTELLIGENCE AT THE SHOP FLOOR. |
| | MC3: Generalizing condition monitoring, to pre-damage warning online decision-making support | - |
| | MC4: Developing digital platforms, application development frameworks that integrate sensors and systems | In the “Decentralised Technical Intelligence” Science and technology challenge the following area is mentioned: <ul style="list-style-type: none"> ICT Architectures, Platforms and Standards for Industry 4.0 Inside the “2. Digital transformation” research and innovation domain: DIGITAL AND SMART MANUFACTURING PLATFORMS FOR MASS CUSTOMISED PRODUCTS. Digital platforms in a broader sense are also mentioned in: “6. Customer driven manufacturing” research and innovation domain: FACTORIES OF THE FUTURE MANUFACTURING THE PRODUCTS OF THE FUTURE: COLLABORATIVE PLATFORMS FOR VALUE CREATION. And in “10. New business models and logistics networks” research and innovation domain: INNOVATIVE PRODUCT DESIGN AND MANUFACTURING BASED ON THE FRUGAL CONCEPTS, (FUNCTIONAL – ROBUST – USER FRIENDLY – GROWING – AFFORDABLE – LOCAL) SUPPORTED BY ADVANCED ICT PLATFORMS |
| Major Challenges in SRA 2019 | MC1: Developing digital twins, simulation models for the evaluation of industrial assets at all factory levels and over system or product life-cycles | See MC1 in SRA 2019 |

| | | |
|--|---|---|
| | MC2: AI-enabled cognitive, resilient, adaptable manufacturing | See MC2 in SRA 2019 |
| | MC3: Developing digital platforms, application development frameworks that integrate sensors/actuators and systems | See MC4 in SRA 2019 |
| | MC4: Human-centred manufacturing | <p>The “7. Human centred manufacturing” research and innovation domain: The research related to this theme will address four main areas: 1. Understand how the human workers behave and reason in a manufacturing environment; 2. Protect the workers in manufacturing; 3. Support the workers in manufacturing who take care of variable individual skills; and 4. Empower human workers in terms of skills, flexibility and adaptability.</p> <p>Inside the “3. Robotics and flexible automation” research and innovation area: AUGMENTING THE HUMAN.</p> |
| | MC5: Sustainable manufacturing in a circular economy | <p>The Road to Circular Economy Science and technology challenge: “Manufacturing systems are the driving factors for circular economy and therefore have a specific responsibility for their execution. Circular Economy requires an even more enhanced level of integration along the life cycle and value chain across sectors and system boundaries.”</p> <p>The “9. Circular economy, resource and energy efficiency” research and innovation domain with topics about MATERIALS AND ENERGY (recovery, recycle, efficiency); Design, Refurbish and Remanufacture; and Maintenance and Reuse</p> <p>The “10. New business models and logistics networks” research and innovation domain: MANUFACTURING STRATEGIES AND BUSINESS MODELS FOR CIRCULAR ECONOMY</p> |
| Emerging themes not covered in ECS 2020 | Multi-technology co-engineering enabled by digitalization | Engineering IT System / Tools for co-design bio / mech / el / digital |
| Non-technical themes | Skills development, re-skilling, up-skilling | <p>Education and training is a section to highlight the importance of skills.</p> <p>Also in the “7. Human centred manufacturing” research and innovation domain: SKILLS AND KNOW-HOW MANAGEMENT; ACTION-BASED LEARNING FOR HIGH ADDED-VALUE MANUFACTURING SKILLS.</p> |
| | Business models | The “10. New business models and logistics networks” research and innovation domain: DEVELOPMENT OF SUSTAINABLE BUSINESS MODELS FOR INDUSTRY 4.0 TECHNOLOGIES; MANUFACTURING STRATEGIES AND BUSINESS MODELS FOR CIRCULAR ECONOMY |

| | | |
|--|------------------------|---|
| | Standardization | Safety, security and regulations are mentioned inside the area ICT. In the “Decentralised Technical Intelligence” Science and technology challenge the following area is mentioned: <ul style="list-style-type: none"> ICT Architectures, Platforms and Standards for Industry 4.0 |
| | Others | Innovation and entrepreneurship is a section to highlight the importance of this topic; with a focus on SMEs and Start-ups |

4.1.2 Emerging trends and potential gap with the ECSEL SRA

Technical topics

In the "1. Manufacturing technology and processes" research and innovation priority domain, it is mentioned that Future manufacturing will move to new paradigms:

- **Nature Inspired Manufacturing** that will lead to more sustainable design and manufacturing ecosystems, from the organisational to the technology, by combining different “actors and activities” with efficient processes to recycle and reuse materials.
- **Bionic Manufacturing**, which, through technology, will enhance and augment relevant human capabilities. It is the winning combination for highly automated and robotised processes and is capable to provide flexibility and adaptability to new customer requirements.
- **Fully circular digital and physical threads**, that will implement a use-centric set of relations aiming at providing the required specific product and service, while optimising the usage of resources, including materials and energy (also in transports), creating a balanced and sustainable ecosystem.

Topics related to these three paradigms are explained below:

Nature and bio-Inspired Manufacturing

This paradigm is mentioned in the "1. Manufacturing technology and processes" section. And SYSTEMIC BIO-INSPIRED MANUFACTURING PLATFORMS is mentioned as research and innovation priority domain. “Truly systemic manufacturing platforms shall be enabled by developing novel bio-inspired manufacturing concepts, which shall leverage the current implementation of advanced cyber-physical systems (integrating hybrid twins, cognitive automation, Artificial Intelligence, among other state-of-the-art techniques) to unprecedented resilient production environments, introducing a new manufacturing paradigm. “

In the “5. Biological transformation of products, processes and value creation” section, bio components and systems are also proposed as priority domains:

- **Biosensors:** Biosensors are composed of a biological sensing element (enzyme, antibody, DNA, receptor or complete cell) in direct contact with a physical sensor (transducer). Few examples exist, like a highly sensitive “electronic nose” for gas sensing

- *Bioactuators*: Nowadays, research is exploiting many physical and material effects to realise smart actuators.
- *Smart bio-manufacturing devices*: Combination of synthetic biology, **bioelectrochemistry**, and artificial intelligence could allow the development of selfoptimising biomanufacturing devices for local manufacturing of consumer goods.

Nature and bio-inspired manufacturing is not addressed in the ECSEL SRA, however, the interdisciplinarity between ECS research fields and Biology/Life sciences could be very relevant.

Bionic Manufacturing

This paradigm is mentioned in the "1. Manufacturing technology and processes" section and it is related to enhance and augment relevant human capabilities.

There are specific priorities that mention augmenting workers capabilities defined in the "7. Human centred manufacturing" section for protecting: DESIGN OF NEW EQUIPMENT, INTERFACES, PERSONAL PROTECTION DEVICES, for supporting TRAINING ENVIRONMENTS; and HUMAN-CENTRIC DATA AND INFORMATION MODELS AND TOOLS and for empowering: AUGMENTED HUMANS - UNOBTRUSIVE ASSISTING TECHNOLOGIES FOR WORKPLACE SUPPORT. Also in in the "3. Robotics and flexible automation" section: AUGMENTING THE HUMAN or the "8. Agile manufacturing systems design and management" section: HYBRID PRODUCTION SYSTEMS.

Technologies such augmented reality and virtual reality could be very relevant in Industry 4.0; and they are in the context of ECS sector. In the SRA 2020 has become more relevant in the Digital Industry chapter thanks to the new challenge: "MC4: Human-centred manufacturing". Nevertheless, these technologies may not be receiving the deserved attention.

Circular economy and sustainability

Fully circular digital and physical threads paradigm is mentioned in the "1. Manufacturing technology and processes" section. And entire section "9. Circular economy, resource and energy efficiency" is related to that with priorities in Materials and Energy (recovery, recycle, efficiency); Design, Refurbish and Remanufacture; and Maintenance and Reuse topics.

Especially in the area "Design, Refurbish and Remanufacture", in several priorities Cyber physical systems or ECS play a key role:

- PROCESS MODELLING AND CONTROL IN DEMANUFACTURING AND REMANUFACTURING: The research aims at increasing the knowledge about demanufacturing and remanufacturing process modelling and about cyber-physical systems for process control in circular economy businesses.
- DIGITALISING AND AUTOMATING DE- AND REMANUFACTURING PROCESSES AND SYSTEMS
- NEW TECHNOLOGIES FOR REMANUFACTURING, REFURBISHMENT AND RECYCLING OF PRODUCTS AND COMPONENTS
- MONITORING OF THE ENERGY FOOTPRINT OF THE PRODUCTS

In the SRA 2020, Sustainability and Circular economy has become more relevant in the Digital Industry chapter thanks to the new challenge: “MC5: Sustainable manufacturing in a circular economy”. Nevertheless, in the area of the European Green Deal, to deepen and detail more this topic is needed.

Other technical topics inside Digitalization

Digitalization is mentioned in the "2. Digital transformation" section with a focus on QUALITY in production systems, DYNAMIC and FLEXIBLE production systems and DIGITAL-REAL CONVERGENCE in production systems end ecosystem.

The priorities in this section are very aligned with the challenges of the Digital Industry chapter in ECS SRA: Digital platforms and tools, AI, digital twins and simulation, etc. and other chapters: Design and engineering tools, cybersecurity and connectivity, etc. However, it is interesting to see the application of these technologies: zero-defect manufacturing, mass customization of products, dynamic production and logistics, etc.

Nevertheless, there are some priorities that are not present or not explicit in the ECS SRA that could be relevant:

- **DIGITAL PROCESS PIPELINES:** “Seamless data exchange and processing are required in order to facilitate connection between design, manufacturing and recycling phases, thus increasing the knowledge content and its exploitation.”
- **INTEGRATING NEUROCOGNITIVE PROCESSES WITH AI IN FACTORIES AND VALUE NETWORKS:** “Innovative companies are witnessing the beginning of a massive shift towards neurocognitive manufacturing, which studies and combines humans’ cognitive capabilities with the sensing capabilities of machines, computational models, intelligent assets and Artificial Intelligence”
- **KNOWLEDGE AND DATA FUSION FOR MANUFACTURING:** “Novel approaches to combine different levels of information coming from experts, measurement, digital-twins/simulations; big data streams inline and in-site should be developed.”
- **DIGITAL SERVICISATION:** “Building successful business innovations based on data and services call for a visionary approach to future markets”
- **DIGITAL MARKETPLACE FOR EXCHANGE OF QUALIFIED RESOURCES IN DYNAMIC VALUE NETWORKS:** “Digitalisation of assets and resources is the main driver that disrupts the traditional static supply chain to dynamic value networks that are arranged on demand to couple the needs of buyers with the providers of manufacturing capacity”
- **NEXT GENERATION INDUSTRIAL DATA MANAGEMENT:** “There is a need to develop a systematic approach to support industrial/ manufacturing companies to deploy a strategic data management process. An effective and strategic data management process will provide companies with data awareness and data maturity, enabling an effective data-driven approach to their decision-making.”
- **THE INTERNET OF WEARABLE THINGS IN MANUFACTURING:** “Wearable technologies boost the convergence between the physical and digital world and enable more seamless workflows, meaning greater productivity. This new paradigm is empowered by advancements in microelectronics, ICT, big data and cloud computing, supporting employees to be more productive, easily report mechanical problems, service disruptions and other potential issues

at the shop floor level, and, simultaneously, enriching the digital representation of factories with worker-related data”

Non-technical issues

The ECSEL SRA could have gaps regarding new business models; innovation and entrepreneurship with a focus on SMEs; and education and training; whereas these topics are highlighted in the ManuFUTURE roadmap:

New business models related to Industry 4.0 and Circular Economy

The “10. New business models and logistics networks” research and innovation domain mentions new business models for Industry 4.0 and for Circular Economy

- DEVELOPMENT OF SUSTAINABLE BUSINESS MODELS FOR INDUSTRY 4.0 TECHNOLOGIES
- MANUFACTURING STRATEGIES AND BUSINESS MODELS FOR CIRCULAR ECONOMY

Innovation and entrepreneurship with a special focus on SMEs: "The primary objective is to provide a fruitful environment to create startups, accelerate technology uptake in SMEs and to support companies with their transformation focusing on enabling technologies with high manufacturing application potential."

Education and training: "The primary objective is to develop, across Europe, a skilled workforce through education, reskilling and upskilling people of all ages, gender and origin to ensure that the required competences for future manufacturing are available." Sub objectives are:

- Societal Awareness
- Industry Involvement
- European focused Skills
- Identification of competences
- Application-driven qualification
- Life-long Learning
- Education On-and Off-the-Job

5 Mapping of new ECSEL lighthouse projects

This section will define the criteria for assessing the new ECSEL lighthouse projects, a summary of those projects and an assessment of them taking into account the criteria defined.

5.1 Classification criteria for assessing projects

Three items from the ECSEL's SRA 2019 and 2020 have been used to assess the projects:

- The key application areas (see Figure 2): Transport and Smart Mobility, Health and Well-being, Energy, Digital Industry and Digital Life.
- The essential capabilities (see Figure 2): Systems and Components: Architecture, Design and Integration; Connectivity and Interoperability; Safety, Security and Reliability; Computing and Storage; and Process Technology, Equipment, Materials & Manufacturing for ECS.
- The challenges identified for the Digital Industry (SRA 2019):
 - Major Challenge 1 (MC1): Developing digital twins, simulation models for the evaluation of industrial assets at all factory levels and over system or product life cycles.
 - MC2: Implementing AI and machine learning to detect anomalies or similarities and to optimize parameters.
 - MC3: Generalizing condition monitoring, to pre-damage warning online decision-making support.
 - MC4: Developing digital platforms, application development frameworks that integrate sensors and systems.
- The challenges identified for the Digital Industry (SRA 2020):
 - MC1: Developing digital twins, simulation models for the evaluation of industrial assets at all factory levels and over system or product life-cycles
 - MC2: AI-enabled cognitive, resilient, adaptable manufacturing
 - MC3: Developing digital platforms, application development frameworks that integrate sensors/actuators and systems
 - MC4: Human-centred manufacturing
 - MC5: Sustainable manufacturing in a circular economy

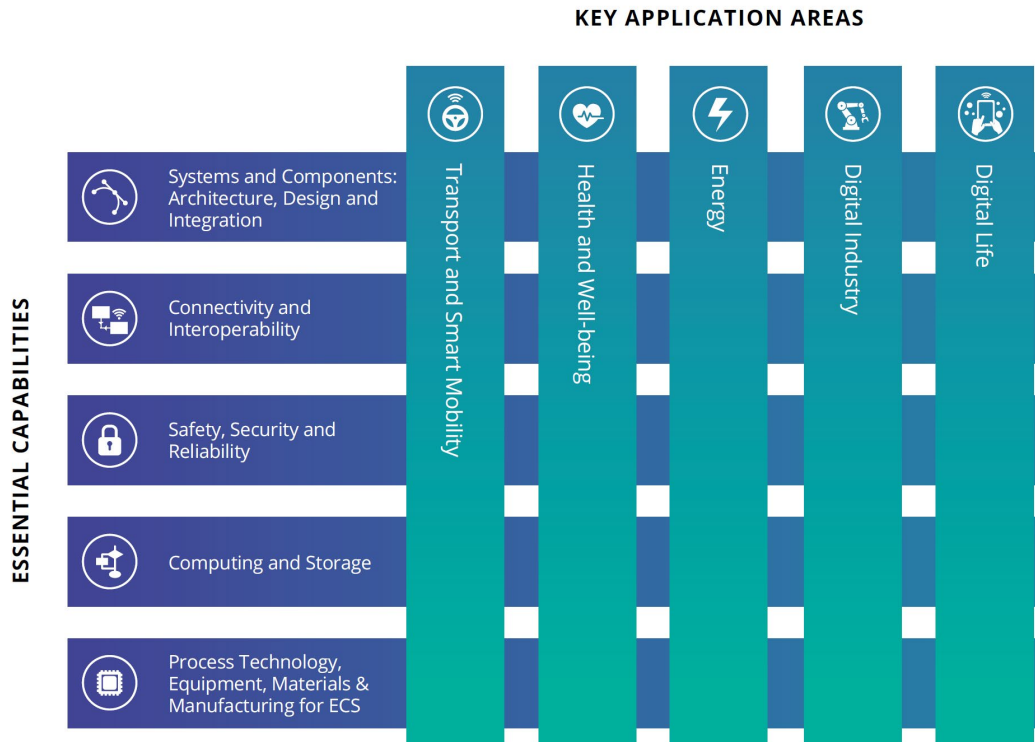


Figure 10: Key application areas and essential capabilities of ECSEL SRA 2019 and 2020

And for ECSEL's SRA 2021 equivalent concepts have been used. Challenges are not considered as they are still in elaboration.

- Application areas (see Figure 11): Mobility, Energy, Industry, Agrofood, Health and Digital Society
- Technologies as enablers in SRA 2021 (see Figure 11): Systems; Embedded Software; Components and Modules; Process Technology; and Equipment, Materials & Manufacturing
- Transversal topics in SRA 2021 (see Figure 11): Edge Computing and Artificial Intelligence; Connectivity; Architecture and Design; and Quality, Reliability, Safety & (Cyber-) Security.

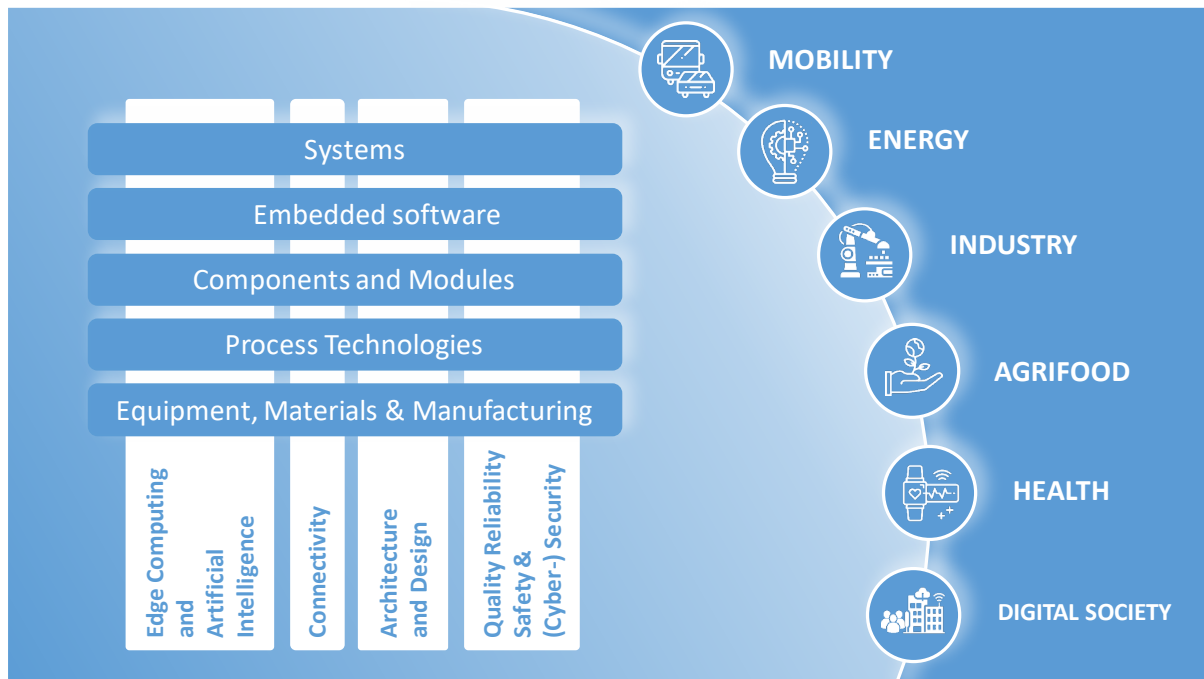


Figure 11: Application areas, technologies and transversal topics in ECSEL SRA 2021

5.2 Brief description of the projects

This section presents a brief description of all the projects in the Industry 4.E lighthouse presented ordered by their starting date. For more information about the projects, see annex in section 11.

- AI4DI: Artificial Intelligence for Digitizing Industry:** The project aims to transfer machine learning (ML) and AI from the cloud to the edge in manufacturing, mobility and robotics. To achieve these targets they connect factories, processes, and devices within digitised industry by utilizing ML and AI for human machine collaboration, change detection, and detection of abnormalities
- CPS4EU: Cyber Physical Systems for Europe:** This project's ultimate objective is to strengthen the CPS value chain. And for achieving these goals CPS4EU will: Develop 4 key enabling technologies (computing, connectivity, sensing, cooperative systems); Incorporate these CPS modules through pre-integrated architectures and design tools; Instantiate these architectures in dedicated use cases from strategic application: automotive, smart grid and **industry automation**; and Improve CPS awareness and usage for all industrial sectors.

The previous projects were mapped in the Deliverable D1.1 and in the annex 12 a summary of the mapping of all the projects is shown.

5.1 Analysis of lighthouse projects

This section presents the mapping of the lighthouse projects regarding the criteria of key application areas, essential capabilities and challenges of Digital Industry covered.

Disclaimer: We do not claim this analysis to be complete or precise as ECSEL projects are very broad and not all the activities are gathered in public documents. We have collected information from the website of the project, CORDIS, etc.

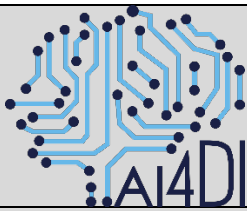

5.1.1 Regarding the key application areas

In AI4DI, Digitizing Industry using AI is the main goal, so the main key application is **Digital Industry**. 5 different supply chains are considered: Automotive; Semiconductor; Machinery; Smart food and beverage production; and Transportation. And in an indirect way, the key application **Transport and Smart Mobility** (automotive, transportation) is addressed. For the application areas in SRA 2021, Industry is the main area; and indirectly for the sectors where it is applied: **Mobility** (automotive, transportation) and **Agrofood** (Smart food and beverage production) are addressed.

In CPS4EU, three key industrial sectors are mentioned: automotive, smart grid and industry automation. So, at least three key application areas are covered: **Digital Industry**, **Energy** and **Transport and Smart Mobility** (automotive). For the application areas in SRA 2021, **Industry**, **Energy** and **Mobility** (automotive) are addressed.

In the Table 1 a summary of the mapping of the new projects and the key applications areas is found. Both of the projects addresses the Digital industry key application area as we expected.

Table 4: Mapping of projects regarding key application areas (in green main area, in yellow other application areas)

| | |  |  |
|---|-------------------------------------|---|---|
| | | https://ai4di.automotive.oth-aw.de/ | https://cps4eu.eu/ |
| Key Applications Areas in SRA 2019 and 2020 | Transport and Smart Mobility | | |
| | Health and Well-being | | |
| | Energy | | |
| | Digital Industry | | |
| | Digital Life | | |
| Applications Areas in SRA 2021 | Mobility | | |
| | Energy | | |
| | Industry | | |
| | Agrofood | | |
| | Health | | |
| | Digital Society | | |

5.1.2 Regarding the Essential capabilities

AI4DI addresses clearly the transversal topic **Edge Computing and Artificial Intelligence** in SRA 2021, as it is the main goal of the project. However, the project will as well develop hardware and software modules as internet of things (IoT) devices for sensing, actuating, and connectivity processing. So, AI4DI also partially addresses **Systems and Components, Architecture, Design, and Integration; Connectivity and Interoperability** and **Computing and Storage** of SRA 2019 and 2020; and the technologies of SRA 2021: **Systems; Embedded Software; and Components and Modules**; and the transversal topics of SRA 2020: **Connectivity**; and **Architecture and Design**. Moreover, in the supply chain of Semiconductor, AI will be applied to Manufacturing, Fault detection and Visual inspections so **Process Technology, Equipment, Materials, and Manufacturing for ECS** essential capability of SRA 2019 and 2020 and **Equipment, Materials & Manufacturing** technology of SRA 2021 are partially addressed.

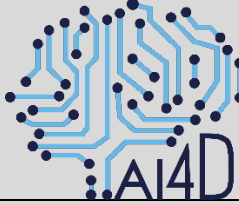

CPS4EU focus on CSPs and it will develop

- 3 computing modules devoted to master real-time systems: HP Embedded Computing; AI computing and Vision computing.
- 2 connectivity modules to master dynamic communication: Connectivity V2X / M2M module and Cybersecurity module.
- 2 innovative interfaces with the physical world through the integration of sensors and actuators towards the autonomous system paradigm: Ultra precise localization system module and Perception and interpretation of environment module.
- A collaborative systems to master multi-scale modeling and behavior prediction: Cooperative algorithms module
- 4 pre integrated architectures and CPS tools to handle the explosion of the complexity of CPS systems.

So, CPS4EU addresses most of the essential capabilities of SRA 2019 and 2020: **Systems and Components, Architecture, Design, and Integration** (pre integrated architectures, sensing modules...); **Connectivity and Interoperability** (connectivity modules); **Safety, Security, and Reliability** (cyber-security module) and **Computing and Storage** (computing modules). And it addresses most of the technologies of SRA 2021: **Systems** (CPSs); **Embedded Software** (Software of the CPSs); **Components and Modules** (several modules). And most of the transversal topics of SRA 2020: **Edge Computing and Artificial Intelligence** (AI computing module); **Connectivity** (connectivity modules); **Architecture and Design** (CPS tools); and **Quality, Reliability, Safety & (Cyber-) Security** (cyber-security module)

The main essential capabilities addressed in the project are summarized in the Table 2.

Table 5: Mapping of projects regarding essential capabilities (in green main capability, in yellow other capabilities)

| | |  https://ai4di.automotive.oth-aw.de/ |  https://cps4eu.eu/ |
|---|--|--|--|
| Essential Capabilities in SRA 2019 and 2020 | Systems and Components, Architecture, Design, and Integration | | |
| | Connectivity and Interoperability | | |
| | Safety, Security, and Reliability | | |
| | Computing and Storage | | |
| | Process Technology, Equipment, Materials, and Manufacturing for ECS | | |
| Technologies as enablers in SRA 2021 | Systems | | |
| | Embedded Software | | |
| | Components and Modules | | |
| | Process Technology | | |
| | Equipment, Materials & Manufacturing | | |
| Transversal topics in SRA 2021 | Edge Computing and Artificial Intelligence | | |
| | Connectivity | | |
| | Architecture and Design | | |
| | Quality, Reliability, Safety & (Cyber-) Security | | |

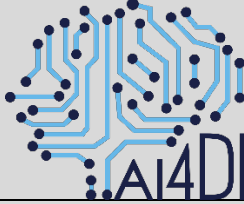

5.1.3 Regarding the challenges identified for the Digital Industry

AI4DI addresses mainly “**MC 2** (SRA 2019): Implementing AI and machine learning to detect anomalies or similarities and to optimize parameters” and “**MC 2** (SRA 2020): AI-enabled cognitive, resilient, adaptable manufacturing” as the main goal of the project is AI. And also addresses “**MC 3** (SRA 2019): Generalizing condition monitoring, to pre-damage warning online decision-making support” as it addresses Predictive Diagnostics in the Automotive Supply Chain. And “**MC 4** (SRA 2020): MC4: Human-centred manufacturing” as it addresses Human Machine Collaboration in the Machinery Supply Chain.

CPS4EU will develop 4 pre integrated architectures with basic modules, so it is addressing “**MC 4** (SRA 2019): Developing digital platforms, application development frameworks that integrate sensors and systems” and “**MC 3** (SRA 2020): Developing digital platforms, application development frameworks that integrate sensors/actuators and systems”. CPS4EU also addresses “**MC 2** (SRA 2019): Implementing AI and machine learning to detect anomalies or similarities and to optimize parameters” and “**MC 2** (SRA 2020): AI-enabled cognitive, resilient, adaptable manufacturing” as Artificial Intelligence is one of the key basic technologies that applies, developing AI computing modules.

The main challenges of Digital Industry chapter addressed in the project are summarized in the Table 4.

Table 6: Mapping of projects regarding Major Challenges (MC) of Digital Industry (in green main challenges, in yellow partially addressed challenges)

| | |  |  |
|--|--|---|---|
| | | https://ai4di.automotive.oth-aw.de/ | https://cps4eu.eu/ |
| Challenges of Digital Industry SRA 2019 | MC1: Developing digital twins, simulation models for the evaluation of industrial assets at all factory levels and over system or product life cycles. | | |
| | MC2: Implementing AI and machine learning to detect anomalies or similarities and to optimize parameters. | | |
| | MC3: Generalizing condition monitoring, to pre-damage warning online decision-making support. | | |
| | MC4: Developing digital platforms, application development frameworks that integrate sensors and systems. | | |
| Challenges of Digital Industry SRA 2020 | MC1: Developing digital twins, simulation models for the evaluation of industrial assets at all factory levels and over system or product life-cycles | | |
| | MC2: AI-enabled cognitive, resilient, adaptable manufacturing | | |
| | MC3: Developing digital platforms, application development frameworks that integrate sensors/actuators and systems | | |
| | MC4: Human-centred manufacturing | | |
| | MC5: Sustainable manufacturing in a circular economy | | |

5.2 Conclusions of the mapping

Regarding the application areas, both of the projects covers **Digital Industry** area (as expected). And CPS4EU is more transversal and can be used in several areas, not only Digital Industry.

Regarding essential capabilities and technologies, both projects are covering quite lots of technologies. The main focus of AI4DI is on AI but it also develops systems and modules. And the main focus of CPS4EU is CPSs which is totally transversal to ECS, so most of the technologies are covered.

Regarding the main challenges of Digital Industry chapter addressed in the projects, AI4DI addresses mainly the challenges related to AI. And CPS4EU is addressing mainly the challenges related to digital platforms.

6 Workshop for getting feedback from experts

In June we held the Workshop “Shaping the Future Roadmap in Digital Industry”, facilitated by the CSA Industry 4.E. This interactive workshop’s goal was to discuss the recommendations on the future of the Industrial digitalisation roadmap and shape next ECSEL/KDT (Key Digital Technologies) research agenda.

This online workshop was held on the 25th of June 2020 (10:00-12:00 CEST), as a co-host event of ECSEL JU Symposium.

The gathered comments and feedback have been used as input to elaborate the recommendations drawn in this deliverable.

6.1 Agenda of the workshop

This is the agenda of the workshop

10:00-10:25 - Introduction and presentation of work done in CSA-Industry 4.E regarding roadmapping and the recommendations drawn. Speaker: Leire Etxeberria

10:25-11:25 - Break out sessions to discuss recommendations around specific topics:

- Key Digital Technologies for Green Deal. 20 minutes
- Artificial Intelligence in Digital Industry. 20 minutes
- Resilience in crisis time (COVID-19, etc.). 20 minutes

11:25-11:45 - Presentation of Digital Industry Chapter of Strategic Research Agenda (SRA) 2020. Speaker: Olli Venta

11:45-12:00 - Wrap up and conclusions.

6.2 Attendees

51 people attended the workshop and they were distributed in 7 different breakout groups to discuss the topics.

The attendees were from different types of organization: 31% from research centers, 33% from universities, 23% from industry, 6% from SMEs and 6% from other kind of organizations (see Figure 1).

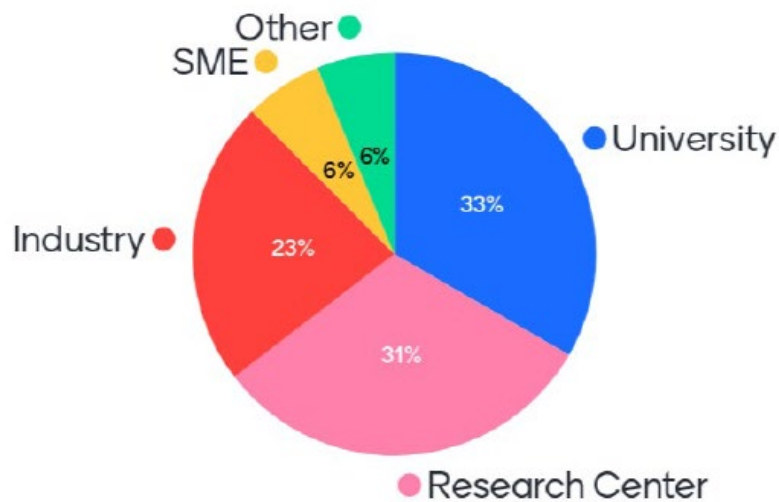


Figure 12: Type of organization of the attendees

The attendees connected from all over Europe and they were from different countries (see Figure 2).



Figure 13: The country of origin of the attendees

6.3 Feedback from attendees

One of the goals of the workshop was to gather the feedback from researchers and practitioners of Industry 4.0 about recommendations on the future of the Industrial digitalisation roadmap.

The workshop was interactive to gather this feedback of the attendees using mentimeter (with questions about the recommendations) and the breakout sessions (the attendees were distributed in 7 different breakout groups) to discuss recommendations around three specific topics:

- Key Digital Technologies for Green Deal
- Artificial Intelligence in Digital Industry
- Resilience in crisis time (COVID-19, etc.)

The annex 13 “Report with results of the Workshop: Shaping the Future Roadmap in Digital Industry” summarizes the comments and feedback of the discussions carried out in the break out sessions. As well as the feedback obtained with the questions of Mentimeter tool; questions connected to the presentations and sessions of the workshop.

7 Final recommendations

Final recommendations have been drawn taking into account the analysis of other roadmaps, the mapping of the lighthouse projects to see which topics they cover and the feedback obtained from experts.

There are two types of recommendations:

- The recommendations related to the topics
- The recommendations that are related to non-technical aspects

7.1 Topics

In this section, new topics or topics that should be addressed more in depth in the next ECSEL/KDT MASP are proposed. These topics are the following:

- Artificial Intelligence
- Sustainability (Green Deal)
- Resilience
- Nature and bio-inspired Manufacturing
- Bionic manufacturing
- Servitisation

From the six initially identified topics, three of them (AI, sustainability and Resilience) are considered very relevant and with a considerable scope and the other three (bio-inspired, bionic and servitisation) are more specific topics with a smaller scope. The feedback of the workshop (see Figure 14) shows that most of the attendees strongly agree that AI, sustainability and resilience should be addressed in the KDT research for Digital Industry.

Do you think that the following topics should be addressed in ECS / KDT research for Digital Industry?

Mentimeter



41



Figure 14: Feedback from attendees of the Roadmapping Workshop about the new topics proposed

Artificial Intelligence

Artificial Intelligence was present in two challenges in the SRA 2019 (“MC2: Implementing AI and machine learning to detect anomalies or similarities and to optimise parameters” and “MC3: Generalizing condition monitoring, to pre-damage warning online decision-making support”) focusing on optimization and maintenance. After our recommendations in the first iteration the topic was broadened in the challenge “MC2: AI-enabled cognitive, resilient, adaptable manufacturing” in ECS SRA 2020.

Due to the high impact of Artificial Intelligence in Digital Industry (roughly 50% of opportunities for exploitation of AI are in manufacturing), further refinement and extension of the challenge is proposed. ECS sector is also key in the development of the AI systems themselves. “AI **systems** are complex. They integrate diverse technologies, from **software** and **hardware** to physical structures.” So AI systems are Electronic systems with embedded software and components, ECS sector is vital to develop them and address the technological challenges of their development. So, other challenges can be extend to add AI specific topics.

Our recommendations:

- “MC2: AI-enabled cognitive, resilient, adaptable manufacturing” challenge could be extended to include AI applied to Digital industry to improve productivity, increase autonomy, improve usability of products and services and support complex decision-making processes. Topics such as “Integration of neurocognitive processes with AI”, “data management” identified in the ManuFUTURE roadmap could be also included.
- Refinement of other challenges of the Digital Industry chapter to include AI aspect.
 - Regarding MC1: “Developing digital twins, simulation models for the evaluation of industrial assets at all factory levels and over system or product life-cycles”, Digital twins used in AI, for example digital twins that provides value to AI data integration

79 (98)

(“By combining data-driven and knowledge-based models, it becomes possible to have a sustainable digital twin along the complete lifecycle (product and production) that provides value to AI data integration”). Also mention in the “Knowledge and data fusion” topic of ManuFUTURE roadmap.

- Regarding “MC3: Developing digital platforms, application development frameworks that integrate sensors/actuators and systems”, Digital platforms for AI: AI systems needs digital platforms: AI platform, data platform and platforms for data and algorithm sharing.
- Regarding “MC4: Human-centred manufacturing”, AI applied to improve human interaction with machines, AI applied to improve worker conditions, etc. The social acceptance and trust of AI is also related to this challenge.
- Regarding “MC5: Sustainable manufacturing in a circular economy”, AI applied to sustainability, such as improvement of energy or material efficiency or waste production.

Sustainability (Green deal)

In the first iteration, sustainability and circular Economy emerging theme was identified and a new major challenge was proposed: ‘Sustainable manufacturing in a Circular Economy’. This challenge was introduced in ECS SRA 2020.

The European Green deal has pinpointed even more the importance of the green transition and the role of digitalization and industry in enabling this transition. Europe needs a digital sector that puts sustainability at its heart; improving the sustainability of all the sectors and also improving the energy efficiency and circular economy performance of the digital sector itself.

Our recommendations:

- The extension and refinement of the challenge “MC5: Sustainable manufacturing in a circular economy” in order to include the topics of the European Green deal and EU Industrial Strategy such as Circular Electronics Initiative, sustainable products’ policy, electronic product passport, etc. And topics of the ManuFUTURE roadmaps related to demanufacturing and remanufacturing.
- Refinement of other challenges of the Digital Industry chapter to remark sustainability as transversal aspect.
 - Regarding MC1: “Developing digital twins, simulation models for the evaluation of industrial assets at all factory levels and over system or product life-cycles”, Digital twins applied to sustainability and Circular Economy: Simulate the usage of energy, use of raw material, waste production, etc. with the goal of improving the energy efficiency and circular economy performance.
 - Regarding “MC2: AI-enabled cognitive, resilient, adaptable manufacturing”, AI applied to improve sustainability and Circular Economy. For example, AI to get efficient resource, energy and material use.
 - Regarding “MC3: Developing digital platforms, application development frameworks that integrate sensors/actuators and systems”, Digital platforms for Circular Economy, etc.

Resilience in time of crisis

The COVID-19 crisis has shown Europe the weakness of European supply chain, the dependence on third countries. We need to recover European industry, competitiveness and sovereignty. This was already known, but it has become more relevant.

The COVID-19 crisis has shown the importance of the digitalization of the industry as well as the importance of the flexibility, resistance and resilience of European industry.

In May commission has launched €50M Horizon call to help industry repurpose manufacturing capabilities in time of crisis. The European Commission is releasing €50 million from the Horizon 2020 research budget to help the manufacturing sector repurpose production lines faster, and is preparing a call worth €20 million dedicated exclusively to switching existing lines over to the manufacture of medical equipment, vaccines and diagnostics. A further €30 million will be dedicated to digital innovation hubs and artificial intelligence for manufacturing, to speed up the digitisation of industrial production.

Our recommendations:

- Include a new Major Challenge on “Resilience in a fast changing world” (reacting on disruptions e.g in supply chains / customer behaviours / etc.)

Nature and bio-Inspired Manufacturing

Bio-inspired manufacturing concepts could leverage the current implementation of advanced cyber-physical systems (integrating hybrid twins, cognitive automation, Artificial Intelligence, among other state-of-the-art techniques) to unprecedented resilient production environments.

In addition, for the biological transformation of products: biosensors, bioactuators and bio-manufacturing devices are needed.

This paradigm is not addressed in the Digital Industry chapter of the SRA.

Our recommendations:

- To include some text about biosensors, bioactuators and bio-manufacturing devices and interdisciplinarity between ECS research fields and Biology/Life sciences.

Bionic Manufacturing

Technologies such augmented reality and virtual reality could be very relevant in Industry 4.0; and they are in the context of ECS sector. In the first iteration, Human-centred manufacturing emerging theme was identified and a new major challenge was proposed: ‘MC4: Human-centred manufacturing’. This challenge was introduced in ECS SRA 2020. However, to enhance and augment relevant human capabilities with bionic technologies is not fully addressed.

Our recommendations:

- The extension and refinement of the challenge “MC4: Human-centred manufacturing” in order to include the bionic manufacturing topic and the topic about wearable things identified in the ManuFUTURE roadmap.

Servitisation

Digital Servitisation for building successful business innovations based on data and services is a key topic as well as digital marketplace for exchange of resources in dynamic value networks.

However, servitisation and digital marketplace topics are not addressed in the SRA 2020.

Our recommendations:

- The inclusion of a new challenge related to servitisation and creation of digital marketplace, related to the priorities: digital process pipelines, digital servitisation and digital marketplace for exchange of qualified resources in dynamic value networks identified in ManuFUTURE roadmap.

7.2 Non-technical, cross-cutting aspects

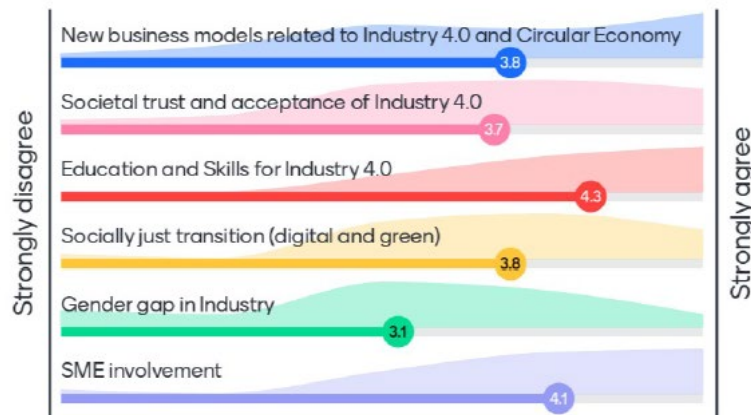
In this section, non-technical and transversal topics that should be addressed are proposed. These topics are the following:

- New business models related to Industry 4.0 and Circular Economy
- Societal trust and acceptance of Industry 4.0
- Education and Skills for Industry 4.0
- Socially just transition (digital and green)
- Gender gap in Industry
- SME involvement

The feedback of the workshop (see Figure 14) shows that most of the attendees strongly agree that Education and skills and the SME involvement area very relevant topic that should be addressed. The support for the other topics is also quite high.

Do you think that the following non-technical topics should be addressed in ECS / KDT research for Digital Industry?

Mentimeter



30

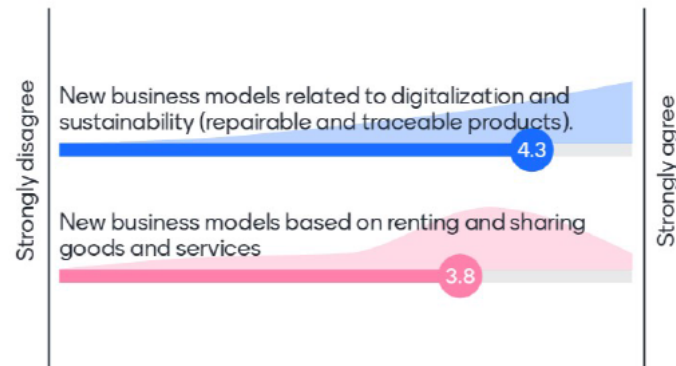
Figure 15: Feedback from attendees of the Roadmapping Workshop about the new non-technical topics proposed

New business models related to Industry 4.0 and Circular Economy

KDT should reinforce the development of new business models related to digitalization and sustainability (repairable and traceable products) as well as the development of new business models based on renting and sharing goods and services.

New business models related to Industry 4.0 and Circular Economy. Do you agree with the reinforcing of the development of

Mentimeter



27

Figure 16: Feedback from attendees of the Roadmapping Workshop about new business models

The feedback of the workshop (see Figure 16) shows that most of the attendees strongly agree with the first recommendation.

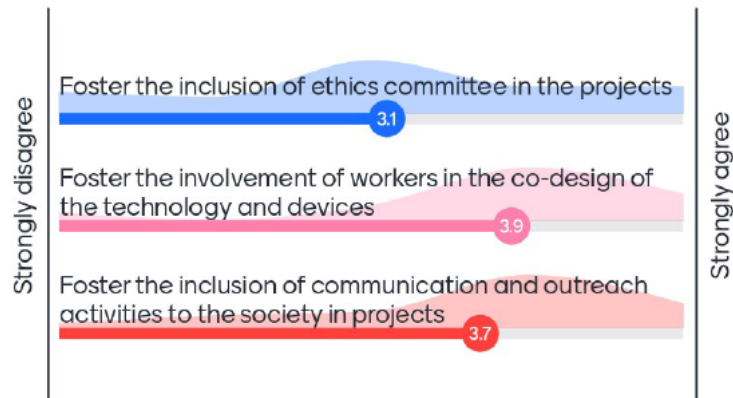
Societal trust and acceptance of Industry 4.0

Foster **Societal trust and acceptance of Industry 4.0** based on European values such as ethical values, human rights, safety and privacy. Possible recommendations:

- Foster the inclusion of ethics committee in the projects
- Foster the involvement of workers in the co-design of the technology and devices.
- Foster the inclusion of communication and outreach activities to the society in projects.
 - To foster societal trust and acceptance of Industry 4.0, society must know about Industry 4.0 and its benefits. Coordination and Support actions such as the CSA-Industry 4.E project could be a good mechanism for fostering communication and outreach activities to the society. For this reason, another sub-recommendation is the inclusion of CSA project type in the KDT programme.

How to foster societal trust and acceptance of Industry 4.0?

Mentimeter



27

Figure 17: Feedback from attendees of the Roadmapping Workshop about societal trust and acceptance of Industry 4.0

The feedback of the workshop (see Figure 17) shows that there is a quite high support of the proposed recommendations.

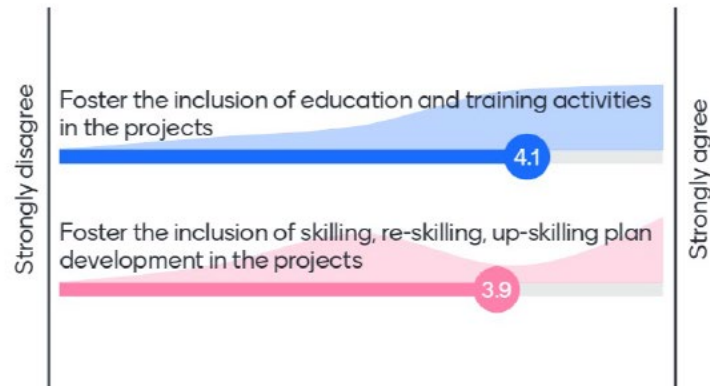
Education and Skills for Industry 4.0

Reinforce **Education and Skills for Industry 4.0**: Skilling, upskilling and reskilling are key enablers in Digital Industry. Possible recommendations:

- Foster the inclusion of education and training activities and skilling plan development in the projects.
- Foster the inclusion of skilling, re-skilling, up-skilling plan development in the projects.

How to reinforce Education and Skills for Industry 4.0?

Mentimeter



27



Figure 18: Feedback from attendees of the Roadmapping Workshop about Education and Skills

The feedback of the workshop (see Figure 18) shows that there is a quite high support of the proposed recommendations.

Socially just transition (digital and green)

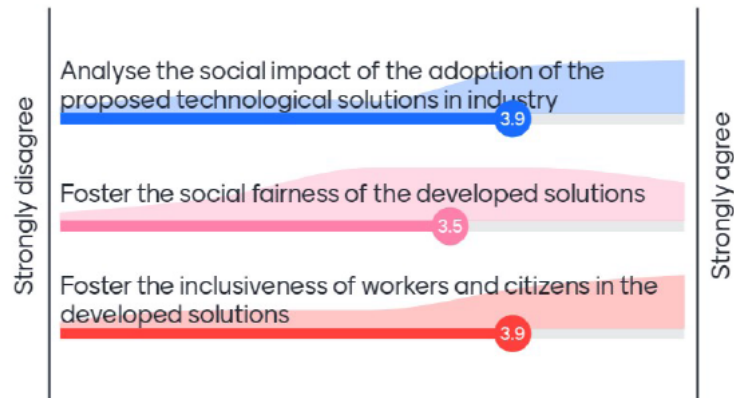
It is important to assure that the digital and green transition is conducted in a fair and inclusive way.

Recommendations

- Take actions to analyse the social impact of the adoption of the technological solutions in industry.
- Foster the social fairness of the developed solutions.
- Foster the inclusiveness of workers and citizens in the developed solutions.

How to foster a socially just transition (digital and green)?

Mentimeter



26



Figure 19: Feedback from attendees of the Roadmapping Workshop about socially just transition

The feedback of the workshop (see Figure 19) shows that there is a quite high support of the proposed recommendations.

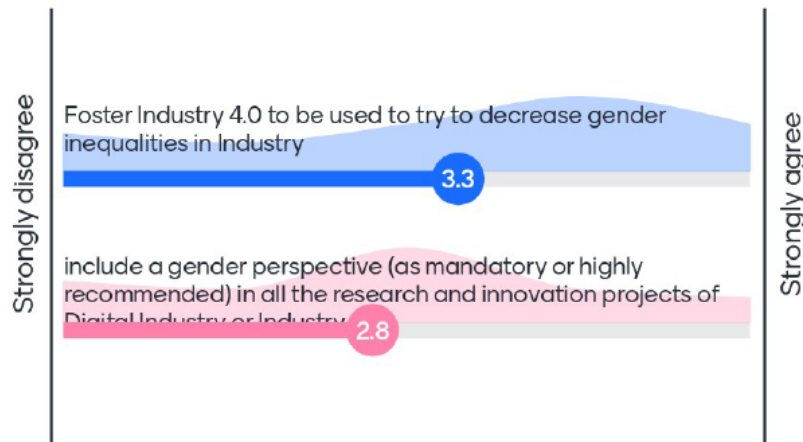
Gender gap in Industry

There is a gender gap in industry and Industry 4.0 paradigm could make a difference to decrease it. Possible recommendations:

- Foster Industry 4.0 to be used to try to decrease gender inequalities in Industry.
- To include a gender perspective (as mandatory or highly recommended) in all the research and innovation projects regarding Digital Industry or Industry 4.0.

How to reduce gender gap in industry?

Mentimeter



26



Figure 20: Feedback from attendees of the Roadmapping Workshop about the gender gap

The feedback of the workshop (see Figure 20) shows that there is a quite high support for the first recommendation.

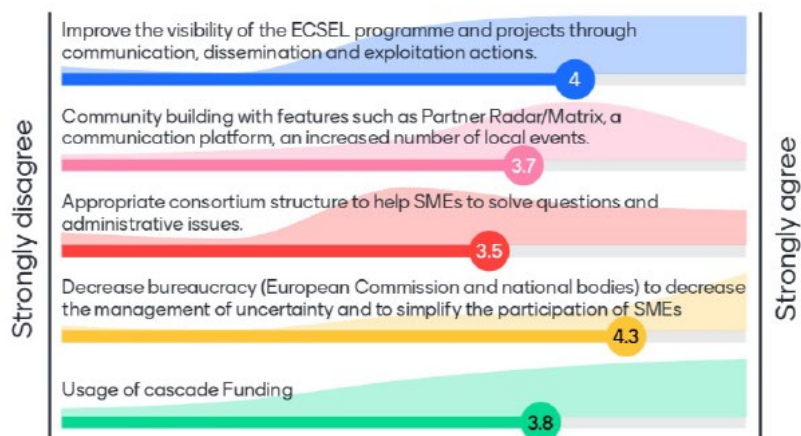
SME involvement

The SMEs will have a key role in the green and digital transitions. The participation of SME in ECS research projects of Digital Industry is very important and should be promoted. As captured in the “D2.5 Engagement and Assessment of Involvements of SMEs”, SME face some difficulties regarding ECSEL projects. Some recommendations to foster and facilitate the participation of SMEs in ECSEL projects are gathered in the D2.5 deliverable. This is the summary of the recommendations proposed:

- Improve the visibility of the ECSEL programme and projects through communication, dissemination and exploitation actions.
- Community building with features such as Partner Radar/Matrix, a communication platform, an increased number of local events.
- Appropriate consortium structure to help SMEs to solve questions and administrative issues.
- Decrease bureaucracy (European Commission and national bodies) to decrease the management of uncertainty and to simplify the participation of SMEs
- Usage of cascade Funding, also known as Financial Support for Third Parties (FSTP). The inclusion of this instrument in ECSEL projects could be used to call for experiments or small projects where SMEs (not in the consortium) could participate with a fast and lightened process.

How to involve SMEs?

Mentimeter



26

Figure 21: Feedback from attendees of the Roadmapping Workshop about the SMEs involvement

The feedback of the workshop (see Figure 21) shows that there is a quite high support for all the recommendations.

8 Conclusions

This deliverable presents the results of the elaboration of recommendations. It presents the approach followed and the feedback obtained by stakeholders. And finally recommendations are made for the KDT programme regarding technical and non-technical topics.

The technical topics that we consider should be addressed or emphasized are the following:

- **Artificial Intelligence:** Very aligned with the importance AI is getting in Europe and European strategy recently. Europe is currently involved in a hype about AI and the combination of Industrial data and AI could lead to great impact in the improvement of products and processes in manufacturing.
- **Sustainability (Green Deal):** Aligned with the importance of the green transition and the role of digitalization and industry in enabling this transition.
- **Resilience:** The COVID-19 crisis has shown the importance of the digitalization of the industry as well as the importance of the flexibility, resistance and resilience of European industry.
- **Nature and bio-inspired Manufacturing:** Biosensors, bioactuators and bio-manufacturing devices and interdisciplinarity between ECS research fields and Biology/Life sciences
- **Bionic manufacturing:** In line with Human-centred manufacturing to enhance and augment relevant human capabilities with bionic technologies
- **Servitisation:** Digital Servitisation for building successful business innovations based on data and services

New challenges or refinements of challenges are proposed to address these topics in section 7.

The non-technical topics that we consider should be addressed or emphasized are the following:

- **New business models related to Industry 4.0 and Circular Economy:** new business models related to digitalization and sustainability (repairable and traceable products)
- **Societal trust and acceptance of Industry 4.0:** For successful adoption of Digital Industry, societal acceptance is key; And for getting the societal acceptance: capturing value, showing the benefit of digital industry for the society and creating societal trust is needed.
- **Education and Skills for Industry 4.0:** Skilling, upskilling and reskilling are key enablers in Digital Industry.
- **Socially just transition (digital and green):** It is important to assure that the digital and green transition is conducted in a fair and inclusive way.
- **Gender gap in Industry:** There is a gender gap in industry and Industry 4.0 paradigm could make a difference to decrease it.
- **SME involvement:** The SMEs will have a key role in the green and digital transitions. The participation of SME in ECS research projects of Digital Industry is very important and should be promoted.

Concrete recommendations of how to address them are proposed in section 7.

KDT programme will be very relevant in the challenging goal of Europe for performing a digital and green transition of Europe in a just manner.

9 References

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- [6] ManuFUTURE 2030, SRIA: Strategic Research and Innovation Agenda, Report from ManuFUTURE High-Level Group, December 2019

10 Versions

| D1.3 | |
|-------------------|--|
| Version - Date | Comments & Recommendations |
| V0.1 – 24.06.2019 | D1.3 complete draft intermediate version |
| V0.2 – 29.06.2019 | D1.3 complete intermediate version |
| V0.3 – 27.03.2020 | Inclusion of new roadmaps analysis: IA PPP and Grean Deal |
| V0.4 – 03.04.2020 | Inclusion of new roadmaps analysis: ManuFuture |
| V0.5 – 23.04.2020 | Finalization of new roadmaps analysis and inclusion of recommendations |
| V0.6 – 07-05-2020 | Inclusion of the mapping of new projects: AI4DI and CPU4EU |
| V0.7 – 10-05-2020 | Update of final recommendations |
| V0.8 – 29-05-2020 | Incorporation of feedback of partners |
| V0.9 – 15-07-2020 | Incorporation of the results of the Roadmapping workshop |
| V1.0 – 18-09-2020 | Complete version for internal review |

11 Annex: Summary of new lighthouse Industry 4.E projects

11.1 AI4DI: Artificial Intelligence for Digitizing Industry

General data:

- Start date: May 2019
- Project duration (months): 36
- Total investment: €30.1 M
- Number of participating organizations: 40
- Number of countries: 12
- Coordinator: Reiner John (Infineon Technologies), Germany
- Web: <https://ai4di.automotive.oth-aw.de/>

Summary: An artificial intelligence boost for European industry

Artificial intelligence plays a central role in societies, economies and industries around the world. However, there has been a lack of AI integration in Europe. As a result, potential users are not sufficiently supported despite the benefits it can provide to all branches of the industry and its digitisation. The EU-funded AI4DI project aims to transfer machine learning (ML) and AI from the cloud to the digitising industry. It will use a seven-key-target approach to evaluate and improve its relevance within the industry. The project plans to connect factories, processes and devices within the digitised industry by utilising ML and AI. It will then collect data on their performance.

Objective

Europe has a lack of intellectual property in integrating artificial intelligence (AI) into digital applications. This is critical since the automatization reached saturated levels and AI in digitisation is an accepted approach for the upcoming transformation of the European industry. The potential of AI in economy and society is by far not enough exploited. Potential users of AI are not sufficiently supported to facilitate the integration of AI into their applications. Enabling of performance, industry and humanity by AI for digitising industry is the key to push the AI revolution in Europe and step into the digital age. Existing services providing state of the art machine learning (ML) and artificial intelligence solutions are currently available in the cloud. In this project, we aim to transfer machine learning and AI from the cloud to the edge in manufacturing, mobility and robotics. To achieve these targets we connect factories, processes, and devices within digitised industry by utilizing ML and AI for human machine collaboration, change detection, and detection of abnormalities. Hence, we gain knowledge by using existing data and arrange them into a processable representation or collect new data. We use this knowledge to change the semantics and the logical layer with a distributed system intelligence for e.g. quality control, production optimization. In AI4DI, we define a 7-key-target-approach to evaluate the relevance of AI methods within digitised industry. Each key target represents a field of activity and the corresponding target at the same time, dividing systems into heterogenous and homogenous systems, and evolving a common AI method understanding for

these systems as well as for human machine collaboration. Furthermore, we investigate, develop and apply AI tools for change detection and distributed system intelligence, and develop hardware and software modules as internet of things (IoT) devices for sensing, actuating, and connectivity processing.

11.2 CPS4EU: Cyber Physical Systems for Europe

General data:

- Start date: July 2019
- Project duration (months): 36
- Total investment: €53.03 M
- Number of participating organizations: 38
- Number of countries: 5
- Coordinator: Philippe Gougeon (Valeo Vision SAS), France
- Web: <https://cps4eu.eu/>

Summary: Applying CPS technologies in modern manufacturing

Cyber-physical systems (CPS) technologies involve the orchestration of computers, and physical and human components. Examples include smart grid and autonomous automobile systems, medical monitoring and robotics systems. Advances in CPS are resulting in systems that respond quicker and with more precision. With the potential to benefit many sectors, the EU-funded CPS4EU project will enable CPS technology providers (mainly European SMEs) to increase their growth in the international market. Its aim is to improve efficiency and productivity, enable the creation of CPS products, and promote CPS awareness and usage for all industrial sectors. Bringing together world-class research centres, SMEs and large companies, the project will develop a pan-European collaboration, facilitating knowledge exchange across all sectors in the value chain.

Objective

In recent years, Cyber Physical Systems (CPS) technologies have become a game changer in strategic sectors such as Automotive, Energy and Industry Automation, where Europe is a world leader. In fact, CPS is a key driver for the innovation capacity of European industries, large and small, generating economic growth and supporting meaningful jobs for citizens. CPS4EU aims to arm Europe with extensive value chain across key sectors by:

1. Strengthening CPS Technology providers, mainly European SMEs, to increase their market share and their competitiveness to become world leaders
2. Improve design efficiency and productivity and enable secure certification
3. Enabling the creation of innovative European CPS products that will strengthen the leadership and competitiveness of Europe by both large groups and SMEs
4. Large Dissemination of CPS technologies.

To achieve these goals CPS4EU will:














1. Develop 4 key enabling technologies (computing, connectivity, sensing, cooperative systems)
2. Incorporate these CPS modules through pre-integrated architectures and design tools
3. Instantiate these architectures in dedicated use cases from strategic application: automotive, smart grid and industry automation
4. Improve CPS awareness and usage for all industrial sectors

CPS4EU gathers major large companies (BMW, VALEO, THALES, TRUMPF, RTE, ABENGOA, LEONARDO, and SCHNEIDER ELECTRIC), a large set of innovative SMEs and world-class research centres (FHG, CEA, DLR, INRIA, KIT, CNRS) to significantly reduce the development time and certification efforts through pan European collaboration, knowledge exchange and access to the strong value chain in strategic markets,

CPS4EU builds on a strong foundation in European and national initiatives. It will enable the European industry to lead strategic markets thanks to high level sharing of CPS technologies across sectors all along the value chain.

12 Annex: Mapping of lighthouse projects

This annex presents the summary of the mapping of the lighthouse projects.

| | |  swarms.eu |  mantis-project.eu |  semi40.eu |  delphi4led.org |  scottproject.eu |  i-mech.eu |  productive40.eu |  idev40.eu |  afarccloud.eu |  https://www.semi.org/eu/MADEin4 |  https://www.arrowhead.eu/arrowheadtools |  https://ai4di.automotive.oth-aw.de/ |  https://cps4eu.eu/ |
|---------|---|---|---|---|---|---|---|---|---|---|--|--|--|--|
| Domains | Systems and Components Architecture, Design, and Integration | | | | | | | | | | | | | |
| | Connectivity and Interoperability | | | | | | | | | | | | | |
| | Safety, Security, and Reliability | | | | | | | | | | | | | |
| | Computing and Storage | | | | | | | | | | | | | |
| | Process Technology, Equipment, Materials, and Manufacturing for ECS | | | | | | | | | | | | | |

| | | | | | | | | | | | | | |
|------------------|---|--|--|--|--|--|--|--|--|--|--|--|--|
| Major Challenges | MC1: Developing digital twins, simulation models for the evaluation of industrial assets at all factory levels and over system or product life-cycles | | | | | | | | | | | | |
| | MC2: Implementing AI and machine learning to detect anomalies or similarities and to optimise parameters | | | | | | | | | | | | |
| | MC3: Generalizing condition monitoring, to pre-damage warning online decision-making support | | | | | | | | | | | | |
| | MC4: Developing digital platforms, application development frameworks that integrate sensors and systems | | | | | | | | | | | | |
| Emerging Themes | Human centred manufacturing | | | | | | | | | | | | |
| | Sustainable manufacturing in a Circular Economy | | | | | | | | | | | | |
| | Multi-technology co-engineering enabled by digitalization | | | | | | | | | | | | |
| | AI enabled cognitive, resilient, adaptable manufacturing; socio-technical system (extension of MC2) | | | | | | | | | | | | |
| | Modelling and Simulation (Digital twin and wider context, extension of MC1) | | | | | | | | | | | | |

Figure 22: Matrix of Industry 4.E Lighthouse Projects and their relation to major challenges as well as emerging themes and innovation accelerators (green – main focus; yellow - tackled but no main focus of the project; white – not tackled)

13 Annex: Report of the Roadmapping workshop



CSA-Industry4.E

Grant agreement No 830845 – ECSEL-2018-3-CSA-Industry4E

Coordination & Support action for Lighthouse Initiative Industry4.E

Report with results of the Workshop: “Shaping the Future Roadmap in Digital Industry”

July 2020

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1 Introduction

This report presents the comments and feedback received in the Workshop: “Shaping the Future Roadmap in Digital Industry”, facilitated by the CSA Industry 4.E. This interactive workshop’s goal was to discuss the recommendations on the future of the Industrial digitalisation roadmap and shape next ECSEL/KDT research agenda.

This online workshop was held on the 25th of June 2020 (10:00-12:00 CEST), as a co-host event of ECSEL JU Symposium. This is the agenda of the workshop:

10:00-10:25 - Introduction and presentation of work done in CSA-Industry 4.E regarding roadmapping and the recommendations drawn. Speaker: Leire Etxeberria

10:25-11:25 - Break out sessions to discuss recommendations around specific topics:

- Key Digital Technologies for Green Deal. 20 minutes
- Artificial Intelligence in Digital Industry. 20 minutes
- Resilience in crisis time (COVID-19, etc.). 20 minutes

11:25-11:45 - Presentation of Digital Industry Chapter of Strategic Research Agenda (SRA) 2020. Speaker: Olli Venta

11:45-12:00 - Wrap up and conclusions.

This document summarizes the comments and feedback of the discussions carried out in the break out sessions. As well as the feedback obtained with the questions of Mentimeter tool; questions connected to the presentations and sessions of the workshop. The gathered comments and feedback will be used as input to finalize “D1.3 Report with recommendations on the future of the Industrial digitalisation roadmap” of the CSA-Industry 4.E project.

2 Notes from Breakout sessions

2.1 Groups and participants

Participants have been assigned to 7 different breakout groups to discuss the topics:

| | |
|---------------------|---|
| | Group 1 |
| Moderator | Andrew Lynch - IMR |
| Participants | Gianfranco Caminale - Leonardo Lukasz Kulas - GUT Mark Southern - UL Nour Ramzy - Infineon Octaviana Marincas –Research Gov Romania |

| | |
|---------------------|---|
| | Group 2 |
| Moderator | Carlos García - IMR |
| Participants | Jesus Carbajosa - CIMNE Karpas Ozols - EDI Michal Kasperek - IMA Silia Maksuti – Forschung-Burgenland Valeriya Kilchystka - UCLOUVAIN |

| | |
|---------------------|--|
| | Group 3 |
| Moderator | Felix Larrinaga - Mondragon Unibertsitatea |
| Participants | Adriana Saraceni - IMR Berta Ferrer - ECSEL Catherine Le Guet – Pfeiffer Vacuum Enrica Bosani - Whirlpool Javad Ghofrani – HTW - Dresden |

| | |
|--|----------------|
| | Group 4 |
|--|----------------|

| | |
|---------------------|--|
| Moderator | Lise-Ann Sheahan - IMR |
| Participants | Mark van Helvoort – Philips Ilona Jankowska - TU/e Hermann Felbinger- AVL Austria Thomas Söderqvist– AB Volvo |

| | |
|---------------------|---|
| | Group 5 |
| Moderator | Matias Vierimaa –VTT |
| Participants | Geza Kulcsar - Incquerylabs John Cosgrove - LIT Maria Callupe - POLIMI Martin Pleschberger – K-AI Mohammad Mahdi - POLIMI Olli Venta - VTT |

| | |
|---------------------|--|
| | Group 6 |
| Moderator | Miren Illarramendi - Mondragon Unibertsitatea |
| Participants | Dory Estrada - Steinbeis Martin Schellenberger – IISB Fraunhofer Silvia Razzetti - POLIMI Wasif Afzal – MDH, Sweden |

| | |
|---------------------|---|
| | Group 7 |
| Moderator | Philip Long - IMR |
| Participants | Alessandro Federici - POLIMI Giacomo Biscardo - POLIMI Haydn Thompson - THHINK Marco Ratusny - Infineon Silvia Castellvi - IDSA |

2.2 Notes of the session about Sustainability, Green Deal

Group 1:

- Going Digital. How there is a major face shift away from old ideas. And where before all of us we would be sitting in Brussels, we can now do this very efficiently online. This pandemic gave us a quite unique opportunity to try new things that could improve sustainability
 - Once we know each other, actually from some points of view it is better and more efficient to meet virtually.
 - An example with lectures, when moving lectures to digital world
 - Huge participation. Much better contact, because they were putting messages in a chat line. Students feeling more confident doing that than raising the hand in the auditorium
 - We should move to the digital world what it can be moved
 - Human contact is important. Find trade-off between digitalization and dealing with people physically.
 - If we would have meet in Brussels for this workshop (instead of being online), we had travelled by plane to meet for 2 hours, producing a huge amount of CO²
 - People has started to observe that they can be more efficient working remotely.
- Digital support for Circular economy:
 - Digital twins for lifecycle management
- Reparable product. We all buy stuff and we hate to throw them to the trash bin. Because I cannot fixed it, I cannot find spare parts or it is cheaper to buy a new one than fixing it.
 - Some part of the legislation should be focused on providing advantages to those that produces things that last more than 6 months or two years.
 - European companies can provide these kind of products
 - Example of a Coffee machine produced in Europe, 13 years old. It is repairable but to by a Chinese machine could be cheaper than repairing. It should be a tax in the products that cannot be repaired.
- Recycle parts. Sometimes it is difficult to separate the different materials of a product in order to recycle correctly. Example: A bottle of wine made by crystal but with paper label and metallic part, it is difficult to remove the paper and to cut the metallic part.
 - Push to make things (recycling) easy → As producer, include changes in your production line
 - Receive some relief from European Union because you produce something easily recyclable
- Bleeding to resilience as a conversation. All of these topics are bleeding to another someway, because there are underpinning strategies and approaches.

Group 2:

- How to bridge the gap in digitisation for SMEs? Only 17% of SMEs in Europe are digitised, it makes difficult to achieve sustainability
- SME feedback is that they are too busy to really look at sustainability
- Need more work on:

- materials reuse and recycling
- Blockchain and smart metering
- Need to consider the whole supply chain, starting from raw materials
- ECS should focus on the automation side. With more automation energy will play a lead role.
- Focus on recycling above avoiding waste.

Group 3:

- Importance of improving the using of resources to reduce waste in the production
- Importance of recycling the material
- Energy monitoring and control in relation not only to the production process but the actual the whole company, the whole factory, including buildings and different elements like in the smart factory
- Try to explore the advantages that digitalization can bring to the primary sector: agriculture, mining, fisheries, etc.
- Importance of improving the efficiency of renewables in general

Group 4:

- Sustainability receiving more prioritisation internally due to pressure on the industry partners as they compete for the natural resources for their production. Material scarcity is a major risk to the business, scarcity is driving innovation and climate action internally. CE by design.
- All parties need to look beyond investment in current battery technology (precious minerals, dirty processes) and look to new solution to power the sensorisation of everything included in the production system. Production lines powered by clean, local, and distributed energy.

Group 5:

- Group discussed about resource efficiency, with all the technological development we may end up to situation where we run out of resources, such as energy or materials, for example. Global cloud vs. Local efficiency.
- In IoT for example, we have lots of devices, lots of expectations but we will also have constrains. Easiest solution is not always most efficient in terms of ecology and sustainability.
- Thus, we should consider not always "doing everything" and "doing it most effectively" but instead rise in engineering and skills how to do things most sustainable way.
- Open software relevance, software reuse for saving resources
- In general however, we should focus more on making KDT to save resources via itself such as reducing accidents, material consumption etc.

Group 6:

- The topic is not our core competence.
- We know that Europe aims to grow economy and at the same type the solutions have to be Green. Anyway, for example to be able to develop an electric car does not mean that it is a Green solution automatically. Are we sure that its batteries are using green

technology? Or the energy we use to charge the battery, are we sure that it comes from green sources. We think that all these topics need to be analysed with more detail and identify which is the current status and identify what things are really green and think about how can we convert the others in green (or if it is necessary or it is good for our economy, society....)

- Circular economy:
 - MDH is a sustainable university because it follows the "Global sustainability Goals". One way to improve efficiency could be to reuse research done by others and not waste money and time doing research in the same topic.
 - Design of recycling: Other topic to consider. When we are designing a device, it would be nice to consider the way that we can reuse it once its first use is finished. There are some industries that we can take as example: semiconductor. They are producing very few waste.
 - Software and Architecture Efficiency: Some decades ago, when we did not have a lot of processor resources, the way we were programming was much more efficient because we needed to in this way because of the processing limitations. Nowadays, we do not have these limitations and therefore, our way to programming is not so good. It would be nice to consider this topic and try to program in more efficient way. For example, it would be nice to identify the relation between the energy efficiency, development effort and the way we program. Thus, we will be able to define which are the good practices of programming if we want to be more efficient.

Group 7:

- Move to Servitisation to track products throughout their life. This gives data to allow use to analyse the carbon footprint and for instance doing the same as farm to fork. We can analyse lost energy, the example of open fridge doors in supermarket which wastes enough energy every year across Europe to power Poland. The other idea is to use data to track scrap and waste product to supply other chains autonomously.
- The second use of data within the green deal framework is to forecast product needs and consumer habits in the future in order to optimize industry and predict customer demand rather than simply reacting in a very ad-hoc way. To achieve this a centralized agency was proposed but immediately issues with privacy and trust come to the fore. For instance, a participant raised the example of wine growers in Bordeaux who are reluctant to share data as it represents a competitive advantage.
- Other topics which were suggested are the huge potential for retrofitting buildings to achieve savings.
- Lastly the topic of power consumption of AI was raised. The participants agreed that AI currently uses a lot of energy but with the advent of GPUs, this will pay off in the future. Likewise a participant believes the idea of edge computing can have a positive effect on green production. For instance the example was given of factory lights been controlled by computer which first send the commands to a server located in a third country. This type of digital travel has a large negative effect and can be eliminated by edge computing.
- The main point was data is required for tracing and tracking however real question remain concerning trust and privacy settings and who manages and/or has access to the data.

Other inputs:

- Eco-design (waiting for new directive of EC)
- Refurbishment, remanufacturing, retrofitting of machine tools
 - Digital upgrade of machines: add sensors, connectivity to machine tools.
- Related to servitisation: New business models: overall efficiency, sell machine plus service during the useful life of the machine, digital upgrade, etc.

2.3 Notes of the session about AI

Group 1:

- Data
 - Digitalization requires a lot of data to be collected, this data must be correct to implement this digitalization
 - Digital must reflect the reality to be trusted, accuracy and the feel should be there for the person making the decision.
 - Data integration
 - Importance of Data quality, how fast you are collecting the data, how real and correct it is.
 - There are already some new technologies (semantic web) that support this very well but still are not popular enough to be actually implemented and scalable.
- Explainable AI to be able to trace back the results of your algorithm, go back to understand why it is behaving this way, so you can trust. Pick the results as trustable source of information and base your work upon them
- Importance of education and skills for most of citizens, not only an elite
- Importance of social trust: make sure that projects communicate and look for the social acceptance.
- Focus on Dependability, reusability, testability, etc. Not just for production processes but for the outcome of production processes like cars for example. We had well known example of Tesla against Audi for example.
 - “The Tesla car is commercially promoted as autonomous but in fact it is not dependable. Recently a person died because of it. Because AI was used to train data from cameras. So Tesla drove by AI, the driver was distracted because he was sure that this car is dependable and on the road there was a white band that was splitted on the side and tesla hit it full speed without braking.” “The only autonomous car is a German car: Audi. You can leave the driving wheel and it will drive in traffic jumps.”
 - Have clear differentiators. If Europe want to apply AI to every life matters, we should promote AI developed in such a way that is dependable, we understand how it works and it can be tested, so we can prove. And also we should test upgrades; AI is a living organism.
- Responsibility, accountability of problems if something happens (with a car)
 - Manufacturer, software designers, others...
- If you crash your car, the car is full of sensors. How to make sure that the car is repaired properly.

- AI can filter some problems, but Human must be the decision taker.
- Consider human aspects of AI, not only technological aspects
- AI applied to quality of products, understand the patterns to anticipate problems in the products
- Privacy in AI

Group 2:

- SMEs do not understand the real-life applications of AI. They have questions around AI
- AI is needed for more resilience and flexibility
- A bottom-up approach is needed to develop AI applications that are applied to real problems. AI needs to be defined from companies challenges
- ECCS should focus on safety-critical applications and explainable AI: make sure AI is trusted.
- KDT should develop flexible AI framework architectures for SMEs
- Develop specific, cheap AI chips to implement AI. Use the edge, and less cloud to minimise energy waste.

Group 3:

- Importance of collaboration between human and machine. And the complexity that brings to the production
- Possibilities of new businesses in relation to Artificial Intelligence since it is not one size fit all. Importance of having companies that do the consulting, analysis, design, development of solutions and the implementation of those solutions, so they can bring the possibilities of new businesses.
- Importance of trust, security, safety and responsibility. If we delegate in machines the decision making, those concerns are important
- Two different approaches or lines of work and research: One is Software developers and the other one is the AI or data analysts. Sometimes there is a gap between those two worlds, the importance of collaboration between those two lines of work.
- Importance of Data handling, storage, interoperability, considering that we are collecting large amounts of data. In order to provide that data to specific stakeholders, it is important to somehow provide metadata for that information, so it can be used according to the specific solution.

Group 4:

- Past investments in AI and predictive maintenance has help the industry partners to continue to perform well remotely during the COVID-19 crisis where products and sites where closed off.
- Providing these successful use cases to industry one what has performed well during the COVID-19 crisis may aid faster adoption of KDT.
- Ethical issues, societal perception/rejection, negative policy and political influence has the potential to disrupt further advancements with AI and its adoption. Security and trust cannot be broken or the technology and its potential to support the rapid advances needed for EU Industry could be halted.

- Digital Twin and simulation has greatly aided the development of AI solutions for EU Industry for the parties in this session.

Group 5:

- You can develop AI without being google or facebook.
- AI is much more than just large AI systems. It's also machine learning, industrial system has to be made smart, comprehending linguistic data, understanding what you are doing jointly. Pan-european CSA for improving natural linguistics in European area. Natural language processing (NLP) is important, there are several languages in EU, languages are different, and there is need for increasing understanding.
- Semiformal documentation, recognizing format description, no human to see them side by side
- Complex decision making processes are important, making human-computer collaboration learning factories, finding right balance between human robot collaboration. We are also moving towards factories that role of human is becoming smaller i.e. reduced jobs.
- As AI problems are specific, better to put effort to SME and medium size companies

Group 6:

- Research in identifying different methodologies for normal and AI software development. AI requires other steps, other methods. Identify them clearly.
- Application of Autonomy and Intelligence in Edge Devices: HPC will be used in the Cloud but why not to develop some AI algorithms to be use at the Edge Level? Based on previously trained algorithms, at Edge level we need to be able to retrain the models and be able to identify and decide what is happening at runtime at Edge level.
- This solutions, need to be Dependable. For that, we need to develop "Explainable AI". We need to understand what is going on in this artificial brains.
- Safety in AI? We allow to perform mistakes to the humans. Maybe we have to allow some mistakes to these artificial brains.
- Academic/Students: Nowadays, future engineers are very well trained in using AI techniques such as Deep Learning. But, we think that they also need to have more skills about mathematics and statistics. We believe that this knowledge will help on understanding how different algorithms work.
- Natural Language Processing: Nowadays, industry is still using natural language to define requirements. In order to automatize the design and development process, it would be nice to develop Natural Language Processing techniques based on AI.

Group 7:

- The idea of digital twin and digital shop floors was raised for optimizing the process. However, the issues raised are the difference between university data openness and industry data namely how a lot of these models are constructed for a university type framework. The data is available but all participants agree that a huge task is pre-processing

which is a tedious process. The other idea is to use standardized processes databases or digital type dictionaries, however this process is seen as challenging.

- Another participant said that while the EU is strongly supporting AI, the challenges are very large mainly concerning the access to data but also the availability of people who have the skills to use this data. AI can have a major effect in automation and the selection of automation paradigms but also there needs to be studies the AI within the product itself and what is it doing.
- There is perhaps a fear that AI and data are not always beneficial i.e., not helping the manufacturer but also can be harmful. For instance, an example was given of the data collected by a farmer and the data which was then used to prosecute the farmer for certain infringements. A second harmful activity is ransomware where the data is seized by third parties and can completely block production in a large car manufacturer. Thus security is crucial but these cases can retard the adoption of AI.
- To encourage the use of AI, SMEs need to be shown success stories and business models about how it can help. Secondly, business models need to be show how AI companies can make money for the implementation.
- Standardization is increasingly important to use AI, this includes perhaps using cloud infrastructure and data-spaces for the eco-system. This eco-system should not necessarily only include likeminded manufacturers but a whole eco-system. A concern was raised about security and trust once again here and how data can be shared. There is fear around sharing AI and data.
- A last point focused on the explainability of AI models which would increase trust

Other inputs:

- Data gathering, analysis, cloud monitoring...
- Improve process/product
- Predictive maintenance

2.4 Notes of the session about Resilience

Group 1:

- Need and urgency. No matter how well we planned or try to organize ourselves, sometimes nature surprise us with stuff we have not seen coming.
 - To move to more digitalization as fast as possible, keeping in mind two aspects: sustainability and social aspect of what we are doing now.
 - How digitalization has affected and will affect our cognitive skills, our human social skills in the next 20 years?
- The Covid crisis shown us that we have to rebuild the value chains and the links, involve more small enterprises from EC, to prepare them to be adapted. And we should build this flexibility in organizations' behaviour: innovation in social behaviour but also in the organizations, in industry... We need to reconsider what means to have the green deal in mind, to have the society and safety in mind. In fact, the agility and flexibility is necessary for the decision making process for the normal life. People have to build now this flexibility and

they have to be aware of how the world is changing and that we need to build some new relations, new type of relations.

- At EU level, we should rethink value chains and cooperation. Part of the innovation and results of our research projects have a big involvement here. We should screen what are the results and to think what we are able to put in place as soon as possible. Because with so much money during the years put in research, we are little bit fuzzy because we work a lot but we do not know yet how much of these results are really taken by the industry, making money from them, using it in the society for the people... Because if we put a lot of money for transition in the new industry, in fact, we do it for the people.
- Connectivity, 5G
 - We are very happy to build roads, rails... because we need people to go from A to B. Now, in the digital world, it is important to build a 5G, wireless technology to ensure that the ideas and the information could transit the European Ecosystem with this. We should invest in Digital Technologies, so for example, to have really good bandwidth everywhere in Europe, so it does not matter where you are, you still can participate as much as you can. And also with 5G, wireless technologies that should be dependable, should be ubiquitous (in every place); and also in factories it should be dependable, then you can have for example a robot with a camera that you can manipulate using your glasses in the future. Communication and wireless communication should be a new infrastructure for Europe. We can meet now, there are means available. So, this is improving, it should be based on infrastructure that can provide many different applications.
 - For example, connectivity among vehicles is one of the keys to provide safety on the roads. This is basic infrastructure, digital infrastructure in a safer level in several works is a key, to make new concepts you can work in the enterprise but you can also go on your vacations and inspect something remotely.

Group 2:

- Automation is the first step to deal with current day inefficiencies.
- Quick reconfiguration of robotic systems will lead to more resilient systems
- Attention to cybersecurity.
- A better communication strategy is needed so companies and population in general understand the problems and the possible solutions better.

Group 3:

- Not many solutions about resiliency, and they are very specific. More research and collaboration is required.
- It is not one size fit all. Its domain/scope/system/factory/whatever has different needs.
- Modelling and simulation considering digital twin, digital platforms. Being able to reproduce things that are not expected somehow and be able to react.
- Proving a recommendation support system that considering the context, changes in the context provide recommendations for humans to act. In prevision of what will come in the future as Decision making by machines. So it is the first step towards decision making by machines which is very futuristic at the moment.

Group 4:

- The COVID -19 crisis has rapidly accelerated the Digital Transformation of large swathes of society. This will be to the benefit of Industry and should be capitalised on.
- Trust and reliability of solutions must be maintained in order to sustain and increase Digital Transformation particularly with the SME where one costly mistake can close the business, large industry should be encouraged to experiment and share the results with SMEs to replicate and scale solutions that have been largely de-risked.
- There is a need to prepare alternatives to reduce risks associated with our reliance on items which could one day become proprietary e.g. internet services, tech giants...
- SMEs and citizens need to retain the right to their data and its use.

Group 5:

- We should put more effort to resilience, CoVid-19 was important wake-up call.
- Flexibility becomes important

Group 6:

- Resilience and Robustness are linked: both have the idea of what (a safe alternative) to do when something unexpected happens. How to react at runtime when something unknown happens?
- For resilience, we need to know previous experience results. For example for Predictive Maintenance, a good KDT is "Real Time Streaming Applications"

Group 7:

- Robustness of supply chains and manufacturing as a service
- Making the system more robust by trying to predict the future trends and thus
- Europe not too bad in terms of supply chain and reacted well the COVID, however there is a fear that crucial supply chains are vulnerable to take over from third parties. Data could be used to find vulnerable suppliers but companies are often reluctant to share this data. A specific example of China buying small failing companies in the aeronautical sector was given.
- One participant felt that lessons haven't been learned from the financial crises of 2008/2009, to predict the effects of the impending financial crises from COVID.
- Manufacturing as a service rather than linear chain supplier to manufacturing. So manufacturing can be offered in response to demand. The participants felt that the single linear supply chain was particularly vulnerable thus this could be really increase robustness.
- A value chain becomes much more robust if data sharing is crucial
- Resilience can be increased by exploiting the potential additive manufacturing. Small lot sizes quick adaptability and less components, so this crisis has really shown the benefit of this approach. Lead time of AM much better than classical techniques which increase agility.

Other inputs

- Flexibility, reconfiguration
 - Personalized tools
 - Robotics
 - Digital skills to program
- Value chain management
- In case of lockdowns or inability to travel (material, assembler, technician...), be able to adapt and meet the need: Remote control, teleservice... to set up a machine...

3 Annex: Results from Mentimeter

The annex presents the results from the Mentimeter tool.

Welcome to the "Shaping the Future Roadmap in Digital Industry" workshop

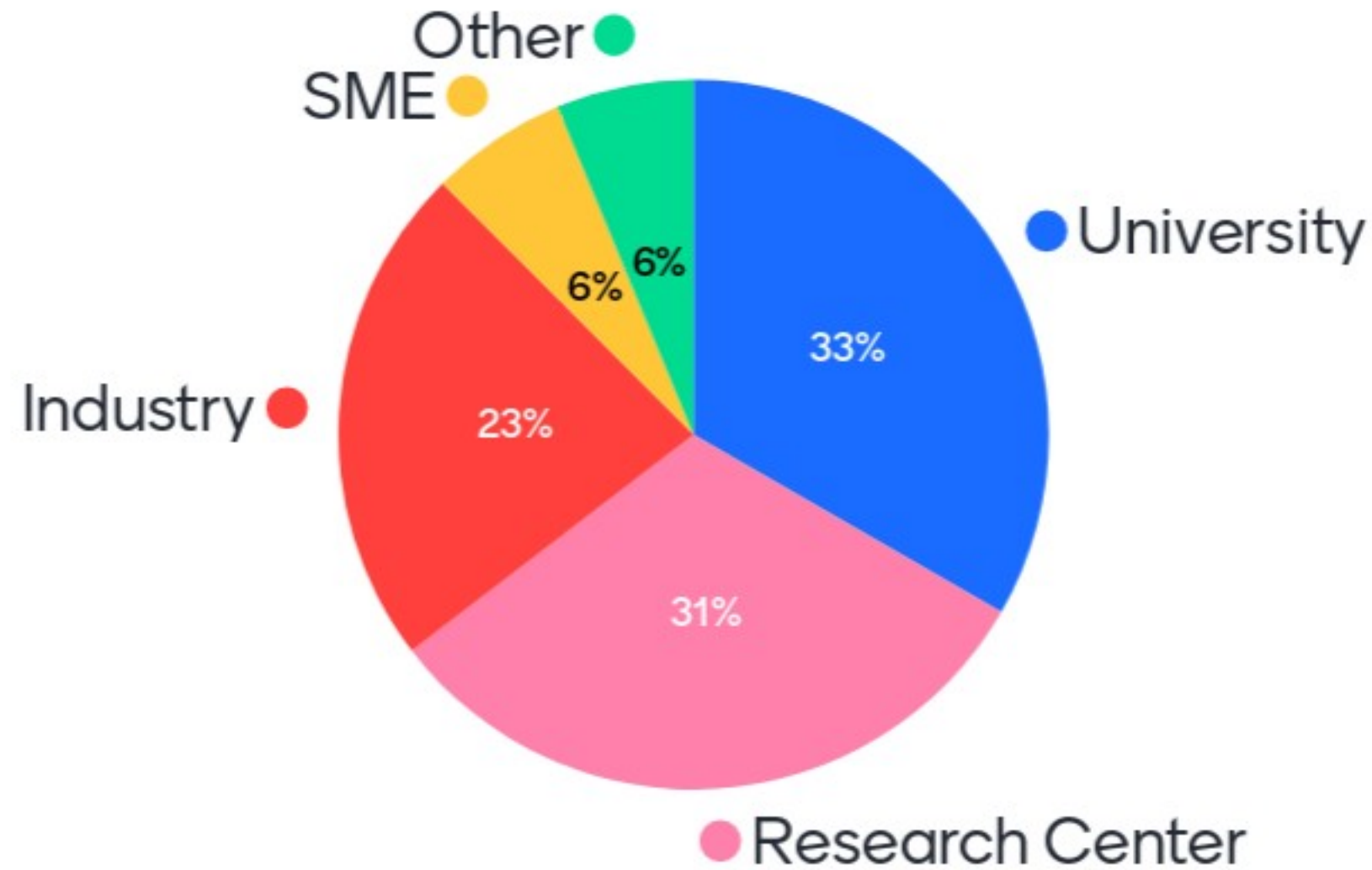
Your opinion and feedback is very important for us



What country are you from?



What type of organization do you represent?



Recommendations for Shaping the Future Roadmap in Digital Industry

We need your feedback about them!



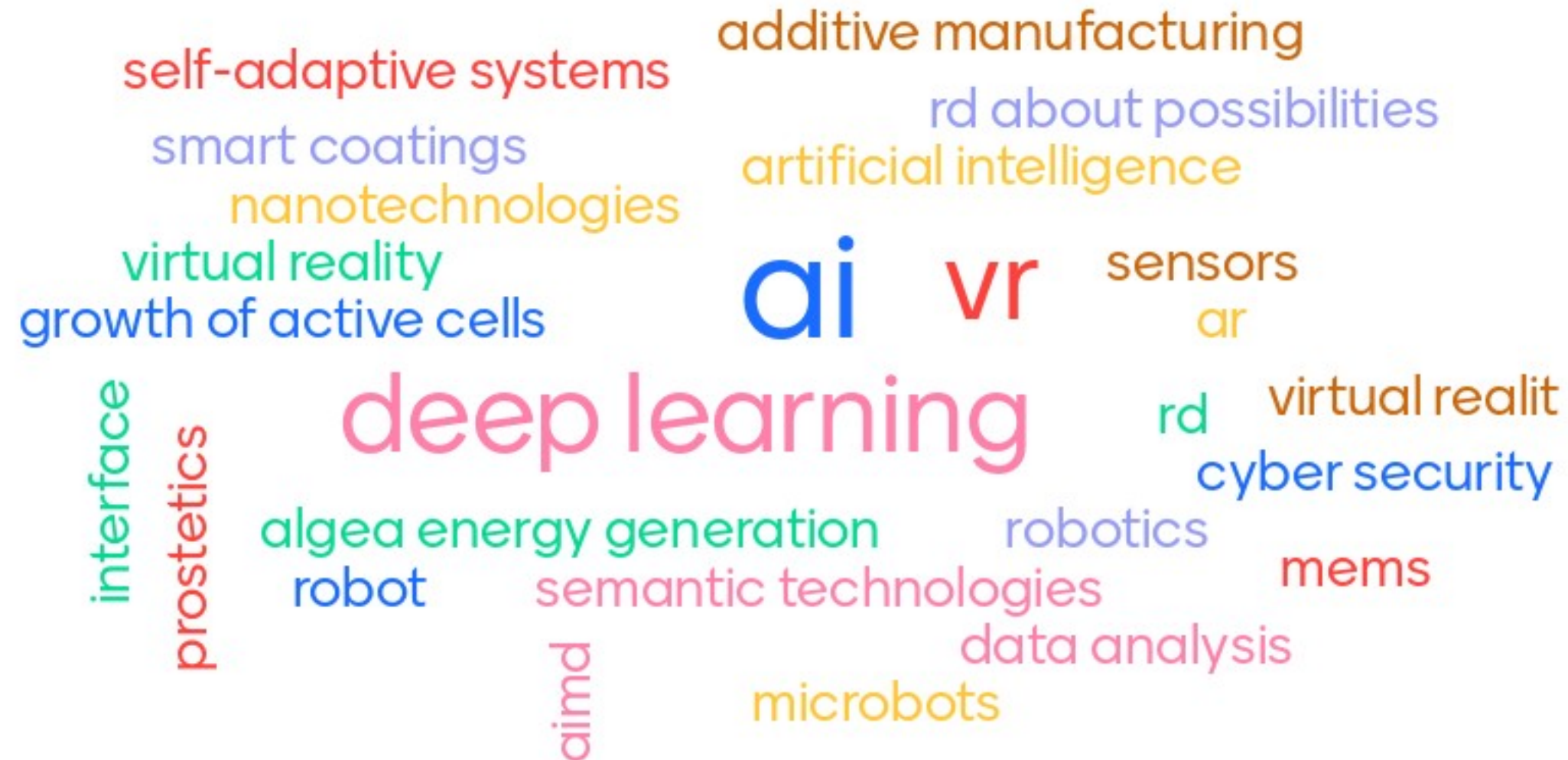
Do you think that the following topics should be addressed in ECS / KDT research for Digital Industry?



Which ones could be the relevant Key Digital Technologies for Nature and bio-inspired manufacturing?



Which ones could be the relevant Key Digital Technologies for Bionic manufacturing?



Which ones could be the relevant topics for servitisation?



Regarding technical topics, any other topic that you would like to add?

Quality assurance, verification and validation of cyber physical system of systems

real time dependable systems, runtime dependability

Interoperability

Resilience

Energy Management

dependability and reliability of wireless communication fir Industry 4.0

Circular Economy (Sustainability), Human-centric digitalization

Merging of AI and Digital Twin together to enhance the performance of them

Legal responsibility for AI decisions



Regarding technical topics, any other topic that you would like to add?

trade off between AI and human decision

Energy management

collaborative robotics

Exploiting natural language processing for a better comprehension of joint proposal, modeling and even implementation efforts.

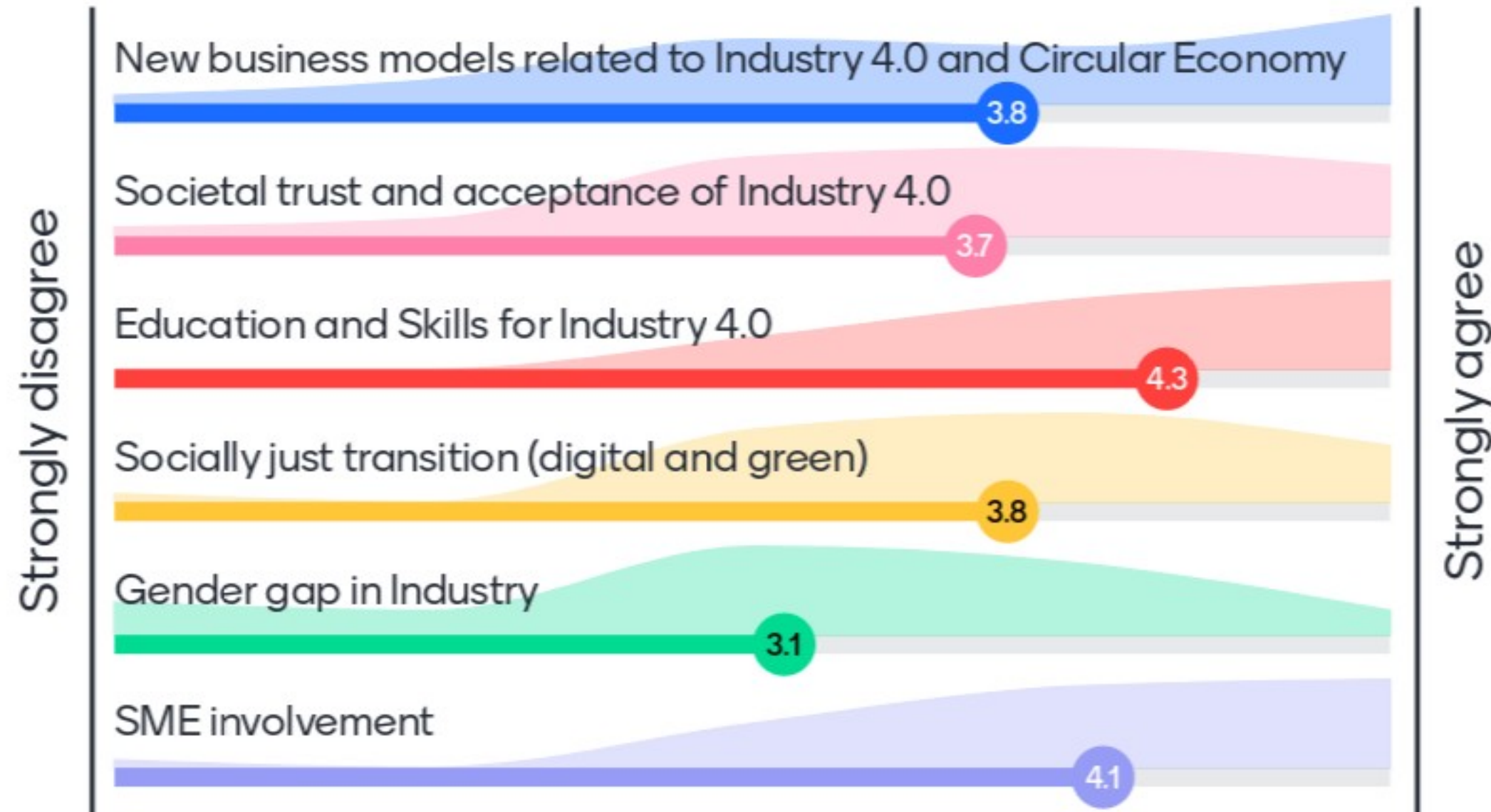
Sensors, Miniaturisation of solutions, highly integrated systems, Modular approach, VR, AI, Digital twins, predictive modeling

Human robot collaboration

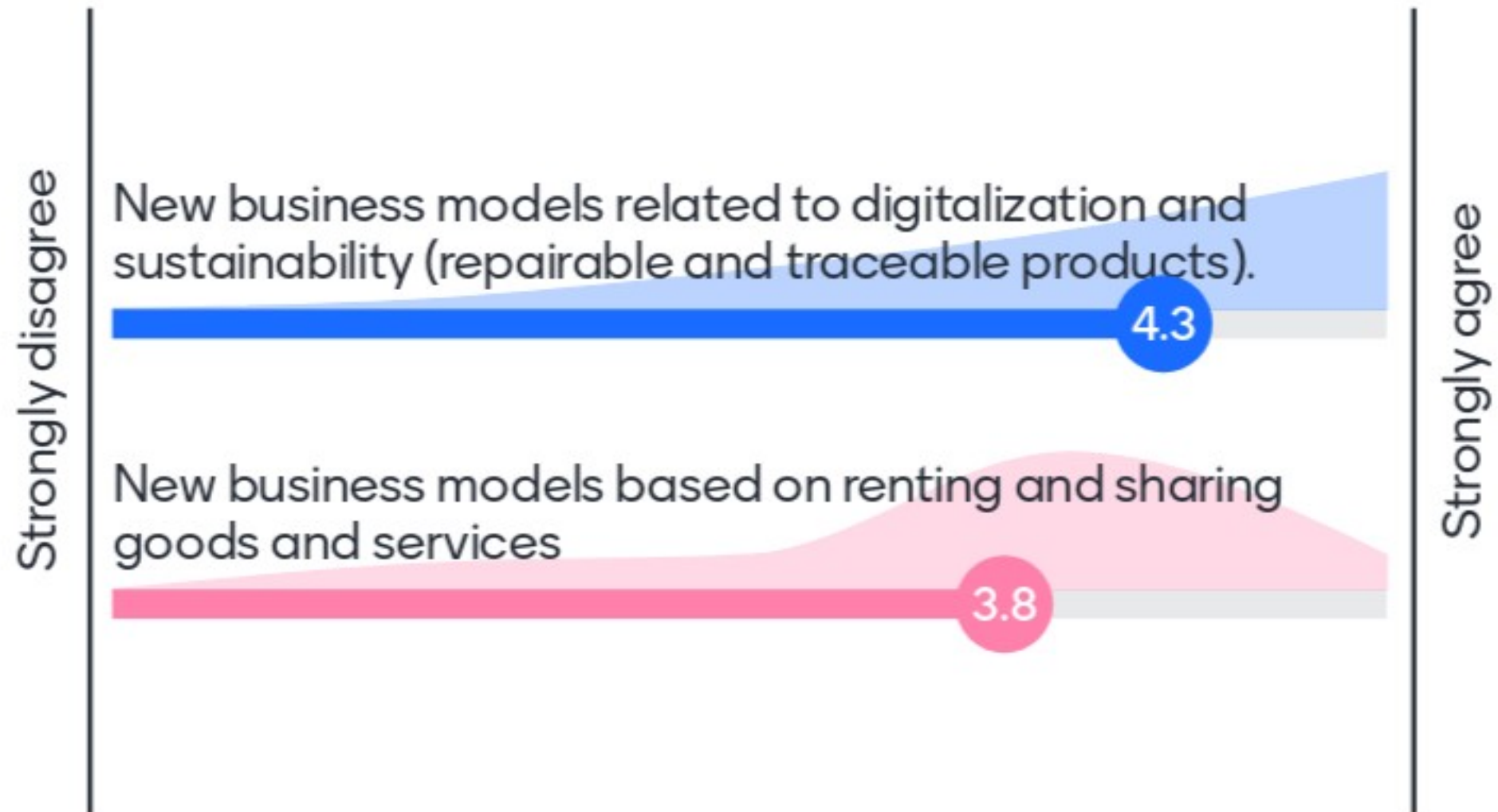
Explainable AI, Robotics, Embedded AI, low-power energy efficient AI chips.



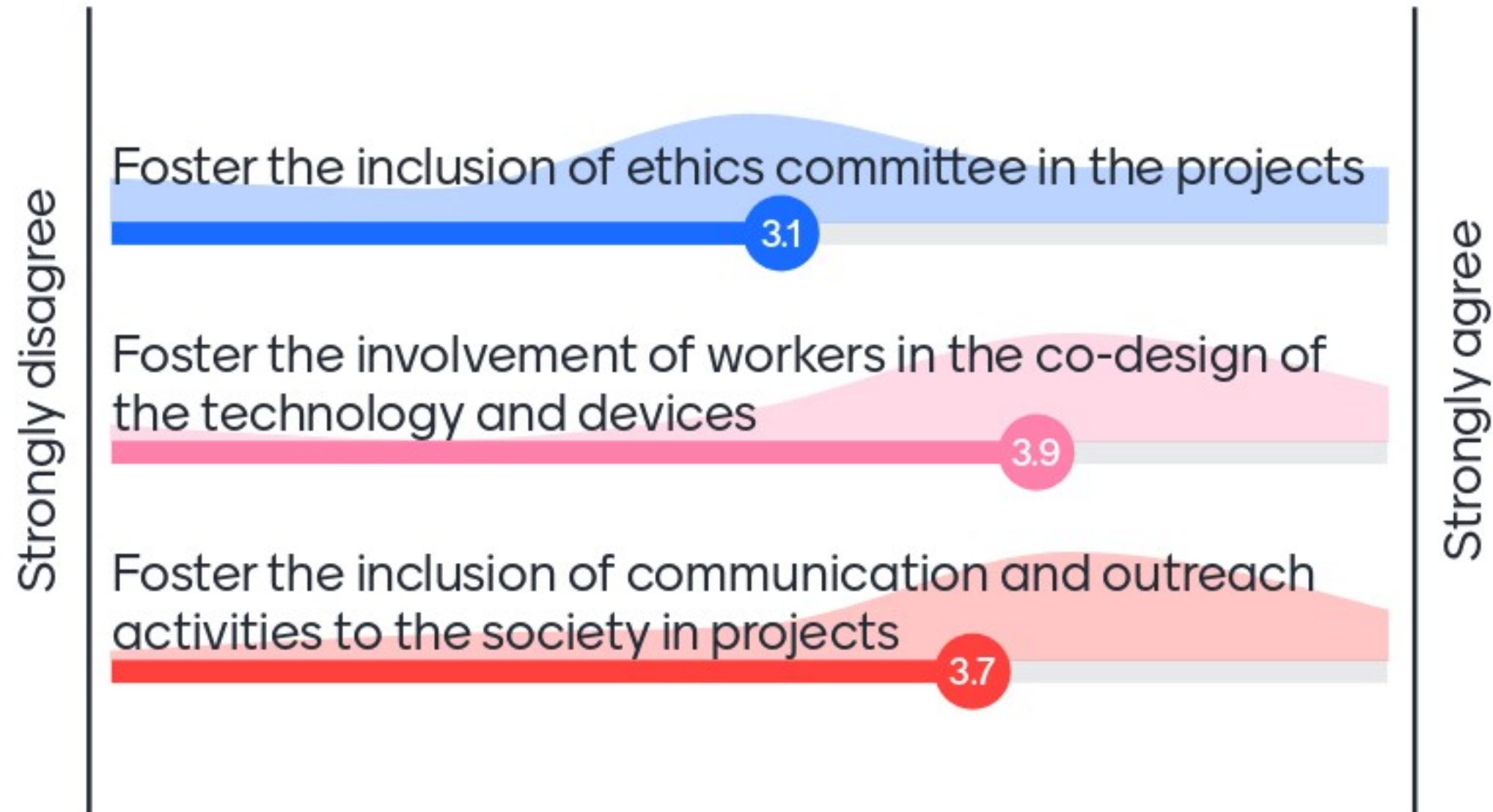
Do you think that the following non-technical topics should be addressed in ECS / KDT research for Digital Industry?



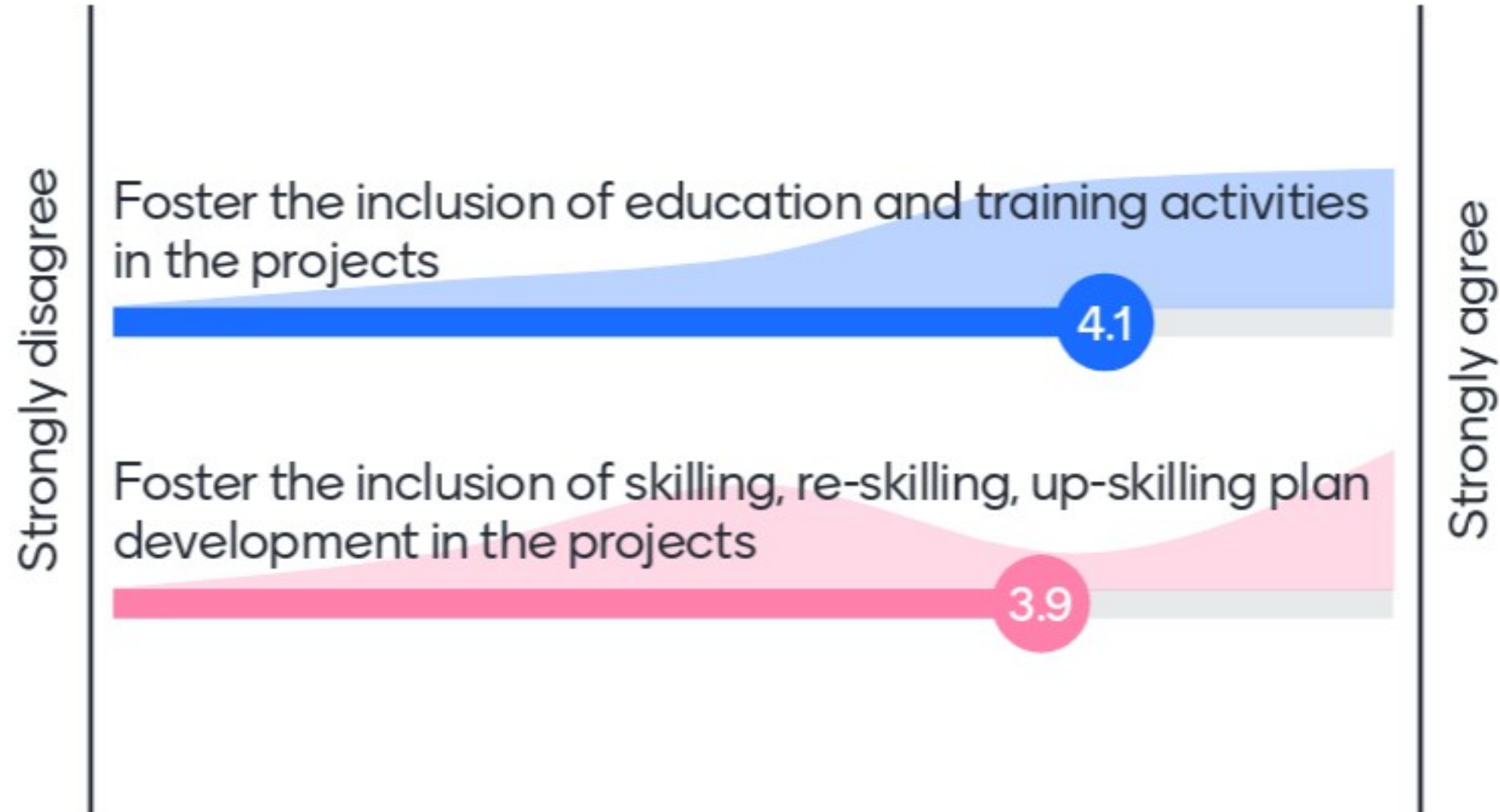
New business models related to Industry 4.0 and Circular Economy. Do you agree with the reinforcing of the development of



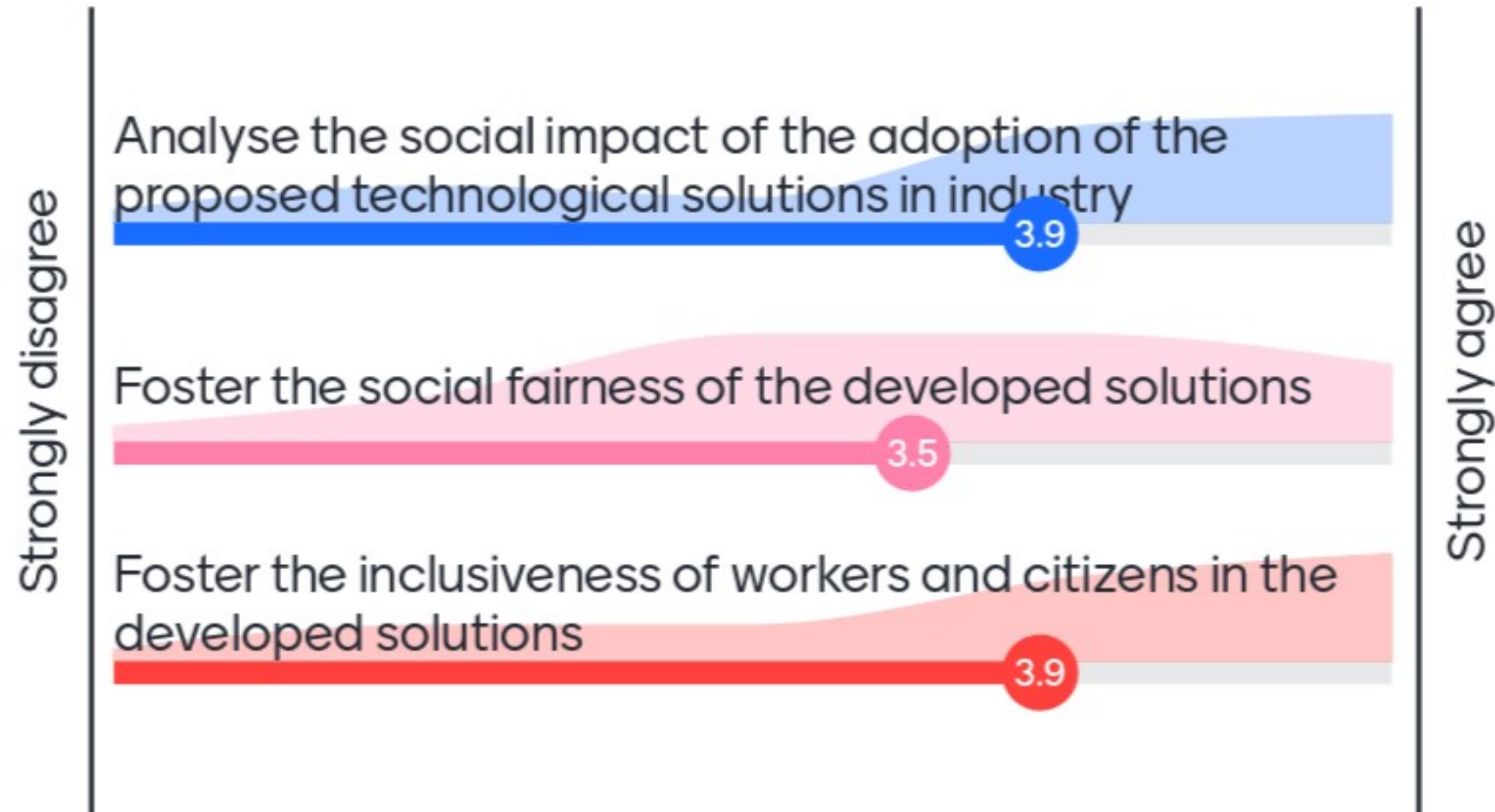
How to foster societal trust and acceptance of Industry 4.0?



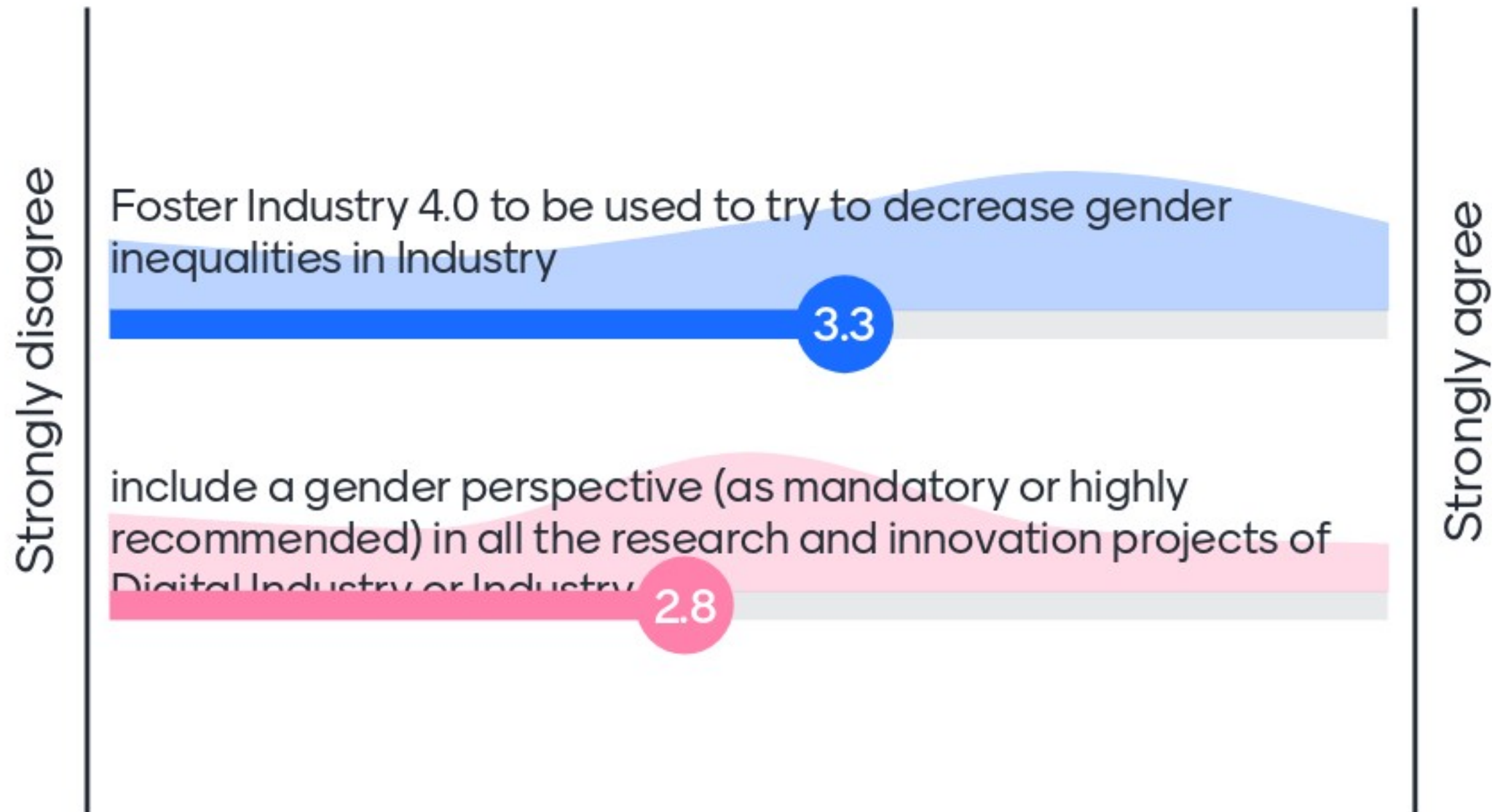
How to reinforce Education and Skills for Industry 4.0?



How to foster a socially just transition (digital and green)?



How to reduce gender gap in industry?



How to involve SMEs?



Regarding non-technical topics, any other topic or recommendation to mentioned topics that you would like to add?

None

none

None

Socialization of research: need to socialize the results and benefits of the research projects and their benefits.

Trustworthy systems - privacy and security

re-skilling of sales force to reinforce adoption of ndustry 4.0 solutions

-/-

physical human interactions are still important

To reinforce gender diversity, create a community to help female to grow.



Regarding non-technical topics, any other topic or recommendation to mentioned topics that you would like to add?

To reinforce gender diversity, create program for girls education

certified programmes of study / upskilling



Break-out sessions



In the Artificial Intelligence topic, any other challenges/topics in KDT research in Digital Industry to be addressed (not mentioned in your room)?

None

-/-

no

None

regulation and laws fitting to right level of safety for humans but enabling application in collaborative environment (social responsibility)

data quality issue

natural language processing for shared data comprehension

Challenges presented during decision making by human-robot collaboration

Data Quality



In the Artificial Intelligence topic, any other challenges/topics in KDT research in Digital Industry to be addressed (not mentioned in your room)?

Predictive modeling using feedback loops from maintenance data.

availability of suitable data



In the Sustainability/green deal topic, any other challenges/topics in KDT research in Digital Industry to be addressed (not mentioned in your room)?

None

-/-

no

trade off between repairability and substitution

About pandemic issue, Europe should consider, among partners, to be independent about strategic products and needs. Europe should act as a whole, not like a sum of countries

software reuse as a means of resource saving

Open resource Softwares

Reinforce industry to re-use parts from older product.
Circular economy by re-use.

lean metrics for energy efficiency



In the Resilience topic, any other challenges/topics in KDT research in Digital Industry to be addressed (not mentioned in your room)?

None

-/-

no

Diversification in terms of products/customers important

None

Over reliance on off-Europe suppliers

None

Agile way of working

Exchange of workforce between EU industries to enable knowledge transfer between companies



In the Resilience topic, any other challenges/topics in KDT research in Digital Industry to be addressed (not mentioned in your room)?

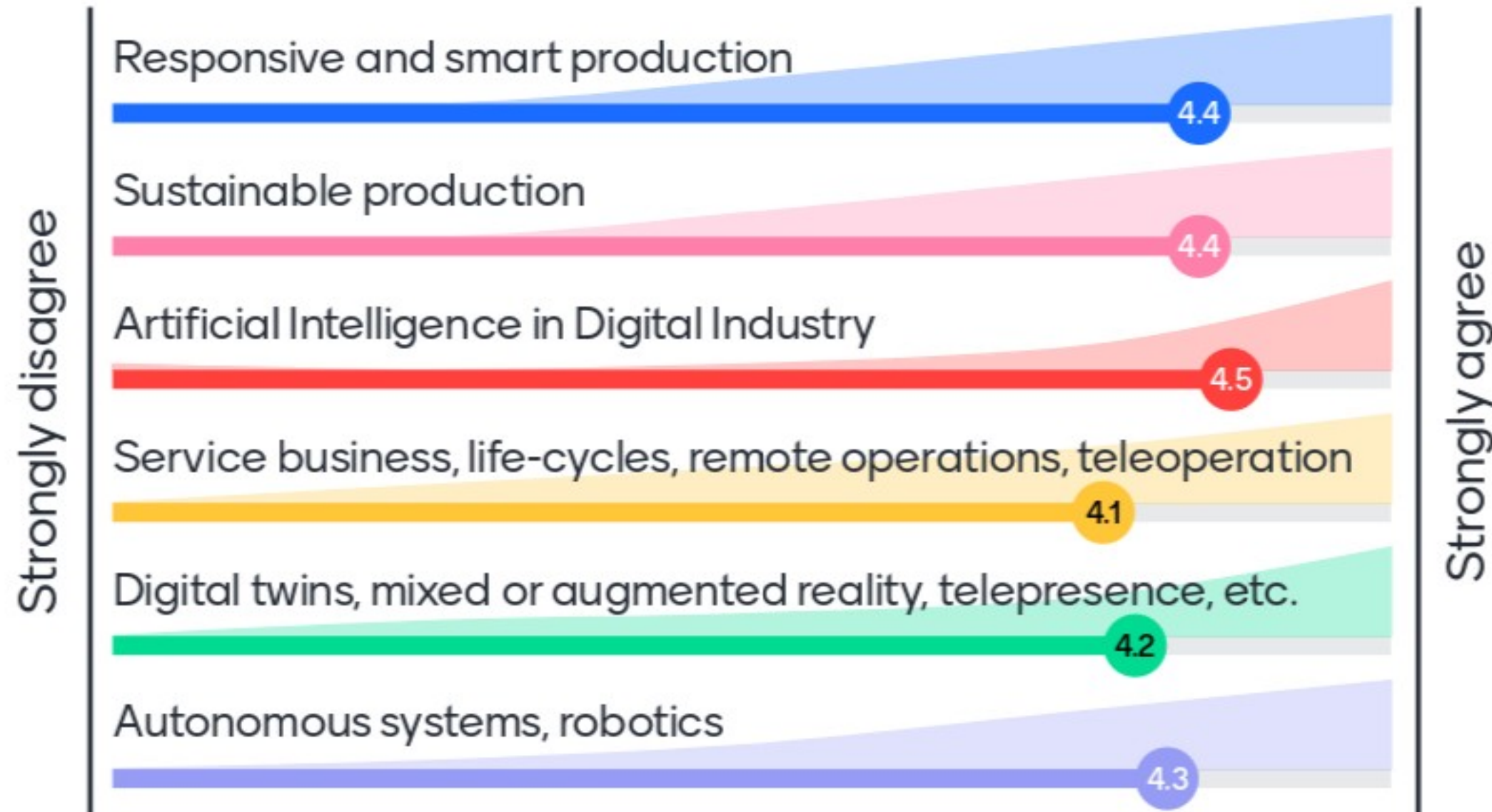
adaptability of automated systems

Strategic Research Agenda 2020

Digital Industry chapter



Do you agree with the following challenges for the Digital Industry Chapter of the SRA 2020?



In "challenge 1: Responsive and smart production", any comment or topic to be addressed?

| | | |
|--|--|---|
| None | no | Advanced analytics, prediction, monitoring, actions triggered |
| Additive manufacturing for combining components, reducing lead times | Additive manufacturing to reduce lead times | none |
| keeping the human in the center | reducing lead time by additive manufacturing | Link front-end and back-end to enable responsive and smart production. Front-end is a bit forgotten at the moment. Front-end (product design done by human) has to become faster. |

In "challenge 2: Sustainable production", any comment or topic to be addressed?

None

no

circular approaches, recycling, business models

Analyze sustainability and green concept taking into account different aspects and including all the phases and components of systems, also software development

Tracking of products

none

quality and care first

none

Energy efficiency leveraging on digital twins



In "challenge 2: Sustainable production", any comment or topic to be addressed?

Use of recycled material

Full automation of production. No human factory.



In "challenge 3: Artificial Intelligence in Digital Industry", any comment or topic to be addressed?

AI assisted quality assurance, verification and validation

no

Explainable, dependable AI/ML

next level of AI --> bring it to industry and apply

Safety of Artificial Intelligence

none

Finding the right balance in the assignment of tasks on human-robot collaborative production systems

linguistic comprehension for a nice collaborative environment

none



In "challenge 3: Artificial Intelligence in Digital Industry", any comment or topic to be addressed?

Connect back-end (servitization) and Front end (e.g. understand customer behavior, have self-learning digital twins in design phase)

AI with 99,999% accuracy

AI, which can be reconfigured for other similar tasks in really short time. AI framework.



In "challenge 4: Service business, life-cycles, remote operations, teleoperation" any comment or topic to be addressed?

Testing, verification and validation as a service

no

Service architectures, engineering procedures covering the entire life cycle

none

Test and varification as a service

consider the full end to end approach



In "Challenge 5: Digital twins, mixed or augmented reality, telepresence, etc." any comment or topic to be addressed?

Simulation based testing and validation of cyber physical system of systems

no

Modeling for digital twin, human-centricity

none

Digital twins as enablers of remote work, aiding in increasing resilience

rapid prtotyping, modeling

None

Digital twin and AI

multi-domain optimisation, new optimisation technics



In "Challenge 5: Digital twins, mixed or augmented reality, telepresence, etc." any comment or topic to be addressed?

Syntetic sata for AI training.

no



In "Challenge 6: Autonomous systems, robotics" any comment or topic to be addressed?

| | | |
|--|----------------------------------|--------------------------------|
| - | no | RPA, human-machine interaction |
| Safety related to autonomus systems. Interoperability. Real time. | Legal issue about responsibility | None |
| sensors | IoT | no |

Do you propose any new Challenge?

-

no

no

no

blockchain

No

european projects should address also the realization of systems TRL9

None

low-cost AI IoT chips (processing on site, not cloud)



Do you propose any new Challenge?

cyberphysical systems

no

product centric metrics of resource
consumption and carbon impacts, from
materials to use, reuse and recycling



To finish

Any other comment?

-

no

no

no

-/-

For some reason could not add things to last few questions

Thanks!

Very interesting workshop

all key topics and opportunities captured



Any other comment?

none

none

Thanks for very interesting workshop
and good organization!

Thank you.

no

