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FORGING

INDUSTRY-ACADEMIA FORUM
TO UNCOVER THE POTENTIAL OF
EMERGING ENABLING TECHNOLOGIES

Prioritizing responsible technologies: insights from FORGING Technology Clustering workshops

D2.3 Insights from clustering and prioritization of promising Emerging Enabling Technologies

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Deliverable abstract
This document provides the findings, insights and feedback gathered during the Technology Clustering workshop series held between November 2023 and March 2024 in the framework of FORGING task 2.5 "Collecting insights and feedback on responsible and sustainable technologies". The 6 technological frameworks of Industry 5.0 concept have been explored to define for each one a set of most promising technologies from a technical as well as an environmental and social point of view. The activity reported in this document is to consider preliminary to the co-creation events to be held in FORGING WP4.

Keywords
Technology clustering; responsible innovation; co-creation; sustainability; social responsibility; Emerging Technologies

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Executive Summary

This document reports the findings of the "Technology Clustering workshop" series aimed at co-creating a cluster of priority technologies in the Industry 5.0 framework. The prioritisation of technologies was based on technical, social and environmental considerations and was aimed at promoting those technologies that would have resulted as the most promising in these respects.

The series of workshops, one for each technological framework, adopted a co-creative approach based on the involvement of diverse stakeholders. Each workshop revolved around two main sessions:

1. During the first session, FORGING partners presented to participants the main results concerning the scouting of emerging technologies as well as the related social and environmental considerations. A reflection tool in the form of "Perspective cards" (outcome of T2.4) was also provided to participants for exploring sustainability and social responsibility aspects. Based on this, a set of criteria was co-defined for each technological framework;
2. In the second session, participants used the co-defined criteria to assess the initial set of technologies to determine which amongst these were the most promising from both an environmental and a social perspective.

The most promising technologies resulting from the workshop discussions are listed in Figure 1 below:

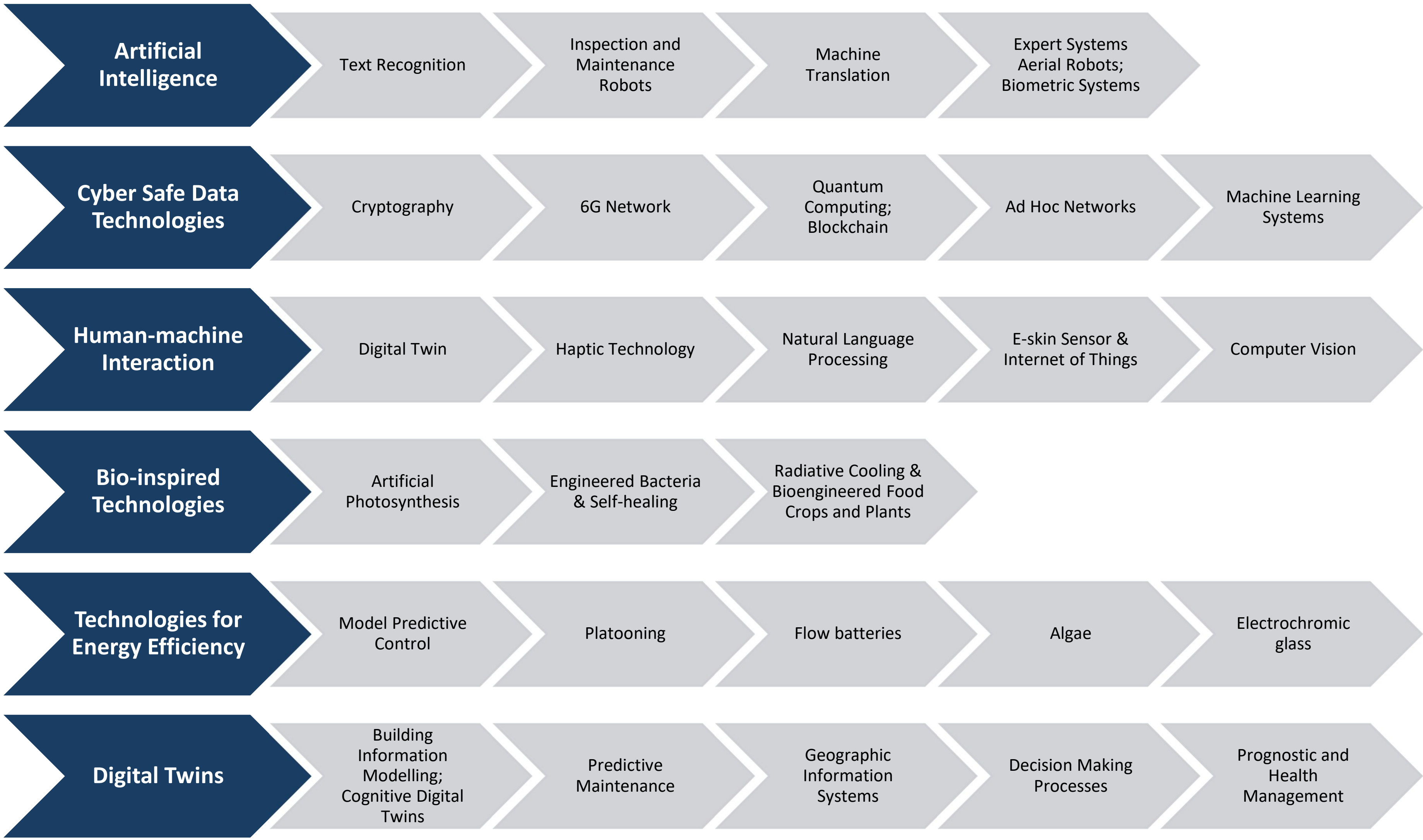


Figure 1 – Most promising technologies identified during the workshop series

1. Introduction

1.1 FORGING overview and context

FORGING is an initiative funded by the European Commission to assist the growth and manifestation of new technologies from their early stages, namely those envisaged in the Industry 5.0 concept[1]:

3. Artificial Intelligence;
4. Cyber safe data transmission, storage, and analysis technologies;
5. Human centric solutions and human-machine interaction;
6. Bio-inspired technologies and smart materials;
7. Technologies for energy efficiency and trustworthy autonomy;
1. Real time digital twins and simulations.

The Industry 5.0 approach reflects the need to better integrate social and environmental priorities into technological innovation and shift the focus from the development of individual technologies to a systemic and sociotechnical approach to technological development.

FORGING aims at providing a pioneer methodology to assist the growth and manifestation of emerging enabling technologies for Industry 5.0 and accelerate their uptake by industry and society.

The FORGING methodology is deployed in three main phases: uncovering technologies through the identification of emerging technologies with expected economic, societal and environmental effects; analysing future societal scenarios for the enabling technologies; and co-creating concrete use cases related to the uncovered technologies.
The results of this Deliverable 2.3, framed within FORGING WP2 "Explore emerging sciences and technologies", have to be considered within the "technology uncovering" phase.

FORGING consortium consists of 6 European partners: INL – International Iberian Nanotechnology Laboratory, GAC Group, STAM SRL, I2CAT – The Internet Research Centre, APRE – Agency for the Promotion of European Research, VTT – Technical Research Centre of Finland.

[1] Directorate-General for Research and Innovation (European Commission), Industry 5.0, Towards a sustainable, human-centric and resilient European industry, 2021, https://op.europa.eu/en/publication-detail/-/publication/468a892a-5097-11eb-b59f-01aa75ed71a1/.

1.2 Purpose of D2.3 and relation with FORGING WPs

Deliverable D2.3 aims to present the main results of Task 2.5 “Collecting insights and feedback on responsible and sustainable technologies”. T2.5 builds on the groundwork laid in WP2, particularly utilizing the analysis and frameworks established in T2.2, T2.3, and T2.4. The insights and feedback gathered during the workshops are essential for refining these frameworks and ensuring their relevance and effectiveness.

The final aim of the task is to co-produce a priority clustering of the technologies identified in FORGING previous analysis carried out under T2.2 “Values awareness and explorations” and T2.3 “Identification of promising opportunity areas”. Specifically, T2.5 aims to co-define evaluation/scoring criteria to prioritise potentially sustainable and responsible emerging technologies. Based on the prioritization criteria elaborated, feedback in relation to the technological portfolio and Strategic Matrix[2] produced in T2.1 and T2.3 have been collected.

The work reported in this deliverable is preliminary to the co-creation activities in WP4. By validating and prioritizing the technological portfolio through collaborative workshops, task T2.5 ensures that the subsequent co-creation activities in WP4 are aligned with stakeholder perspectives and priorities. The prioritised technologies identified as a result of T2.5 workshops will serve as basis to identify use-cases in T4.2.

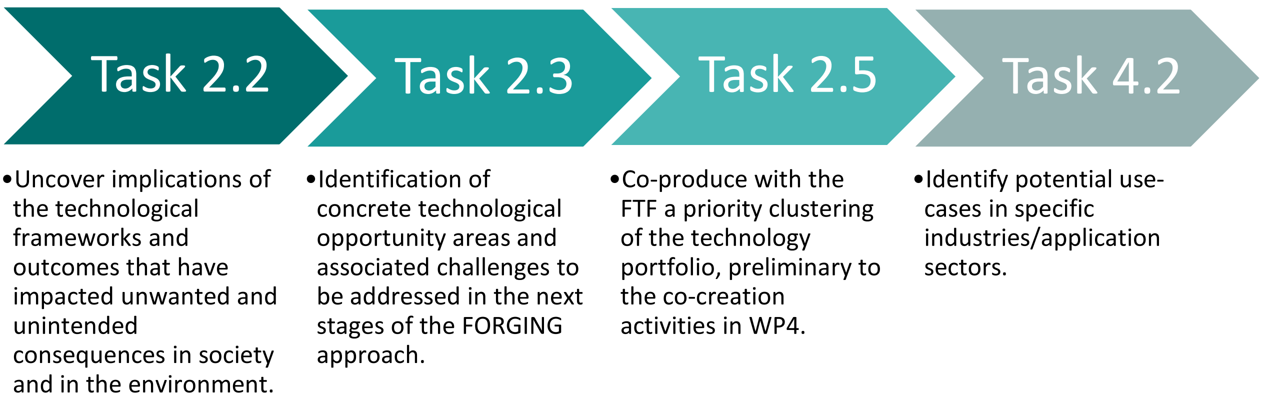


Figure 2 – Relation with FORGING WP2 and WP4

Overall, this task functions as a critical link between the analytical work conducted in WP2 and the co-creation efforts planned in WP4. It ensures that the project's technological portfolio is not

[2] The FORGING Strategic Matrix pairs together the technologies clusters with the potential applications areas. The findings of the technical scouting in terms of emerging technologies and their potential target areas are reported in D2.1 Strategic Matrix which is confidential.

only comprehensive, but also attuned to the feedback and insights of its stakeholders, thereby enhancing the overall coherence and impact of the project.

2. Methodological approach to Technology Clustering

Six co-creative validation workshops in online format, one for each Industry 5.0 technological framework, were organised between November 2023 and March 2024 to co-produce a priority clustering of the most promising technologies in terms of human-centred design, environmental sustainability and social responsibility.

To achieve this, a co-creation approach was adopted with each workshop focusing on two main activities: defining the criteria and evaluating the technologies.

Implemented through the Miro platform, the methodology was specifically designed to guide the stakeholders along a path that, starting from the results achieved in WP2 (i.e. considering the set of technologies that emerged from the analysis and the related environmental and social issues (T2.4)) led them to define the criteria against which to evaluate the presented technologies.

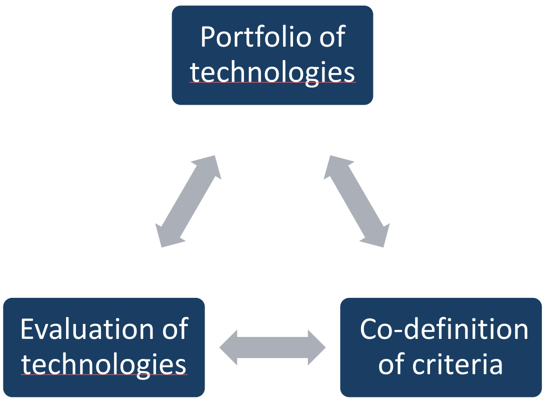


Figure 3 – Workshop logic flow

Throughout the six workshops, the methodology was refined to ensure active and seamless participation of experts.

The same methodology was implemented for the last three workshops, namely bio-inspired technology, energy efficiency, and digital twins. Besides, a voting system provided by Miro platform to select the most relevant criteria and the most promising technologies was included. Such approach facilitated easy clustering of the technologies proving to be highly effective.

Although the series of workshops achieved its final goal of outlining clusters of the most promising technologies from a technical, an environmental and a social point of view, some limitations are worth mentioning. First and foremost, the time limit related to the collective exercise of co-creation: the process of defining and discussing a range of technologies normally represents a long and complex exercise. Yet, the amount of time available for the workshops was limited in a relatively short time (three-and-a-half hours each[3]). Second, the online format of meetings: while having positive aspects such as being more sustainable and accessible, it also presented a complex challenge in terms of attention and involvement.

2.1 Workshop structure and organization

The workshop series was titled “Technology Clustering”. The events about Artificial Intelligence and Cyber safe data technologies served as “pilots” for the other four technology frameworks.

To minimize the carbon footprint and facilitate participation, considering that 24 face-to-face stakeholder gatherings are planned within the FORGING project across various locations, all the T2.5 workshops were conducted online via Microsoft Teams.

The calendar was structured as follows:

- 27.11.2023: Artificial Intelligence;
- 29.11.2023: Cyber safe data technologies;
- 16.02.2024: Human-centric solutions and human-machine interaction;
- 23.02.2024: Bio-inspired technologies and smart materials;
- 01.03.2024: Technologies for energy efficiency;
- 08.03.2024: Real time-based digital twins.

Each workshop, lasting three and a half hours, was structured around two main sessions:

1. In the first session, FORGING partners presented to the participants the main findings in terms of emerging technologies identified as well as social and environmental considerations. Participants were then provided with examples of criteria against which to evaluate a technology, distinguishing them into technical, social and environmental. To facilitate the identification of possible criteria, participants were provided with Perspective Cards (outcome of T2.4). These cards include perspectives that provide detailed prompts around key stakeholders, favouring the exploration of considerations about the societal and environmental impacts of technology.

[3] The duration of the workshops was estimated on the basis of the time needed to complete the steps of the collective activity and the need not to overload participants.

This approach aimed to ensure the selection of technologies that are not only technically efficient or feasible but also environmentally friendly and beneficial to society.

2. During the second session, the co-defined criteria were used to evaluate the set of technologies presented in the previous session to determine which were most promising from both environmental and social perspectives.

For reference, the agendas used in the first workshop (on Artificial Intelligence) and the last one (on Digital Twins) are reported below:

09:00 - 09:15	**Welcome and Introduction** (workshop's goals and agenda)
09:15 – 09:45	**FORGING results presentation** FORGING partners will show the portfolio of emerging AI technologies identified so far
09:45 – 10:00	Q&A session + Icebreaker
10:00 – 11:00	**Session I: Co-definition of scoring criteria** to select Emerging Technologies Participants will co-define scoring criteria to evaluate the technological portfolio, and then they will select a set of criteria
11:00 – 11:15	Coffee break
11:15 – 12:00	**Session II: Co-creation of the priority clustering** Based on the criteria selected, participants will evaluate the initial technological portfolio and create a priority cluster of the technologies
12:00 - 12:30	**Final discussion and conclusion**

09:00 – 09:30	**Welcome and Introduction** • FORGING context; • Workshop goals and agenda; • Icebreaker session
09:30 – 09:50	**FORGING results presentation – Perspective Cards** FORGING partners (VTT) will show the Perspective Cards as project tools aimed at exploring the potential of emerging technologies towards a sustainable and responsible innovation journey.
09:50 – 10:45	**Session I: Co-definition of scoring criteria to select Emerging Technologies** Participants will collaborate to co-define scoring criteria to evaluate the technological portfolio.
10:45 – 11:00	Coffee break
11.00 – 11.15	**FORGING results presentation – Strategic Matrix** FORGING partners (STAM) will illustrate the Strategic Matrix of technologies developed so far by FORGING.
11:15 – 12:15	**Session II: Co-creation of the Priority Clustering** Based on the selected criteria, participants will revise the initial technological portfolio and create a priority cluster of the technologies.
12:15 - 12:30	**Final discussion and Conclusions**

Figure 4 – Agendas from the Artificial Intelligence workshop and the Digital Twins workshop

The organization of the workshops involved several preparatory activities to ensure smooth execution and participation. The preparation phase began with sending out initial notifications, such as save-the-date and LinkedIn posts, well in advance of the actual events. These notifications were followed by formal invitations to potential participants, marking the official start of the engagement process.

To ensure that registered experts were well-prepared to participate in the workshop, two information packages were sent to them before the event. The first set of materials included the workshop agenda, objectives, role of participants, information about the tool used (Miro platform) and additional insights about the FORGING background. This helped participants familiarize with the workshop's objectives and structure. As the workshop date approached, a second set of materials was sent out, providing participants with updated information, value sensitive considerations and the specific set of technologies identified during the T2.1 scouting activity (see Annex I Information Packages).

After each workshop, preliminary results and key points were promptly shared with participants.

This preparation approach and follow-up not only enhanced the effectiveness of each workshop, but also helped foster a collaborative and informed participation to the events.

2.2 Techniques used for gathering insights and feedback during workshops

The challenge of bringing together experts from different fields coupled with that of remote modes may pose a barrier with regards to the full and active involvement.

Therefore, the activities conducted were specifically designed for the online format although the methodology can easily be adapted to a face-to-face setting. Overall, the approach aimed at effectively gathering insights and valuable input from participants ensuring active engagement and facilitating meaningful discussions. Different techniques were combined by alternating moments of presentations by the FORGING partners with collective exercises and open discussion with the participants.

Moreover, the Miro platform provided a virtual space for interaction, enabling participants to share their thoughts and contribute to the collective analysis and evaluation of technologies.

Icebreaker

After the initial presentation of the workshop objectives, agenda and additional project information, an icebreaker exercise was conducted. For the first two pilot workshops (about AI and Cyber), the technique used for the icebreaker required participants to write their name, job title and place of work in a sticky note. For the other four workshops, a different icebreaker based on a divergent thinking approach was adopted. It consists of three steps: (1) pick an object on hand or in sight and think about how it could be used differently from its primary purpose (i.e. how the object is ordinarily used); (2) list as many other purposes for the object as possible; (3) declare the alternative uses we have thought of and see who have been more innovative. This tool has proven to be useful to let participants acclimatize to creativity and overcome the initial barrier of expressing their opinion.

Provide initial input

A specific technique aimed at engaging participants was used to provide initial input and then ask the audience to comment on it as a starting point for reflection. For instance, when defining the criteria, the experts were given an initial set of criteria along with Perspective Cards. They were then asked to provide comments and suggest additional criteria.

Voting session

The Miro voting tool was used to select the most relevant criteria and then to evaluate the technologies against the selected criteria. Real-time polls easily gathered immediate feedback, capturing participants' opinions and preferences.

These collaborative activities encouraged critical thinking and collective decision-making, leading to a consensus on the most promising technologies. By employing these techniques, the workshops effectively gathered valuable insights and feedback, ensuring the successful achievement of the goal to elaborate a priority cluster of technologies.

2.3 Workshop participants

The workshops were attended by a diverse group of experts, including researchers, academics and industry experts from various organisations and countries. For each workshop, Table 1 below provides a detailed overview of participants’ profiles.

Workshop	Number of attendees	Roles of the participants	Types organisations	Countries
Artificial Intelligence	14	Researchers and academics (e.g. Professor, Post-doctoral Researcher, PhD Candidate), Scientific Project Officer, Experts from industry (e.g. Corporate Expert, Cyber Security Specialist, Founder & CEO)	Universities, Research Centres, Tech companies, National Agency	France, Italy, Finland, Portugal, Kosovo
Cyber safe data tech	12	Experts from industry (e.g. Founder & CEO, Legal Consultant), EU Project Manager, Researchers and Academics (e.g. Professor)	Universities, Research Centres, Tech companies, Law firm, Governmental bodies	Spain, Italy, Finland, Netherlan ds
Human-Machine Interaction	11	Researchers and Academics (e.g. Professor, Research Manager, Junior Assistant Professor, Grant Researcher, Early-Stage Researcher), Experts from industry (e.g., Founder), Scientific Project Officer	Universities, Research Centres, Tech companies, Start up, Non-profit consortium, National agency	Finland, UK, Italy, Spain
Bio-inspired materials	9	Researchers and Academics (e.g. Post-doctoral Researcher, PhD Fellow), Technical Consultant, Experts from industry (e.g. Principal Scientist, R&D Project Manager)	Universities, Research Centres, Tech companies, Scientific Institute, Governmental bodies, National agency	Italy, Finland, Spain
Energy Efficiency	16	Experts from public sector (e.g. Director, Founder), Experts from private sector (e.g. Sustainability & Marketing Junior Specialist, Public Funding Consultant, Technical Project Manager, Sustainability Project Manager, Innovation Team Leader, Environmental Engineer), Researchers and Academics (e.g. Assistant Professor, Research Director, Post-doctoral Researcher, Guest Associate Professor)	Universities, Research Centres, Tech companies, private firms, National Energy Technology Cluster, Non-profit network, Consultancy firm	France, Italy, Spain, Greece, Portugal
Digital Twin	17	Researchers and Academics (e.g. Tenure-track Assistant Professor, Associate Professor, PhD Student), Experts from private sector (e.g. Chief Technology Officer, IT Consultant, Software Technologies Group Leader, Sustainability and Marketing Junior Manager, R&D Business Developer), Experts from public sector (e.g. Portfolio Manager, Research Infrastructure Digital Twin Manager, Senior Project Manager and Expert Evaluator)	Universities, Research Centres, Tech companies, private firms' National agency, regional body	Italy, Sweden, UK, Spain, Portugal

Table 1 – Overview of participants' profiles

3. Results from the Technology Clustering workshops

3.1 Priority clustering of Artificial Intelligence technologies

This session provides an overview of the main results of the Technology Clustering workshop on Artificial Intelligence in terms of the criteria co-created against which the participants evaluated the set of technologies.

3.1.1 Criteria for prioritization

As outlined above, a number of criteria were collectively established during Session I of the workshop in order to assess the portfolio of emerging technologies in the field of Artificial Intelligence.

Technical criteria

One of the first elements identified when discussing the technical criteria was the importance of **compliance with security standards**, ensuring that technologies adhere to established regulatory frameworks such as the AI Act. **Interoperability** was among the first criteria identified, assessing how well a new technology can integrate with existing systems and technologies to ensure seamless adoption. **Scalability** was also highlighted, focusing on the ability of a technology to efficiently handle increasing data demands while maintaining performance and reliability. The need for truth and **reality checking mechanisms** then emerged to prevent hallucinations in AI outputs, thereby making sure AI-generated information is accurate and reliable. **Effective data management strategies**, including handling missing datasets, ensuring data quality, and implementing security protocols during storage/transmission were deemed necessary too. Participants also discussed the importance of developing **new hardware concepts** optimized for AI applications and the explainability of AI decisions, to make it clearer how decisions are made by the technology. **Addressing and mitigating algorithm biases**, **promoting transparency** using open data and open algorithms, and **prioritizing modelling approaches** over simple algorithmic solutions were therefore considered crucial technical criteria.

Environmental criteria

Environmental discussions centred around the **use of resources** and the need to cut down on the **carbon footprint** produced during technology manufacture and application. This implied to consider the **entire life cycle** of the technology from creation to disposal with an emphasis on sustainable practices at every stage. Other relevant points included relocating servers closer to areas with **renewable energy sources**, as well as employing **edge AI** which reduces data transfer requirements while enhancing power efficiency in Artificial Intelligence training models.

Discussions also concerned **waste minimization**, recycling hardware components and ensuring a positive impact on ecology. The participants also considered **qualitative assessments of complex data reuse** and preprocessing methods and the potential benefits of low-tech solutions in specific contexts.

Social criteria

With regards to the social aspect of technologies, ethical considerations on how technologies impact privacy and human rights have been considered first. The importance of **user-centric design** was stressed, ensuring that the design process incorporates user needs and perspectives to make technologies more accessible and inclusive for diverse users. **Fairness** came into play too; if AI systems are trained on biased data, they could exacerbate existing inequalities. Consequently, the discussion on equity is paramount in order to face possible surge of inequality resulting from bias data used to train AI systems. The need to reduce **biases in AI systems** and prepare for **workforce transformations** resulting from new technologies, was highlighted as a critical aspect to consider. **Assistive and collaborative technologies** designed to work alongside humans were recognized as crucial for supporting human capabilities. The **integration of data-driven and logical modelling** to enhance **interpretability** by human reasoning was discussed to bridge the gap between data-driven approaches and human understanding. The **impact** of different funding models **on data privacy and security** was also considered, alongside for **transparency** to avoid hidden costs associated with data privacy. The **psychological and cognitive impacts** of technology were significant points of discussion including issues like depression and social isolation. During the exercise discussion also focused on the **educational impact** of technological errors and emphasized the importance of reducing the gender gap and promoting **equality** in technology development and use. **Accessibility** and **inclusivity** were seen as key in achieving these goals, ensuring that technological advancements benefit all members of society.

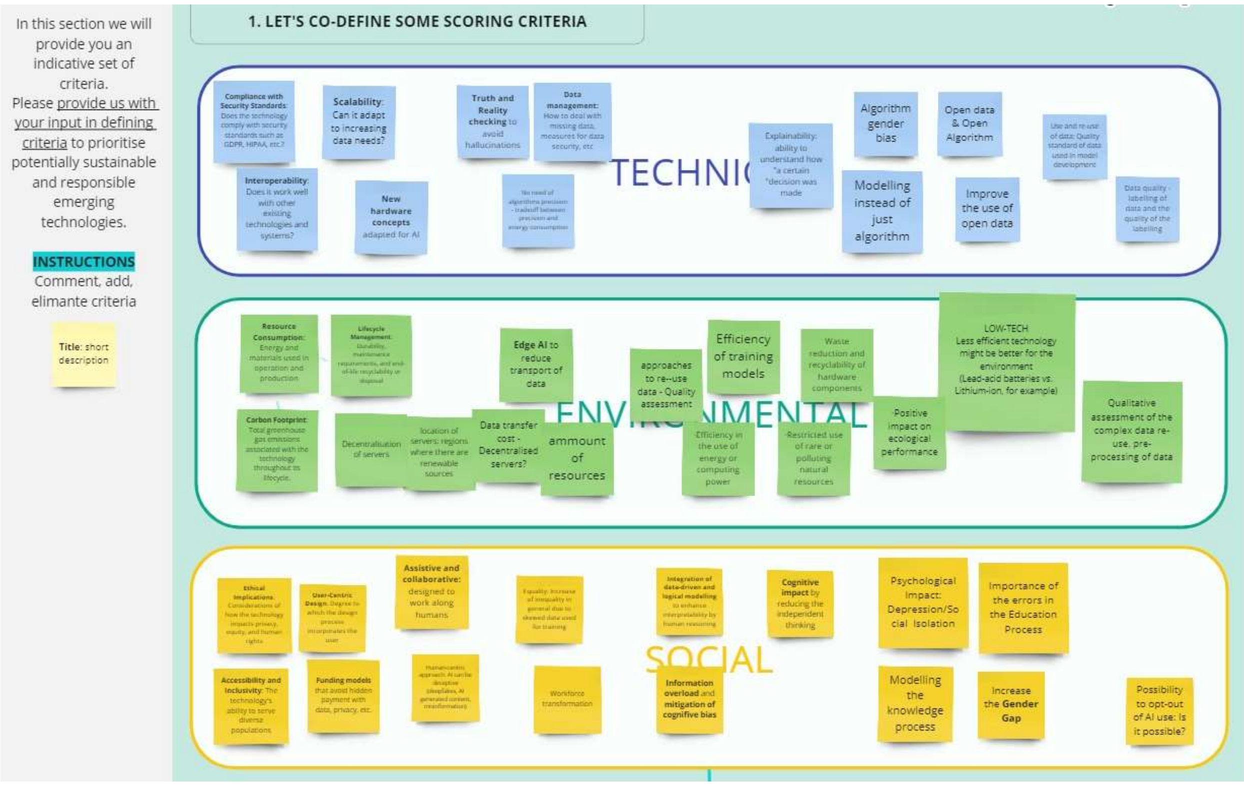


Figure 5 - Screenshot from Session I about co-definition of scoring criteria – AI workshop.

Final set of criteria established

The criteria considered most relevant and therefore selected by the participants at the end of Session I are listed in Figure 6 below:

Technical	Environmental	Social
• Open data & Open Algorithm • Compliance with security standards • Truth and reality checking	• Edge AI • Efficiency of resources • Positive impact of ecological performance	• Positive cognitive impact • Positive workforce transformation • Accessibility & inclusivity

Figure 6 – Set of selected criteria - AI workshop

3.1.2 Final priority cluster

As part of the results of the FORGING analysis, 11 technologies were presented for examination during the workshop and are listed below (Figure 7).

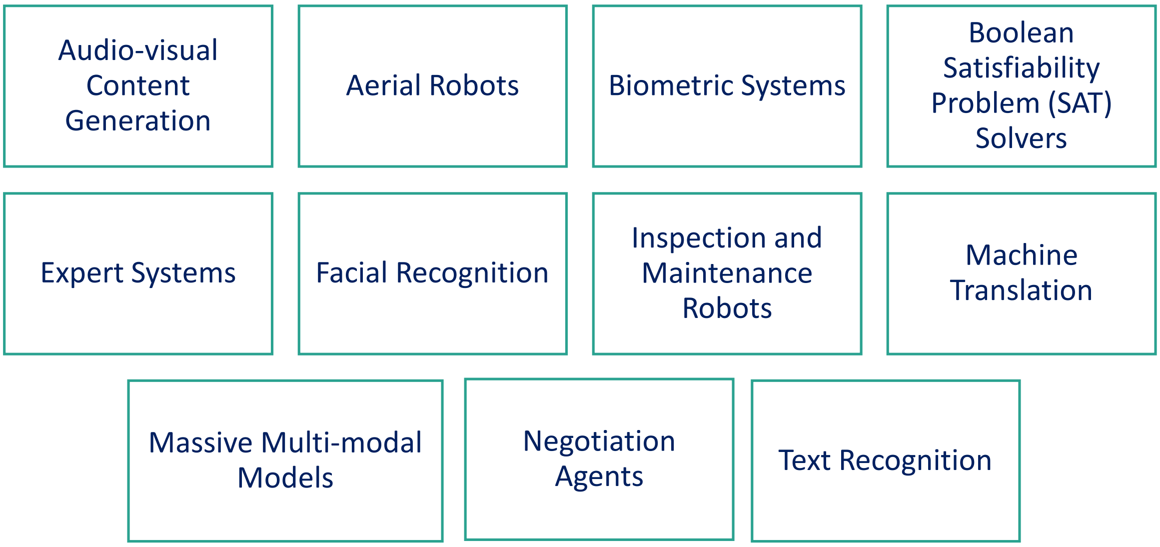


Figure 7 – Initial set of technologies presented in the field of AI

From these technologies, six were deemed the most promising based on the evaluation against the criteria established in Session I of the workshop. Insights from the discussion and assessment of the technologies against the criteria is reported below.

Text recognition technology was considered the most promising for its potential impact in all the three considered field of technical, social and environmental aspects. Technically, it ensures open data as many text recognition tools and datasets are available as open source. From an environmental perspective, it reduces the need for paper and storage of physical material promoting digitization and indirectly benefit the environment. Some factors were considered key to make text recognition environmentally friendly such as the use of renewable energy sources and efficient algorithms that require less computational power to reduce the environmental footprint. Among the mentioned positive aspects of this technology, is its potential in the social sphere with respect to accessibility and inclusivity. By turning several text formats into digital ones, this technology allows more people to access new knowledge and pieces of information, thus spurring inclusiveness and accessibility. In addition, it streamlines data entry and document management impacting the workforce by allowing workers to focus on more complex activities.

Inspection and Maintenance Robots were also positively assessed. From a technical aspect, they ensure compliance with security standards and effective truth, reality checking through their inspection, and maintenance operations. In environmental terms, they utilize edge AI which enables them to operate on-site, while reducing the need for extensive data transmission and cloud resources. These robots minimize downtime and prevent environmental hazards from equipment failures, in this sense contributing to environmental sustainability. Socially, they can enhance safety by performing dangerous tasks that would pose risks to workers. Their adaptability across a wide range of sectors further increases their potential.

As in the case of text recognition, **Machine translation** technologies also meet the open data criterion, even though partially, because many models and datasets are open source. As far as their impact on the environment is concerned, these systems are edge AI-based, which let them work on local devices and use fewer cloud resources without consuming huge computational power. In terms of social impact, a positive aspect is the potential in bridging language barriers improving communication among people from different linguistic backgrounds. This enhancement of cognitive accessibility is significant, as it allows for better understanding and cooperation across languages. One debated aspect concerns the impact on the workforce as this technology can reduce the need for human translators for simple tasks. If not properly mitigated, this factor can become critical.

Expert systems have been considered valuable for their efficiency as they can process large amounts of data while quickly providing answers. The quality of the system is directly proportional to the quality and exhaustive coverage of the knowledge base. Expert systems can be deployed locally using edge AI, optimizing resource use and improving operational efficiency. This local deployment reduces the need for extensive data transfer, making the systems more resource efficient. However, maintaining and updating rules and data can be complex and expensive. Concerning the social aspect, expert systems can enhance workforce capabilities by providing expert knowledge, making informed decision-making more accessible. Generally, the wide applicability allows the domains of application of expert systems to stretch from healthcare to engineering, providing assistance in various fields. The ability of the systems to support workforce tasks could serve to improve productivity by enhancing the quality of decision-making. It increases their accessibility and inclusivity, making the knowledge of experts in relevant areas available to a wider audience.

Aerial robots address the security standards criterion as this is crucial for regulatory compliance in airspace management. These systems can perform truth and reality checking through data collection which make them reliable tools for various applications. Aerial robots use edge AI for autonomous flight and data collection reducing the reliance on data transmission and improving resource efficiency. These robots can contribute positively to sustainability through applications in environmental monitoring, pollution control, and precision agriculture. By providing detailed information they can also help in managing and conserving natural resources. This technology can also help to make the workforce safer by replacing dangerous and repetitive tasks, reducing the need for human intervention into hazardous environments, and thus decreasing the risk of accidents. Although principal use of these devices is in industries, their versatility is evident across sectors from agriculture to monitoring the environment.

Concerning **Biometric systems**, security measures are integral part to their functionality, protecting biometric data from theft or unauthorized use. With regards to truth and reality checking, while they can accurately verify identities, there may be problems associated with false positives or negatives. The positive impact on sustainability is only somewhat significant. Their efficiency of resources is reduced because the systems often require a large amount of processing power. While biometric systems reduce the need for physical security measures, such as keys or cards, production and maintenance of biometric hardware can be resource intensive. They can bring positive workforce transformation as they can ease security procedures and minimize the usage of physical security measures. However, the most debated issue revolves around privacy aspects.

Based on the above presented discussion, the final cluster of most promising technology in terms of sustainability and social responsibility in the AI field is reported below in Figure 8. The technology at the tip of the arrow (Text recognition) is to be intended as the most promising.

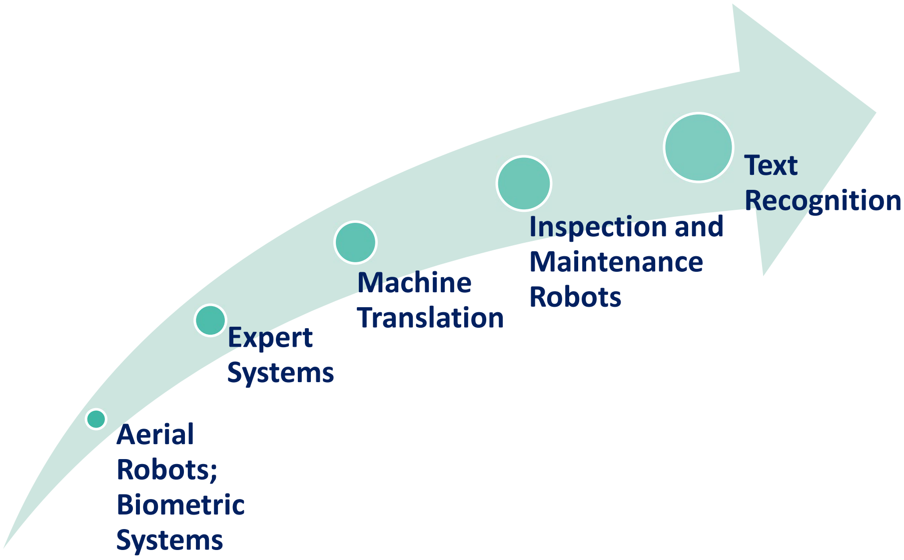


Figure 8 – Priority cluster of AI technologies

3.2 Priority clustering of Cyber safe data technologies

The following session presents a summary of the key outcomes from the Technology Clustering workshop on Cyber safe data technologies (Cyber). The collective discussion about defining criteria and evaluating technologies to identify the most promising ones from an environmental and social, besides a technical point of view, is outlined below.

3.2.1 Criteria for prioritization

Technical criteria

Among the technical criteria, **compliance with relevant legislation** such as the EU Cyber Resilience Act, Cybersecurity Act, Cyber Solidarity Act, NIS and NIS2 Directive as well as the General Data Protection Regulation (GDPR) and AI Act in the part relating to cybersecurity was firstly considered. **Compliance with industry-specific standards** (verticals) and horizontal standards has also been deemed essential. **Scalability** was identified as another relevant criterion, assessing whether the technology can handle increasing data volumes or concurrent users without performance degradation. Also, **portability** was identified as key, requiring the system to support multiple platforms, including mobile systems and different operating systems and hardware. Further criteria included **strong authentication feature**, **intra-quantum security** for secure integration of quantum and classical technologies, and **configurable privacy levels**, which allow users to choose to what extent of data sharing they want to authorise. **Patching** was considered necessary to update, fix, or improve computer programs or supporting data. Finally, the criteria included **resilience** as crucial for recovering from and coping with adverse events, while **backup capabilities** are essential for data recovery in the event of breaches or system failures.

Environmental criteria

A huge part of the debate revolved around sustainability raising questions such as: is the technology sustainable? How efficient is it? Also, is the technology bio-inspired? Therefore, environmental criteria focused on minimizing the **environmental impact** of the technology. This included efforts to reduce the **carbon footprint**, namely the level of environmental impact in terms of **Green House Gas emissions** throughout the life cycle of the technology. Linked to this goal, is the criteria about the **circular design** of the technology as well as assessing how easily the system can be recycled or reused. **Energy sources** were also discussed, mainly the energy used within the infrastructure for example in data centres.

Social criteria

Social aspects were extensively discussed, and the criteria identified touched upon ethics, accessibility and privacy. **Fairness** and **bias** have emerged primarily, aiming to avoid inherent biases in decision-making processes and data handling. Considering the crucial role of the human factor, several criteria reflected this asset; among them: **transparency and explainability** to ensure that the technology is understandable and its processes are clear to users; promoting **trust and informed decision-making**; **data privacy and data ownership**, emphasizing the ability to delete data when necessary and protecting user privacy; **customization** considerations address specific needs for vulnerable populations, such as children, the elderly, and the digitally illiterate etc. **Accessibility** was emphasized, enabling all users to utilize the technology easily, regardless of disabilities. **Inclusivity** was included among the criteria to ensure that all users, regardless of gender, race, or other aspects, can use the technology. In general, all these criteria are linked with the objective of solving problems that people care about. **Workforce evolution** was also discussed, debating the need for new skills to manage new technology and address obsolete skills. Discussion also included considerations about whether the technology could potentially be used for **harmful purposes**. Public vs. private **surveillance approaches** or coordination were considered, along with measures to manage cyberbullying and other forms of online abuse. Finally, considerations in case of **conflict and protection of critical infrastructures** (CIs) were discussed. Figure 9 summarises the criteria.

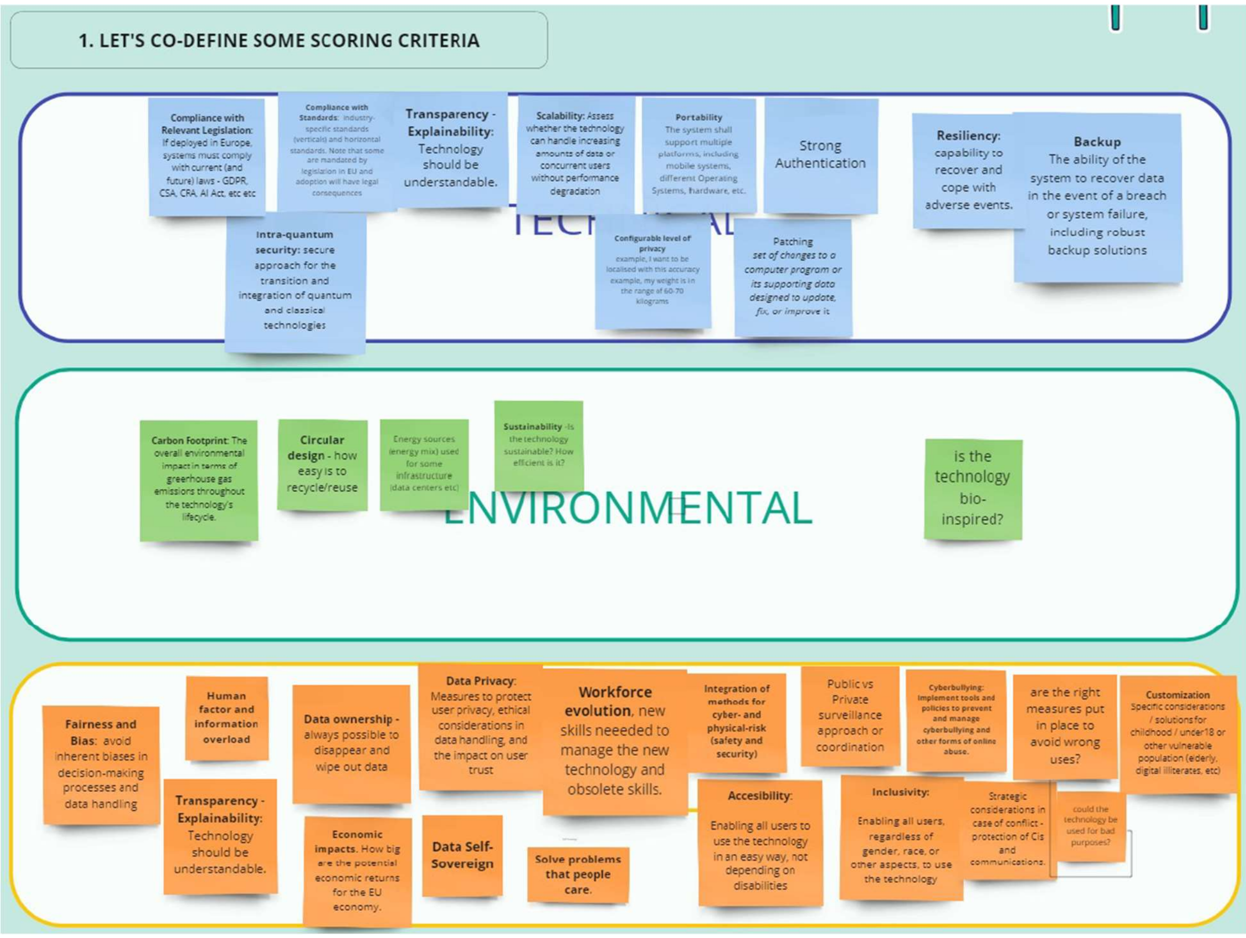


Figure 9 – Screenshot from Session I about co-definition of scoring criteria – Cyber workshop

Final set of criteria established

Session I of the Technology Clustering workshop on Cyber safe data technologies ended with the selection of the most relevant criteria in the field which are reported below in Figure 10:

Technical	Environmental	Social
• Resilience • Compliance with legislation and technical standards • Scalability & interoperability	• Circular design • Carbon footprint • Energy sources	• Inclusivity & Accessibility • Transparency & Explainability • Fairness & bias-free

Figure 10 – Set of selected criteria – Cyber workshop

3.2.2 Final priority cluster

In the case of the workshop on Cyber, 18 technologies were identified in the framework of the analysis carried out in WP2. Given the number of technologies and workshop time limitation, a further step was added in the co-creation process, to select only 6 technologies to be considered for evaluation according to the identified criteria.

6G Networks	Ad Hoc Networks (Vehicular/Mobile/ On-Demand Distance Vector)	Blockchain	Cloud Services	Cyber Cartography, Detection, Segmentation
Data Mining	Edge Computing	eHealth, Mobile Health, Telemedicine	Encryption Technology	Endpoint Security Software
Fingerprints, Retinal Imaging	Pv6	Machine Learning System	Multi-Factor Authentication	Next Generation Processor Technologies
	Open-Source Tools	Quantum Computing	Endpoint Security Software	

Figure 11 – Initial set of technologies presented in the Cyber workshop

Through Miro's voting system, 6 technologies were selected for further consideration and assessment in the workshop: Machine learning system, Quantum computing, Blockchain, Ad hoc networks, Cryptography, and 6G network.

Cryptography is generally considered highly resilient due to its very design for the protection and integrity of data. Because of the use of standardized algorithms and its regulatory relevance, compliance with legislation and technical standards is high. Scalability was considered moderate since cryptographic methods are constantly being upgraded to deal with security threats that are emerging. On circular design and carbon footprint, the way it will be implemented can differ widely in different settings. The impact from an energy source perspective was considered neutral. In social terms, cryptography stands to a certain extent as accessible and inclusive because it is somehow embedded into many everyday technologies. It enhances transparency with verifiable systems, and it is designed to secure data and communications.

6G Networks are expected to be very resilient, being built on top of the solidity of 5G standards. Conformity to legislation and technical standards is foreseen as being high based on already existing frameworks. Scalability and interoperability will also be high, as intrinsic in the network design. Environmentally, 6G networks are expected to yield a high circular design score by benefitting from improvements in hardware recyclability. Although the carbon footprint is yet to be assessed, they are expected to bring improvement in energy efficiency over predecessors. Socially, the 6G networks will be much inclusive and accessible to a wide spectrum of end-users. They will maintain high transparency, much like 5G, and be seen to be fair in the access and use process, although actual implementation details may vary.

Quantum Computing, at this point in its development, is not interoperable with different systems due to a lack of standardization, and it is also not scalable. Compliance with legislation is unknown, and a holistic legal framework for integration of quantum computing technology into different sectors is yet to be developed. Inherent resilience and resistance to certain types of attacks are part of the technology itself and it also provides future perspectives for enhancing resilience in systems. Environmentally, quantum computing would be rated neutral in circular design and sources of energy due to its nascent stage, and hence the potential improvement once the technology is fully mature. That said, it is expected to have a rather high carbon footprint due to the large energy needed for maintaining quantum states. At the same time, consider that the processing time is much shorter compared to current computing machines. Currently, the inclusivity and accessibility of quantum computing are very low because it is confined in highly specialized environments. While it has high explainability among experts, it lacks public transparency. Its potential to ensure fairness and avoid bias depends largely on the specific applications developed.

Blockchain is known for being immutable and therefore robust. However, in terms of resilience, if a targeted attack succeeds, the consequences could be severe. It is inherently scalable, but problems persist regarding interoperability. Compliance with legislation and technical standards is currently low given the evolving regulatory landscape. Concerning the environmental aspect, blockchain relies on energy-intensive hardware that is hardly recyclable, with proof-of-work algorithms, and it has an extremely high carbon footprint. In terms of energy sources, this would also be rated low because of the huge consumption coming from mainly non-renewable sources. In the idea of blockchain, there is great potential for inclusivity although current technical barriers bring down its accessibility. By design, it is inherently transparent, even though the technology requires technical knowledge for full explainability. Blockchain ensures high fairness, yet it varies in current implementations and can potentially avoid bias effectively.

Ad Hoc Networks are a general category difficult to evaluate as a whole because a lot depends on the environment in which they are deployed. Their resilience varies widely depending on the specific application. Compliance with legislation and technical standards also depend greatly on the deployment context. For instance, a high risk of non-compliance is likely to happen particularly in vehicular networks as could be the case with connected cars not being fully compliant with GDPR. Scalability and interoperability are low due to the inherent nature of ad hoc networks, which are not designed to be interoperable with different networks. From an environmental perspective, Ad Hoc Network are designed for low energy use, making their carbon footprint and energy sources impact relatively low although require hardware manufacturing. Socially, ad hoc networks have moderate inclusivity and accessibility, varying by deployment context, and are generally transparent, though with some variability. Fairness is also moderate, with potential for data misuse impacting the bias-free assessment.

Machine Learning Systems (MLS)

With regards to resilience, the first technical criteria selected, MLS were rated low due to the high degree of dependency on data quality and lack of robustness against unexpected issues. Compliance with legislation and technical standards varies significantly based on implementation and jurisdiction make it difficult to assess unequivocally. In terms of scalability and interoperability, Machine Learning does not appear to perform strongly because of the high computational requirements that will be needed coupled with the heavy dependence on data. Moreover, in environmental dimension, MLS don't excel. They depend on specialized hardware that is difficult to recycle, and the energy-intensive nature of computations, primarily sourced from non-renewable energy, cause a high carbon footprint. In social terms, these systems are not fully accessible to all categories of users. Transparency and explainability are low, especially in complex models while these systems are facing existing challenges of purging biases from data. Figure 12 below shows the cluster of priority technologies in the Cyber framework resulting from the co-creation workshop where at the top is the technology considered most promising.

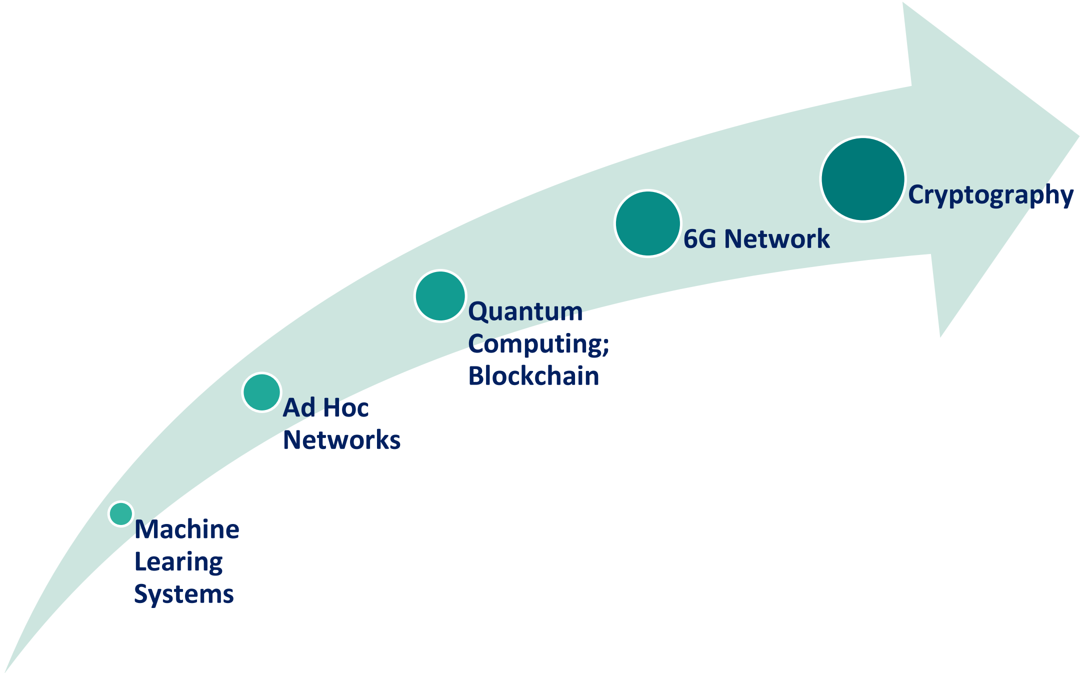


Figure 12 – Priority cluster of Cyber technologies

3.3 Priority clustering of Human-Machine Interaction technologies

The following section provides the reader with the main outcomes from the workshop on Human-machine Interaction Technologies, detailing the co-identified scoring criteria and the final assessment of technologies carried out by expert participants.

3.3.1 Criteria for prioritization

Technical criteria

Several technical criteria were indicated by participants to assess human-machine interaction technologies. **Usability** was one of the first to be discussed. Experts agreed on considering the overall user experience as a key factor: for a technology to be considered good enough, it must be easy, intuitive, and seamless to use. This is closely related to the **social acceptance** criterion, as the adoption of a technology might largely depend on its usability degree. Experts also pointed out the **compatibility** criterion, with regards to the need for a newly developed technology (or a technology under development) to interact with already existing forms of technology and thus to be compatible with them. Furthermore, it was highlighted that end-users and final consumers are not necessarily technical users, and for this reason the "**assisting**" criterion was deemed as much important as the previous ones. Due to a difference that might arise in terms of technical skills in working environments (and especially among industrial workers), technologies need to be "assisting" in order to be used by people who might not be familiar enough with new technological processes and products. The "assisting" criterion relates to two other ones – **accessibility** and **inclusivity** – that were also debated during the workshop. An additional criterion stressed out by participants was transparency, namely ***balanced*** **transparency**, in technology development processes. It refers to the need for a right balance of information based on the level of use, and to the creation of multiple levels of transparency and intelligibility at different stages of processes (on a need-to-know basis). Additionally, attendees discussed **personal data management** as a criterion related to the control level that every individual has over their own data management, transfer and export. As it emerged during the workshop, this criterion is connected to **data governance issues** and ultimately to the aforementioned transparency in technological processes. Lastly, one expert indicated the **minimisation of critical failure** as a criterion to take into account when assessing a technology, which implies **reliability** considerations as well.

Environmental criteria

Among environmental criteria, an initial discussion focused on supply chain-related issues, and specifically on a technology's **supply chain dependence degree** and on the **supply chain impact** on the sustainability of such technology, including considerations about the **greenhouse gas**

emissions of specific logistical and shipping processes. According to participants, these criteria are (although indirectly) linked to the **traceability** of parts and materials and to **materials provenance and composition** – all equally deemed as important in the assessment of human-machine interaction technologies. Other related criteria were indicated, all belonging to the same "cluster" which was summarised by the "**carbon footprint**" sticky note: the low **power consumption** (mainly applicable to data centres), the (fair) **trade-off between performance and energy efficiency**, the **use of recyclable materials**, the **efficient use of resources**, and **waste management**. In relation to these criteria, **digital and technological responsibility** and **alignment with the Sustainable Development Goals** were also indicated as factors to consider when developing (and assessing) a technology. Another environmental criterion mentioned was the **human-centred design**. Interestingly, it was stressed that the design should not take into account human beings exclusively, but also other potentially impacted entities, such as animals, forests, and so forth. This led to the introduction of two additional criteria, one about a technology's **effects on specific ecosystems** and the other one about a **continuous assessment** of its environmental effects, even in the long term.

Social criteria

With regards to the social domain, a number of criteria emerged during the workshop, as shown in Figure 13. Many of them belong to the broader **inclusivity** criterion, such as **human agency and skills development**, and **universal design**, meaning a design that makes the technology usable for different target groups (with special regards to marginal user groups). This had already been included among technical criteria, together with the **explainability** from the user's point of view, but it is just as relevant from a social inclusion perspective. One expert pointed out that even from an economical perspective it would be best to produce technologies that are usable for the highest possible number of people, even though it makes the interface design phase more challenging. Another social aspect that attendees considered relevant is the **lack of labour exploitation** in technology development processes and through the (industrial) production chain, which has to do with the **ethical use of resources**. Ethics was indicated as notable criterion itself, together with **privacy**. On another hand, a consistent part of the discussion about the identification of social criteria focused on the alignment of the public opinion and the technological development, which proved to be a very important criterion. **Trust**, **confidence** and **desirability** are some of the criteria in this domain that were highlighted as more relevant. **Impact on employment** and the enhancement of **equal opportunities** are also criteria falling under the same domain, as they all facilitate the social acceptance of new technologies. Finally, participants agreed on the importance of criteria related to **state intervention in early adoption of technology**, which resulted in the sticky notes "capping costs of access (state subsidy)" and "public procurement".

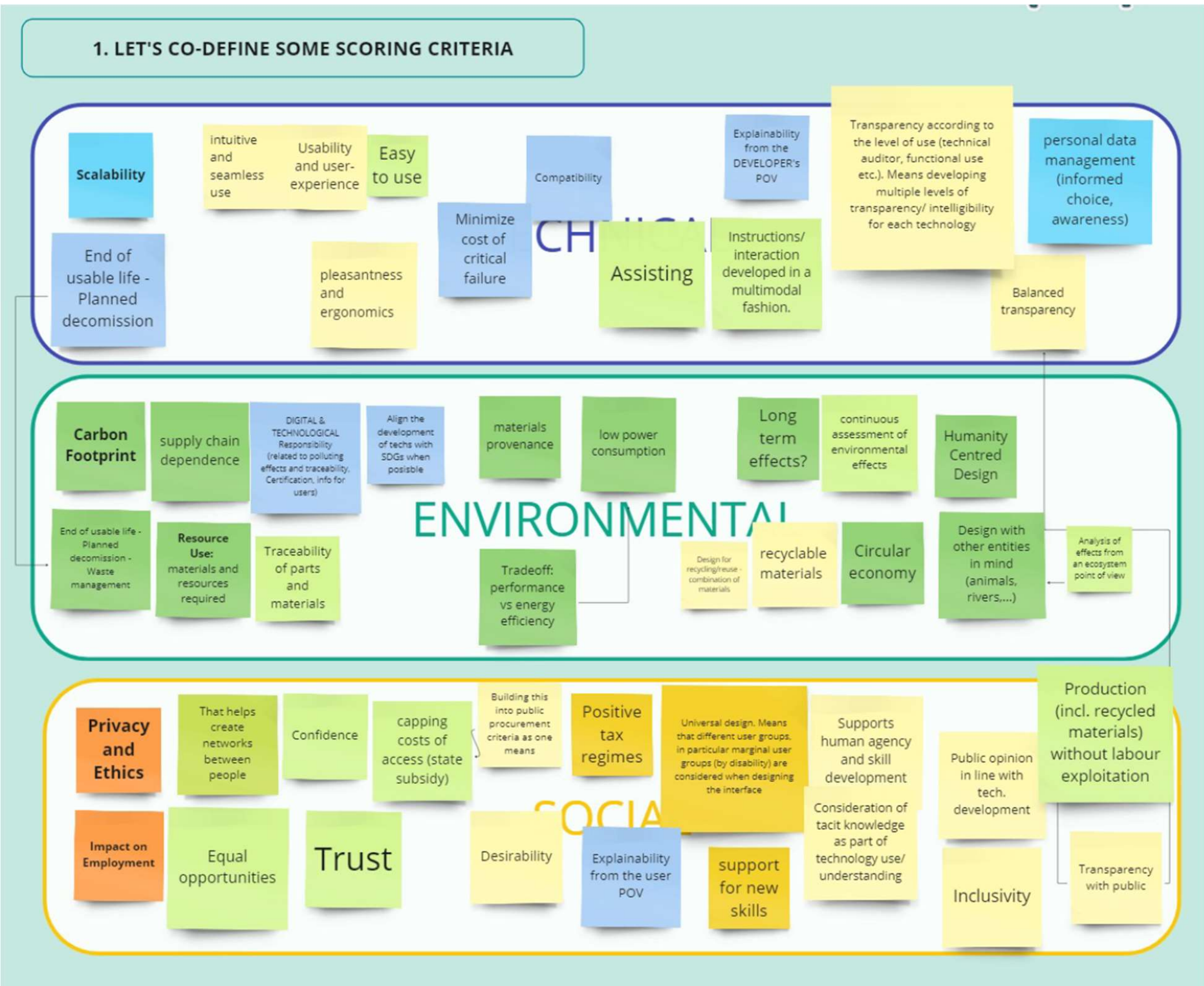


Figure 13 - Screenshot from Session I about co-definition of scoring criteria – Human-machine Interaction workshop

Final set of criteria established

Out of all criteria co-identified during the first session of the workshop, those selected by experts to assess human-machine interaction technologies in Session II are listed in the Figure 14 below.

Technical	Environmental	Social
• Usability and end-user design • Personal data management • Balanced transparency	• Sustainable production without labor exploitation • Carbon footprint • Resource use	• Universal design • Privacy and ethics • Impact on employment

Figure 14 – Set of selected criteria – Human-machine Interaction workshop

3.3.2 Final priority cluster

The second session of the workshop was entirely dedicated to the assessment of Human-Machine Interaction technologies. In a highly interactive debate, participants discussed the technological portfolio presented by the project partners, consisting of the six technologies included in the Figure 15 below. In this case, the portfolio did not need to be narrowed down, as it was already limited to six technologies, that are all described below and listed from the "most promising" to the "less promising" according to the co-creation process carried out by participants based on the nine co-identified criteria.

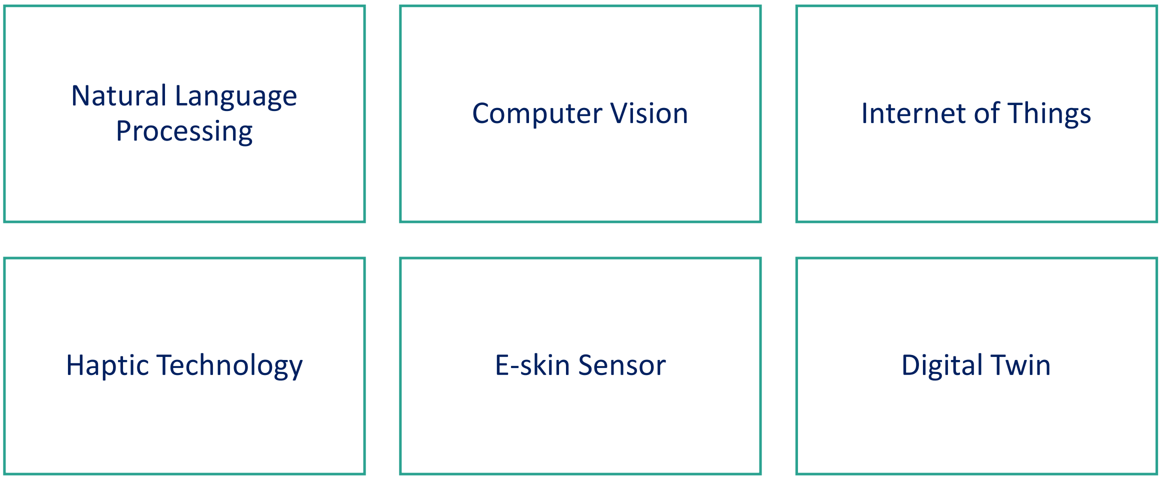


Figure 15 – Initial set of technologies presented in the Human-machine Interaction workshop

Digital Twin obtained the best average evaluation during the co-creation session on technology assessment. Technically speaking, it is the most promising enabling technology as it offers "another layer to where you can process information", and it produces "something new for the picture" – experts stated during the discussion. Digital twin needs to be well designed, otherwise it brings confusion to the user, but in terms of transformative potential it was considered very much promising. On top of that, it was also defined as a much ecological technology, thus matching the environmental criteria better than any other technology of the portfolio. Finally, its social potential was considered beneficial given its capacity to capture key information about our society's working processes and thus to enhance their optimization.

The evaluation of **Haptic Technology** also resulted in an overall positive assessment. Participants particularly appreciated the debate about it because – as stressed out – it appears to be a technology long neglected. They concluded that it is not only technically enabling, but also largely sustainable, and that it holds a positive social impact potential (for instance, as an empowerment tool for industrial workers). However, most of the privacy-related issues have not yet been explored.

Natural Language Processing (NLP) emerged as one of the most promising enabling technologies in terms of usability, while in terms of personal data management and balanced transparency some limits were pointed out. The same applies to the sustainability and the carbon footprint of this technology, which was not highly rated by participants. On the contrary, their feedback was quite positive with regards to its universal design, although a need persists of developing more adaptability to the continuously evolving language forms. NLP was also described as rather privacy compliant and ethics sensitive, yet more can be done regarding the intellectual property rights: who owns the data that is being produced and processed? This question has not been fully investigated yet. The technology's impact on employment was also discussed, resulting in the conclusion that while NLP may generate significant progress in terms of education (namely in workforce upskilling and development), it may also result in a higher labour exploitation rate or in a substantial lack of human oversight.

Internet of Things (IoT) was highly rated when discussing its usability and end-user design: experts described it as highly versatile since it can be implemented in several different ways, and as user-friendly, both in its the simplest use-cases and in more complex ones. In terms of personal data management, participants' assessment was a little less satisfactory as IoT refers to the interconnection of different devices, which implies the integration of different user data and information, resulting in a lower degree of personal control over it. When assessed against the environmental criteria, IoT was valued as a medium-to-high sustainable technology, given that its production does not require much hardware. From a social perspective it was considered a fairly promising technology altogether, despite some privacy concerns and ethical limits partially related to a scarce technological knowledge and awareness of the general public.

E-skin Sensor is a technology in which the human-machine interaction is maximized. In fact, it is not even an interaction, it is more properly a *cooperation*, as one expert argued. Yet, its potential to ensure a high degree of personal data control or a fair and balanced transparency is not clear. Considering the materials and resources used, e-skin production can be considered relatively sustainable, but different levels of sustainability depend on different degrees of carbon footprint. As for its universal design, there is no general assessment that can be made based on these criteria: it depends, for instance, on the user, on the application. The remaining social criteria – privacy and ethics, and impact on employment – fall under a poorly researched area according to the experts, also considering that they largely depend on the single systems and products that are essentially customized.

Computer Vision does not adequately meet the technical criteria indicated by participants. In fact, some difficulties emerged while scoring its usability and end-user design, as participants highlighted that it may vary remarkably. It was also noted that it is complicated to rate the way data are used and to understand the end-user's control over their personal data; from the data management perspective, it was thus unclear whether there is or not a protection of such data. Computer vision does not seem to ensure data security nor balanced transparency, especially when it comes to biometric data. Environmentally speaking, different perspectives emerged while assessing this technology: some participants supported the idea of its overall sustainability based on the fact that there is not any physical product that needs to be produced, while others pointed out that sustainability is still far from being reached as sensors production on a large scale requires a lot of power, water, and other resources. Even in terms of carbon footprint, whilst efforts are in place to reduce it, computer vision is not yet compliant according to participants. From the social perspective, this technology has not turned out particularly promising as well. Issues related to labour exploitation emerged, together with privacy-related and ethical concerns, while in terms of universal design it turned out to hold a positive potential.

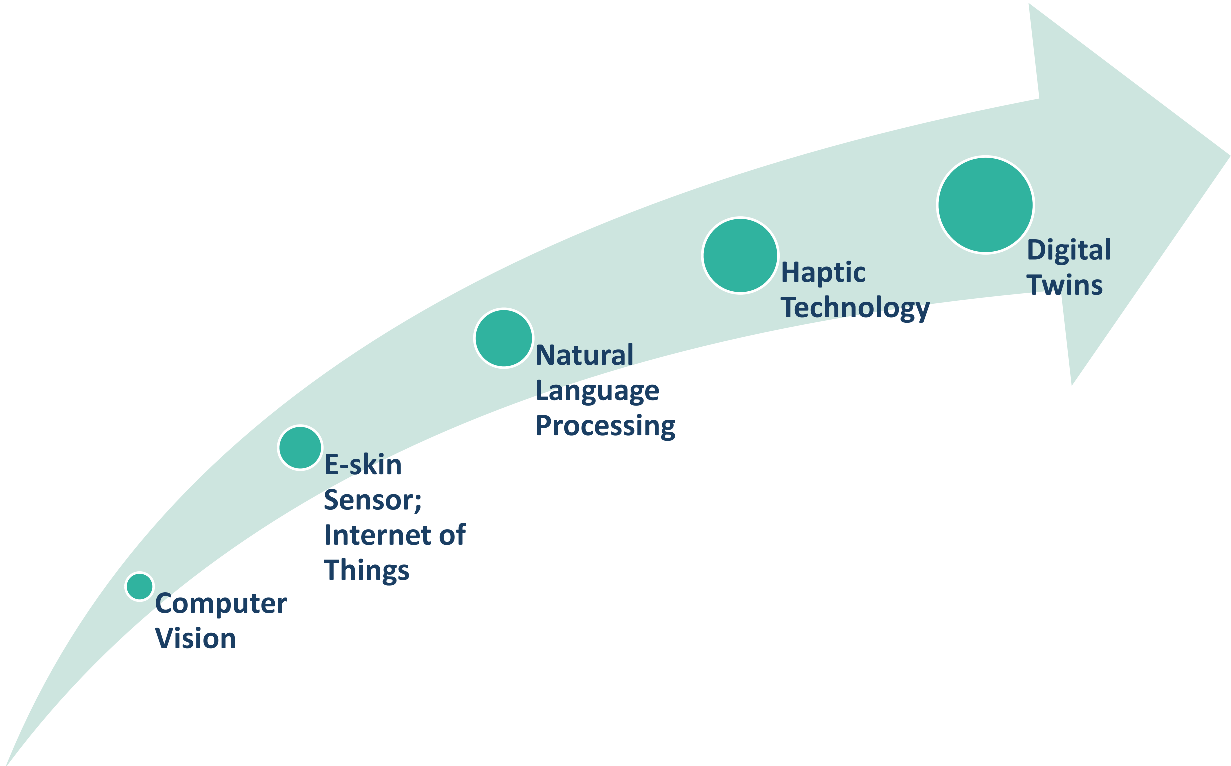


Figure 16 – Priority cluster of human-machine interaction technologies.

3.4 Priority clustering of Bio-inspired technologies

In this section results gathered during the workshop on Bio-inspired Technologies are presented. The section explains the process through which prioritisation criteria were identified and illustrates the co-creation process that led to the final cluster of the most promising technologies.

3.4.1 Criteria for prioritization

Technical criteria

The debate about technical criteria to assess bio-inspired technologies started with the identification of **scalability** as a first relevant criterion, defined by one participant as a technology's potential to be scaled up efficiently in a way that it can meet the demand without any losses in terms of performance. Another participant stated the importance of **interoperability**, claiming that data and information need to be flowing easily from one application or one system to another; it was also stressed out that when it comes to bio-inspired technologies, **integration** with already existing systems is key for them to work efficiently. Moving forward, the **robustness** criterion was mentioned by one expert that linked it to the **consistency of the technology performance** and to the so-called "**internal sustainability**". The expert further explained that robustness is something that impacts **reliability**, which was a point of discussion itself. The **durability** of a technology and/or a material and their **biodegradability** (meaning their capacity to be reabsorbed into the environment after use) were also identified among relevant scoring criteria. In this regard, participants agreed that the technology assessment may vary, as sometimes very durable materials might be needed, while some other times materials with shorter life span might be preferred. **Lifecycle assessment** was included among technical criteria as well, although the discussion highlighted that such criterion should be considered as "overlapping" between the technical domain and the environmental one.

Environmental criteria

From an environmental perspective, **waste reduction** was one of the main points of discussion. On this topic, participants stated that the ability to minimise waste production is one of the most important criteria a technology (or a technological process) must fit, as well as the potential to reduce **energy consumption** or to save energy and the **involvement of a small number of natural resources** (first and foremost water). With regard to waste reduction, another underlined criterion was the **upcycling of existing waste** into new functional materials. More specifically, as a response to the "**no-waste generated**" sticky note, some participants pointed out that sometimes waste can be given new functionalities – so this was also added to the criteria board. Additionally indicated criteria were the technology's **contribution to biodiversity conservation**, the **use of green chemistry strategies** in technology development (e.g., the use of more environmentally friendly solvents), the **use of abundant biopolymers** (e.g., cellulose), and the

use of side streams and by-products as raw materials. Of course, the technology's potential to reduce **greenhouse gas emissions** and other pollutants was mentioned among relevant criteria as well. One last environmental criterion taken into account was the application-specific **durability** of materials, directly linked to the durability criterion included in the above paragraph (technical criteria).

Social criteria

As for the social criteria, **equality enablement** was one of the first criteria to be added to the board, starting from questions like: how can a technology ensure social equality? How can it respond to the needs of vulnerable social groups? This led to the introduction on the board of the **inclusivity** and the **affordability** criteria, which explains the sticky note titled "cost of access to the technology": the **availability** of a technology to as many people as possible strictly depends on its cost, that needs to be considered as a scoring criterion. Moreover, participants highlighted the **creation of health and wellbeing** as other relevant social criteria, encompassing a technology's **potential to create jobs** and its capability to ensure **fair working conditions** and labour practices. Lastly, criteria pertaining to the human rights domain were taken into consideration, and specifically **privacy preservation**, **fundamental rights protection**, and regulations (**legal boundaries**) applicable to technological development.

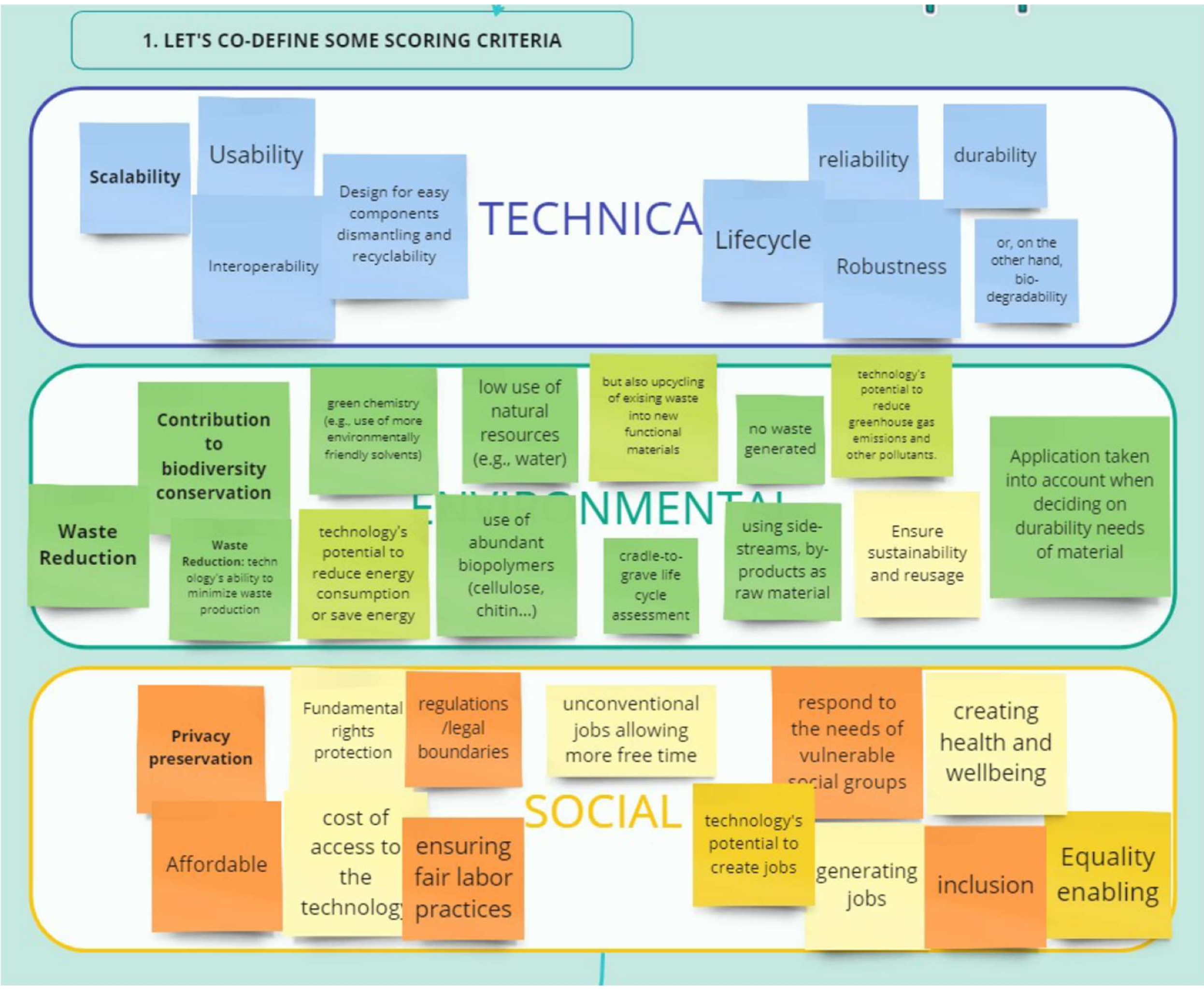


Figure 17 – Screenshot from Session I about co-definition of scoring criteria – Bio-inspired Technologies workshop

Final set of criteria established

At the end of the first session of the workshop on Bio-inspired Technologies, the criteria selected by participants were those shown in Figure 18.

Technical	Environmental	Social
• Lifecycle • Interoperability • Biodegradability	•Sustainability and reusage •Cradle-to-grave lifecycle assessment •Potential to reduce energy consumption	• Inclusion • Creating health and wellbeing • Equality enabling

Figure 18 – Set of selected criteria – Bio-inspired Technologies workshop

3.4.2 Final priority cluster

This paragraph is intended to illustrate the co-creation of the final cluster of bio-inspired technologies starting from the technological portfolio initially presented to the experts (see table below) and based on the previously identified criteria (see paragraph 3.4.1).

It is noted that Artificial Photosynthesis was not part of the original portfolio, but it rather resulted from the review session of the Strategic Matrix that allowed to gather experts' feedback. Therefore, it should be considered as an expert integration to the Matrix' portfolio.

Engineered Bacteria	Bioengineered Food Crops and Plants	Self-healing
Radiative Cooling	Wet Adhesives	Artificial Photosynthesis

Figure 19 – Initial set of technologies presented in the Bio-inspired Technologies workshop

While the original set of technologies included 6, only 5 of them resulted as "most promising" from the assessment and as shown by the Miro board's voting system, as reported in Figure 20: (1 – most promising) Artificial Photosynthesis; (2a) Self-healing; (2b) Engineered Bacteria; (3a) Bioengineered Food Crops and Plants; (3b) Radiative Cooling.

For each technology, participants were asked to indicate examples of potential ways and sectors of application, in order to facilitate the assessment. The results collected during this exercise are presented below.

Artificial Photosynthesis was considered as the most promising enabling bio-inspired technology based on the technical, environmental and social criteria identified in the previous co-creation session. Experts discussed about systems that can mimic the natural process of photosynthesis to capture solar energy and convert it into chemical energy and recognized them as technological breakthroughs.

Self-healing was also indicated among the top promising bio-inspired technologies, despite the need to be further researched. Participants highlighted how self-healing materials can help us reduce maintenance costs and energy consumption, achieve a lower environmental impact, and enhance energy efficiency, thus proving to be a significantly sustainable technological solution. Potential application examples were discussed:

- biocompatible materials for biomedical application in the healthcare and pharmaceutical sector;
- self-healing polymers in aerospace;
- spectrally selective films for greenhouses and mulch to mitigate water scarcity;
- edible and biodegradable films and coatings for packaging in the materials and manufacturing sector.

Engineered Bacteria obtained an evaluation just as positive as self-healing; hence it represents another top promising bio-inspired technology. As emerged from the debate, it is particularly interesting within the food production and agriculture sector.

Bioengineered Food Crops and Plants, with an overall assessment similar to that of radiative cooling, were considered particularly suitable in agriculture. The best practice of the Indian startup “Green Pod Labs” was shared, about the engineering of a defence mechanism for fruits and vegetables to stay fresher for longer. Another good practice mentioned was the creation of bio albumen by “Onego Bio”, that modifies the fungus *Trichoderma reesei* to produce animal-free egg white key-protein. The genome editing of avocado, and lettuce was also discussed as an example of application.

Radiative Cooling was indicated as a technology applicable to the building environment in several ways, particularly in the materials and manufacturing sectors. The following examples were pointed out:

- radiative cooling materials for thermoelectric generation to eliminate the need for air conditioning, or at least reduce it, or else to increase the coefficient of heat pumps’ performance;
- radiative cooling paint and panels that work during the night to generate electricity;
- radiative cooling transparent films to enhance the efficiency of PV modules;
- radiative cooling for water harvesting from humid air, water desalination.

One participant also highlighted the possibility to use radiative cooling in combination with other technologies, such as photovoltaics, for instance by applying it on top of solar panels so that it can extend their lifetime and ultimately enhance their efficiency (as the hotter solar panels get, the shorter their lifetime is). Yet, it was emphasized that the TRL of this technology is still rather low in Europe[4], with some exceptional cases.

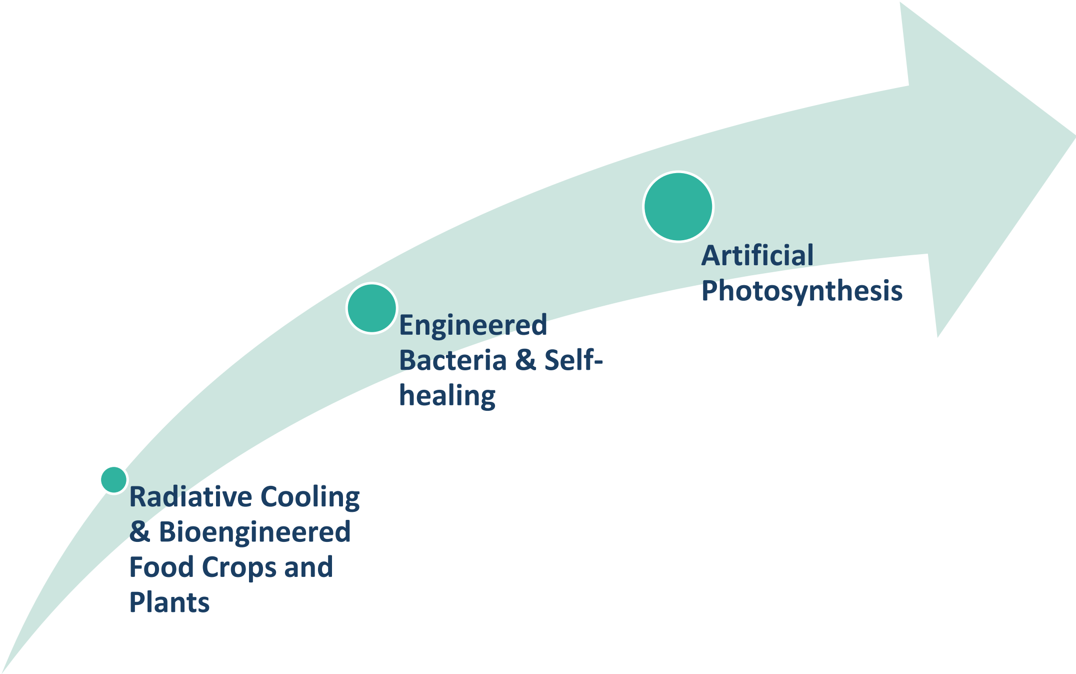


Figure 20 – Priority cluster of bio-inspired technologies

[4] This actually applies to all discussed bio-inspired technologies. Experts stressed out that the market entry in Europe encounters many regulatory issues that make technology uptake particularly long and expensive, as shown by the case of genetically modified organisms.

3.5 Priority clustering of technologies for Energy Efficiency

The main outcomes from the Clustering workshop on Energy Efficiency technologies is here presented with a specific focus on co-defined criteria and assessment of technology portfolio.

3.5.1 Criteria for prioritization

Technical criteria

On the one hand, some co-identified technical criteria focused on key capabilities required in Energy Efficiency technologies, such as **integration**, **encryption**, **data minimization**, as well as the need for **real-time data collection** to monitor, track, have critical materials at one's disposal, perform simulations to forecast and plan accordingly. In addition, addressing **vulnerabilities to malicious agents and cyber-attacks** resulted as paramount. On the other hand, more human-oriented requirements were identified such as an affordable **cost** of the technology, **user-friendly design** as well as **ease of installation**.

Environmental criteria

The discussion around environment highlighted several criteria to be consider, such as **waste generation**, reduction of **energy use**, **water consumption**, and **nature-based solutions**. The **9R framework** (Refuse, Rethink, Reduce, Reuse, Repair, Refurbish, Remanufacture, Repurpose, Recycle and Recover) was considered extremely relevant for environmental sustainability. Other attributes emphasized by participants included **cooling efficiency**, **durability**, and **responsible usage of raw materials**. Moreover, **life cycle assessment** resulted as important as reducing **carbon footprints** and GHG emissions, waste management, usage of renewable energy, and **material availability**. Meeting high levels of **energy efficiency** and **responsible usage of electricity** by the data centres completed the bill of expectations.

Social criteria

Equity in the distribution of technology benefits was a major social criterion considered, ensuring that technological advancements do not exacerbate inequalities. Addressing **energy poverty**, considering **gender impacts**, and the overall **impact on health and well-being** were deemed crucial. The **affordability** of technology and ensuring **decent job conditions** for workers were also highlighted. **Accessibility** and security measures for **personal data protection** were deemed key along with **policies and directives** governing these aspects. The role of **citizens' education** in understanding and utilizing these technologies was also noted as a significant factor.

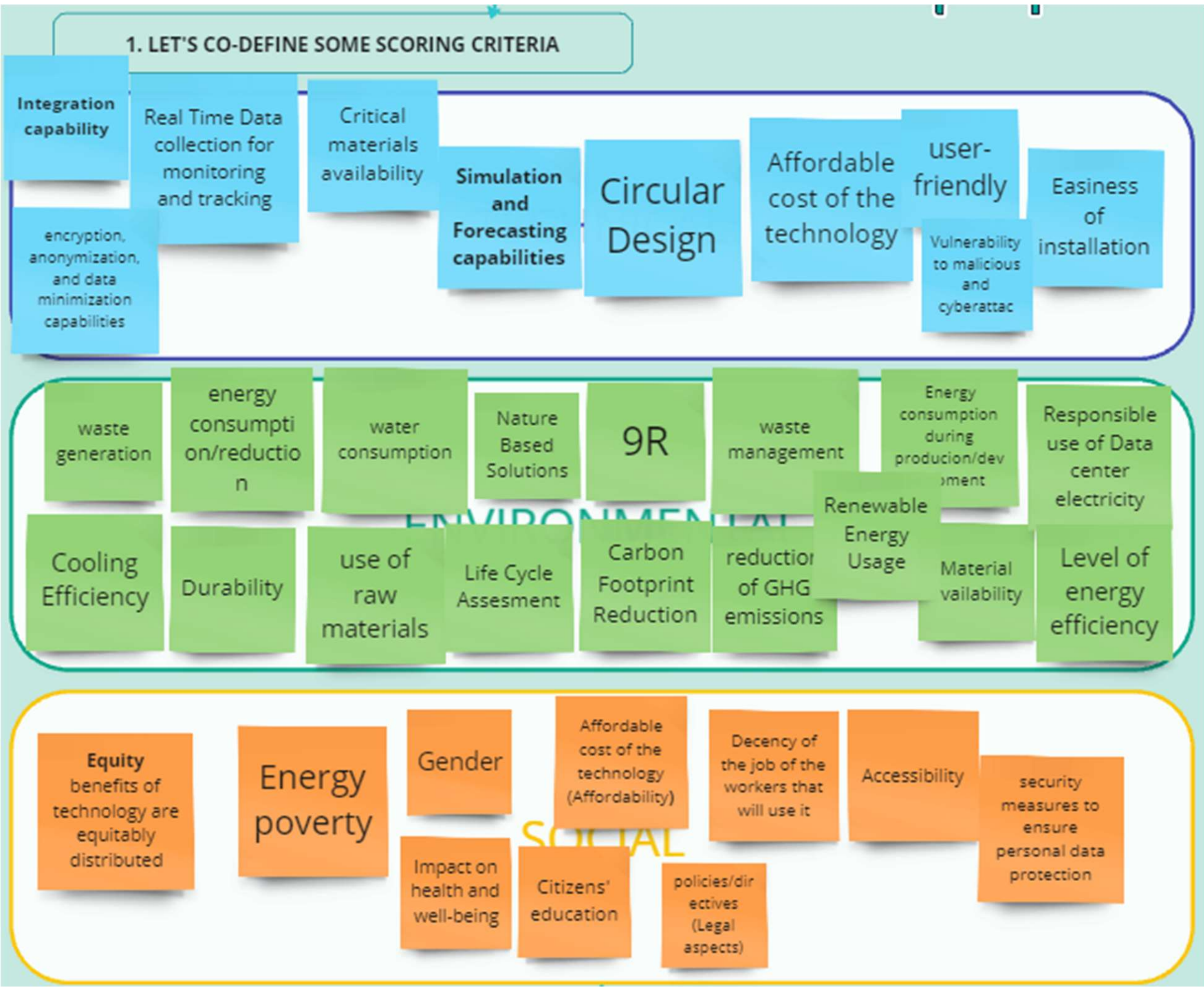


Figure 21 – Screenshot from Session I about co-definition of scoring criteria – Energy Efficiency workshop

Final set of criteria established

Following the initial group exercise, where participants co-identified possible criteria for evaluating technologies, the following ones received most votes:

Technical	Environmental	Social
• Integration capability • Circular design • User-friendly	• Waste generation • Reduction of GHG emissions • Life Cycle assessment	• Equity • Affordability • Decency of the job/Accessibility

Figure 22 – Set of selected criteria - Energy Efficiency workshop

3.5.2 Final priority cluster

During the second session of the workshop, 8 technologies in the field of Energy Efficiency were presented as result from the analysis activity carried out in WP2. Such portfolio of technologies is reported below:

Platooning	Model Predictive Control	Electrochromic Glass	Liquid Desiccant
Membrane Reactor	Algae	Blade technology	Flow batteries

Figure 23 – Initial set of technologies presented in the Energy Efficiency workshop

Based on the final set of criteria established, 5 technologies among the 8 presented were considered most promising.

Model Predictive Control (MPC) can contribute significantly to reducing greenhouse gas emissions by optimizing energy consumption and storage. This technology has been considered a good solution to minimize the cost of energy and to maximize efficiency at the same time. It also supports circular design by enabling continuous improvement and adaptation. MPC could enhance equity by potentially lowering energy costs for consumers. Despite initial setup costs, it is considered affordable in the long run. The technology also promises job creation in software development, system integration, and energy management, promoting job decency and accessibility.

Platooning systems, especially in transport, have huge potential for integration and can still reduce fuel consumption by coordinated driving. The aspect of circular design seemed less relevant, but the technology would turn out to be user-friendly for implementation in logistics and public transport. Platooning seems to offer high environmental added value through reduced GHG due to its optimized use of fuel. In maritime sector, for instance, vessels can be equipped with automation systems to travel in close formation, thus optimising the use of waterways and improving maritime transportation efficiency. From a social point of view, platooning technology was deemed as equitable, potentially lowering transportation costs and making public transport more affordable in the future. It can also generate jobs in technology development and fleet management promoting job creation.

Flow batteries were highly regarded for their integration capability in grid-scale energy storage. They are considered user-friendly to some extent while their design allows for scalability and flexibility. Significant contribution to greenhouse gas mitigation by storing renewable energy was noted for the flow batteries. Nevertheless, when considering life cycle assessment some potential environmental challenges arise related to extracting and processing of vanadium – a key component. Equity and affordability of flow batteries are challenging due to the high cost of vanadium and system installation. Nevertheless, they offer potential for job creation in the renewable energy sector.

Algae technology was deemed as a versatile and integrating technology in several industries, including the production of biofuels and carbon capture. It allows for circular design since it is harvested on a continuous basis and subsequently processed. The level of user-friendliness depends highly on the specific application ranging animal food production to cosmetic sector. Algae-based systems are considered to have a positive impact in terms of environmental sustainability by reducing greenhouse gases through CO_2 absorption. These systems also stand out for the low levels of production waste and the high capacity for recyclability. In social terms, algae technology was considered equitable, providing low-cost solutions for energy and food production, which can benefit low-income communities. It was viewed as affordable and capable of creating a wide range of jobs, from research to agricultural labour.

Electrochromic Glass was first noted for its integration capability within existing building structures. The friendliness of its use, which allows adjustment either manually or automatically to enable the control of solar energy flux, was also a characteristic highlighted. Technology's circular design was identified as an area needing improvement, especially concerning recycling and reuse at the end of its lifecycle. Participants noted that electrochromic windows could reduce greenhouse gas emissions by reducing the need for air conditioning and artificial lighting. The technology demonstrated a good life cycle assessment, but concerns were raised about the waste generated during production and disposal phases. In terms of equity and affordability, electrochromic glass is considered an expensive technology that remains inaccessible to low-income households. At the same time, it could create decent jobs in installation and maintenance, possibly resulting in an increased equity over time.

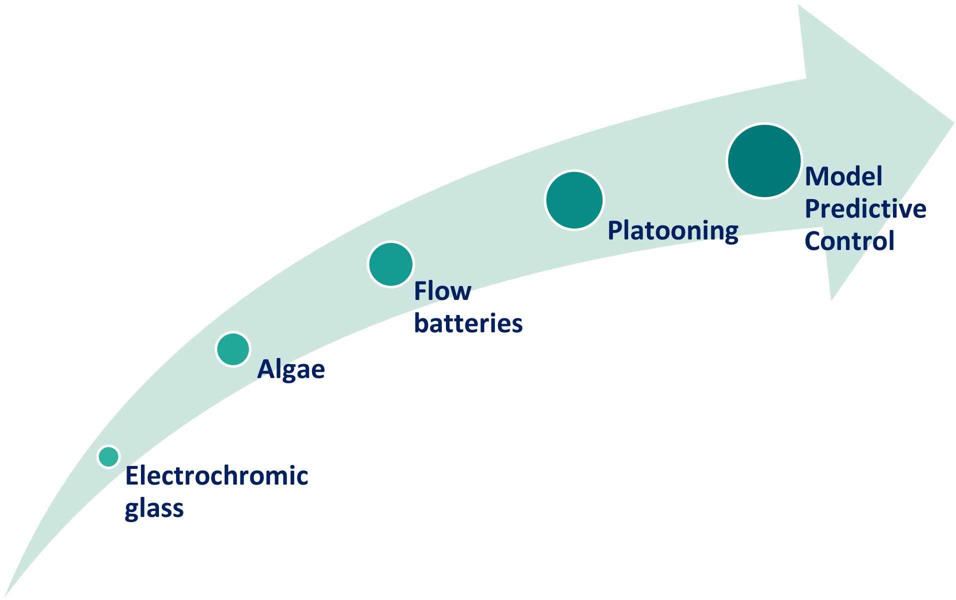


Figure 24 – Priority cluster of Energy Efficiency technologies

3.6 Priority clustering of Real Time Digital Twins and simulation technologies

The below paragraph outlines the main outcomes of the workshop on Real-Time Digital Twins and simulation technologies. After summarizing the scoring criteria co-identified during the first session of the expert discussion, it presents the final cluster of technologies co-created in the second session.

3.6.1 Criteria for prioritization

Technical criteria

Several technical criteria were underscored prior to the assessment of digital twins and simulation technologies. The discussion kicked off with the introduction of the interoperability criterion, referring to the capacity of a technology to interact with existing systems, platforms, and processes. One expert further elaborated this criterion by adding the sticky note "**interoperability and federation of digital twins in a safe and secure way**" to the board. S/He explained that it is not merely about the connection and/or integration of different digital twins, but the real challenge rather lies in data sharing processes: who controls the data? Who has access to it? Ultimately, it is a matter of **data ownership, protection, security, and sovereignty**. Such factors are summarised in the sticky notes "Data security: measures in place to protect data and prevent unauthorized access", "Secure data exchange" and "Data sovereignty: having the right to control and own my data". This logic was eventually integrated into the debate about social criteria as well. In the case of technical criteria, the discussion focused on what might *technically* happen when data are share from one digital twin to another: is **data integrity** impacted? Could anybody (e.g., a malicious agent) manipulate that data during the transition? Other criteria related to the interoperability and federation of digital twins were considered just as important, for instance: **communication reliability**, or **explainability and traceability of dynamic collaboration**. In terms of communication, the **latency** and any other aspects related to its **speed** and **reliability** degree – such as communication performance and security – were considered as well. One participant also mentioned the **emergent behaviour** of the system as a criterion to take into account, given that complex systems might incur unpredictable and/or undesirable factors. Furthermore, the **standardisation of interfaces** was highlighted among technical criteria. According to one expert, the **combination between the return of investment and the socio-economic value expected** of real-time digital twins is another technical criterion to consider, given how expensive it can be (both financially and environmentally) to produce this sort of technology compared to a digital shadow or model. This also explains why the "**maintenance cost**" and the "**upgrading cost** of the technology" sticky notes were added.

Environmental criteria

Moving forward, participants listed a series of environmental criteria well suited to the assessment of digital twins. Among those, **resource efficiency**, **carbon footprint**, the **use of renewable energy sources**, and **energy consumption in data centres' power stations** were some of the most debated ones. As real-time digital twins and simulation technologies typically require high levels of energy consumption, **environmental impact assessments** are key, and for this reason a related sticky note was added to the board. Similarly, the **adjustment of power usage according to the demand** was another mentioned criterion. One participant wrote "**Planet Earth monitoring**" as a sticky note referring to existing programs aimed at Earth observation and monitoring through simulation technologies that allow scientists to capture data about the planet to then process it in the virtual world. Finally, participants agreed on introducing the criterion of **balance between the technology's lifecycle duration and the added value** it actually brings.

Social criteria

Social considerations generated a rich discussion among participants, who co-identified several criteria to assess digital twins based on socially relevant issues. The main ones were summarised by one participant in the first sticky note that was put on the board: **personal data management and ownership**, **social trust** in digital technologies, **accessibility** and **inclusion**. These criteria were then repeated in other sticky notes, as they were the main focus of the whole discussion. Another criterion concerning the low degree of **digitalisation of society** was introduced as one participant pointed out that there is a general lack of **public readiness** to adopt digital twins. This is clearly related to **accessibility** issues and to **educational gaps**: people who do not understand technology or who do not have access to technology are certainly not encouraged to trust it or to easily adopt it. Other highlighted criteria, such as **equity**, **explicability**, and **democratisation of access to data and services** offered or generated by simulation technologies, are also part of the same challenge: making technology available to as many people as possible, so that the largest possible segment of society can benefit from the value it brings.

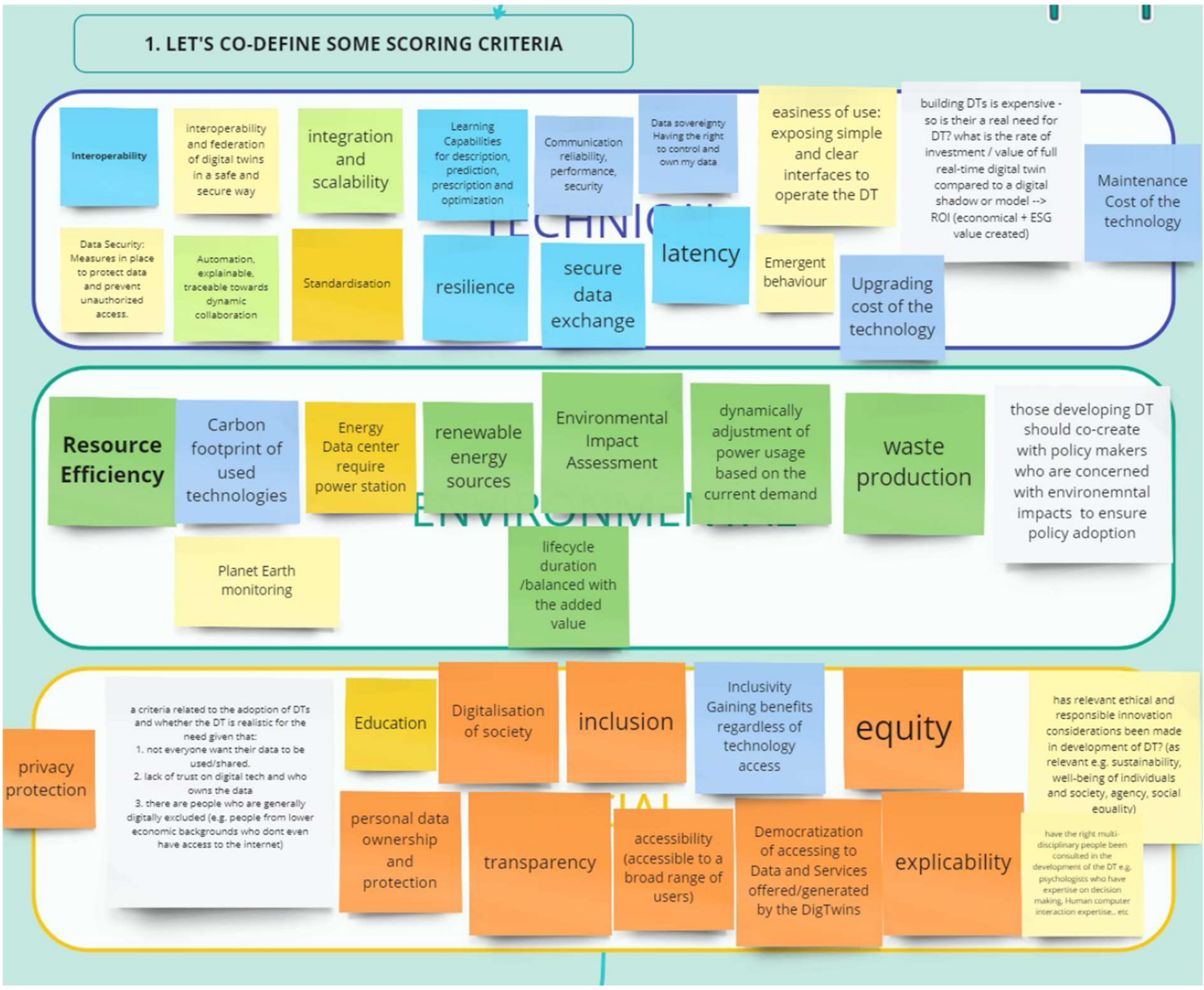


Figure 25 – Screenshot from Session I about co-definition of scoring criteria – Real-time Based Digital Twins and Simulation workshop

Figure 26 contains the set of criteria selected by participants as the most relevant to assess the workshop's technological portfolio. As for previous workshops, such selection was carried out through the Miro board voting system.

Technical	Environmental	Social
•Standardisation •Safe and secure interoperability and federation of digital twins •Usability	•Renewable energy sources •Environmental impact assessment •Lifecycle duration	•Personal data ownership and protection •Transparency •Accessibility

Figure 26 – Set of selected criteria – Real-time Based Digital Twins and Simulation workshop

3.6.2 Final priority cluster

Figure 27 below illustrates the initial portfolio presented to expert attendees by the FORGING consortium, based on project results collected through the WP2 implementation and within the real-time digital twins and simulation technological framework.

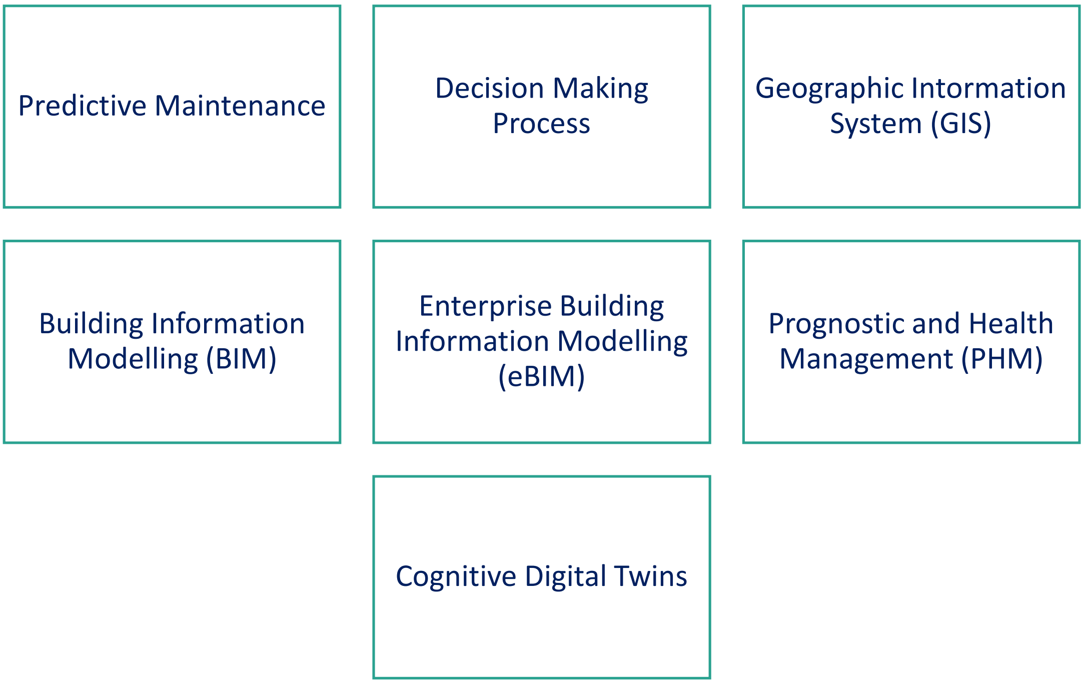


Figure 27 – Initial set of technologies presented in the Real-time Based Digital Twins and Simulation workshop

Starting from this portfolio, participants engaged in an active discussion aimed at assessing the proposed technologies and at co-creating the final cluster of most promising ones. To do so, they shared with each other examples and best practices of concrete potential uses of each technology in different application sectors. The co-created cluster of most promising technologies is shown in Figure 28.

Geographic Information Systems, **Building Information Modelling** and **Enterprise Building Information Modelling** were gathered in a single cluster of technologies with a high potential of application in the urban sector, and specifically in smart cities planning. In fact, experts indicated several ways in which their use could be (better or at all) implemented: to improve air quality management, to optimize retrofitting, to achieve better traffic management, to boost urban water systems, to facilitate infrastructure investments evaluation (e.g. for electric vehicles charging stations), to improve crisis management mechanisms, to accelerate decarbonization of heat and power systems, for traffic and people flows prediction, and more broadly speaking, for urban safety enhancement.

Predictive Maintenance's potential use was mainly associated to remote sensing mechanisms in different sectors of application, namely health, agriculture, and transportation. For instance, one participant mentioned specific systems designed to predict maintenance needs for agricultural drones. The possibility to use this technology to detect possible diseases and act before they arise was also discussed, as a form of implementation of predictive maintenance to advance public health systems. Another possible way to benefit from it in the health sector is by monitoring hospitals affluence, or the number of people buying medications in pharmacies, or else the geographical spread of illnesses. Lastly, one expert referred to the use of predictive maintenance for roads and highways maintenance, citing the Digital Roads of the Future Initiative implemented by the University of Cambridge.

Prognostics and Health Management was indicated as a potentially well-suitable technology in space engineering, for instance when it comes to air traffic control management and to space telecommunication, but also in the manufacturing sector, in terms of optimization of network performance.

Cognitive Digital Twins were linked to environmental observation, meaning that some participants see in this technology the potential to enhance environmental observation mechanisms.

Decision Making Processes were related to the virtualization of manufacturing processes and indicator prediction: by virtualizing certain processes before they happen, it is possible to "try out multiple combinations of different potential solution before actually bringing them to the field" – an expert explained – and by doing so, the costs of the manufacturing process can be reduced.

Overall, building Information Modelling (BIM) and Cognitive Digital Twins secured the highest evaluation, obtaining the most votes; followed by Predictive Maintenance, which also received an overall positive evaluation. Geographic Information Systems ranked third, while Prognostics and Health Management (PHM) and Decision-Making Processes resulted as the less promising technologies and collected a lower number of preferences.

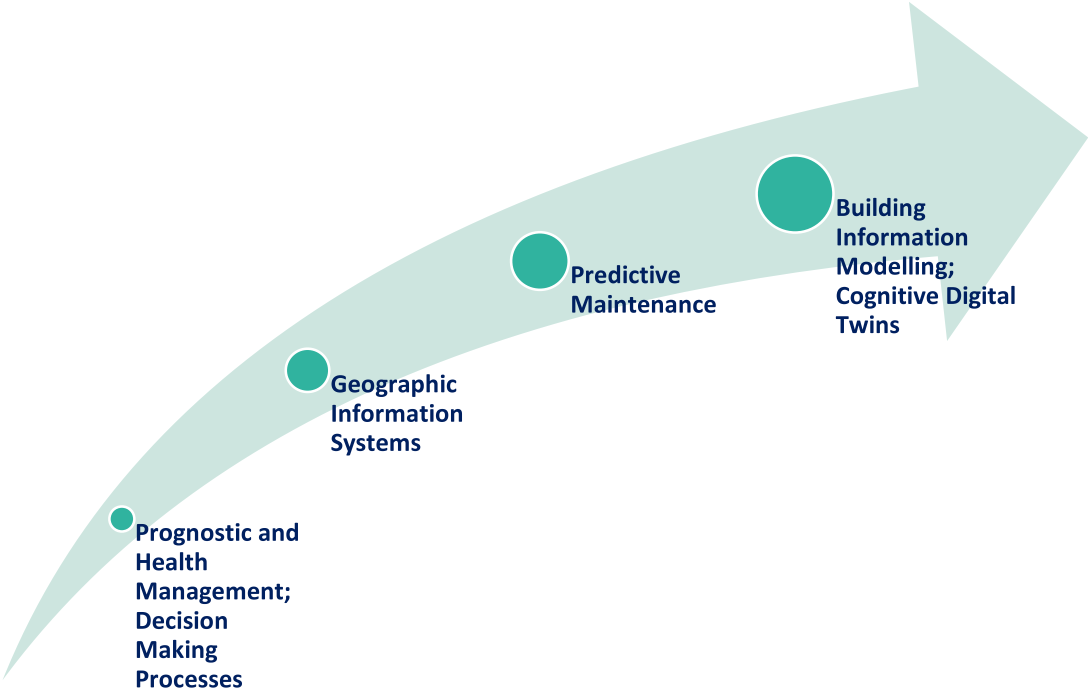


Figure 28 – Priority cluster of Real-time Based Digital Twin and Simulation technologies

4. Conclusions

The Technology Clustering workshops series was a crucial step along the FORGING process to gather feedback and insights on emerging technologies identified within the project. During the workshops, a clustering of these technologies was achieved based on their potential not only in technical terms, but also in the environmental and social dimensions.

Although much depends on the specific application of each technology, some patterns emerged throughout this event series regarding the co-identified criteria and the related technical, socio-economic and environmental challenges that novel enabling technologies pose.

As for criteria, the **usability degree of examined technologies** was a recurring point of discussion: participants often stressed the importance of designing technologies in a user-friendly manner and by keeping in mind the end-user's needs, thus fuelling the project's human-centric approach and following up on FORGING's value-sensitive innovation journey. Other key technical considerations highlighted in more than one workshop include the **interoperability** with existing systems and the adherence to legal frameworks. From an environmental point of view, experts primarily focused on the importance of sustainable resource use and management, comprehensive lifecycle assessments, minimizing energy consumption, and reducing carbon footprint and emissions. These factors were seen as foundational in understanding and assessing the impact of emerging enabling technologies on the environment, from the design phase to the market uptake. In terms of social impact, some of the critical factors commonly debated were personal data privacy and security, inclusivity and accessibility, and fair working conditions. The broader topic of the impact that such technologies might have on the employment/jobs was highly discussed, and experts pointed out several times the **ethical challenges** that may arise throughout the supply chain in this domain. A concern over both data ownership and management, and the risks of misuse of personal information in the digital age clearly emerged. Discussions were also centred on the challenge posed by novel technologies when it comes to ensuring that technological advancements benefit a broad spectrum of society, including marginalized communities.

Overall, the co-creation activities carried out during this series revealed a strong consensus that **environmental and social considerations should be integrated into the design, assessment and evaluation processes** of new technologies. The holistic approach adopted in each workshop allowed participants to be able to discuss both technical ways to foster advanced innovation while taking into account ethical issues and aligning with socio-economic goals of sustainability and equity. The insights gathered from these workshops will inform the subsequent co-creation activities planned in FORGING WP4, ensuring that the project's technological portfolio aligns with stakeholder perspectives and preferences. The prioritized technologies will serve as a basis for identifying concrete use cases and further developing innovative solutions that support the digital and green transitions.

The main findings are summarised in Table 2 below:

Industry 5.0 Technological Framework	Co-identified Assessment Criteria			Co-created Cluster of Technologies
	Technical	Environmental	Social	
ARTIFICIAL INTELLIGENCE	• Open data and open algorithm • Compliance with security standards • Truth and reality checking	• Edge AI • Efficiency of resources • Positive impact of ecological performance	• Positive cognitive impact • Positive workforce transformation • Accessibility and inclusivity	**1. Text recognition** **2. Inspection and maintenance robots** **3. Machine translation** **4. Aerial robots; Biometric systems**
CYBER SAFE DATA TECHNOLOGIES	• Resilience • Compliance with legislation and technical standards • Scalability and interoperability	• Circular design • Carbon footprint • Energy sources	• Inclusivity and accessibility • Transparency and explainability • Fairness and bias-free	**1. Cryptography** **2. 6G network** **3. Quantum computing; Blockchain** **4. Ad hoc networks** **5. Machine learning systems**
HUMAN-MACHINE INTERACTION	• Usability and end-user design • Personal data management • Balanced transparency	• Sustainable production without labour exploitation • Carbon footprint • Resource use	• Universal design • Privacy and ethics • Impact on employment	**1. Digital twins** **2. Haptic technology** **3. Natural language processing** **4. E-skin sensor; Internet of Things** **5. Computer vision**

BIO-INSPIRED TECHNOLOGIES AND SMART MATERIALS	• Lifecycle • Interoperability • Biodegradability	• Sustainability and reusage • Cradle-to-grave lifecycle assessment • Potential to reduce energy consumption	• Open data and open algorithm • Compliance with security standards • Truth and reality checking	**1. Artificial photosynthesis** **2. Engineered bacteria; Self-healing** **6. Radiative cooling; Bioengineered food crops and plants**
TECHNOLOGIES FOR ENERGY EFFICIENCY	• Integration capability • Circular design • User-friendly	• Waste generation • Reduction of GHG emissions • Lifecycle assessment	• Equity • Affordability • Decency of the job/accessibility	**1. Model predictive control** **2. Platooning** **3. Flow batteries** **4. Algae** **7. Electrochromic glass**
REAL-TIME BASED DIGITAL TWINS AND SIMULATION	• Standardisation • Safe and secure interoperability and federation • Usability	• Renewable energy sources • Environmental impact assessment • Lifecycle duration (balanced with the added value)	• Personal data ownership and protection • Transparency • Accessibility	**1. Building information modelling; Cognitive digital twins** **2. Predictive maintenance** **3. Geographic information systems** **8. Prognostic and health management; Decision making processes**

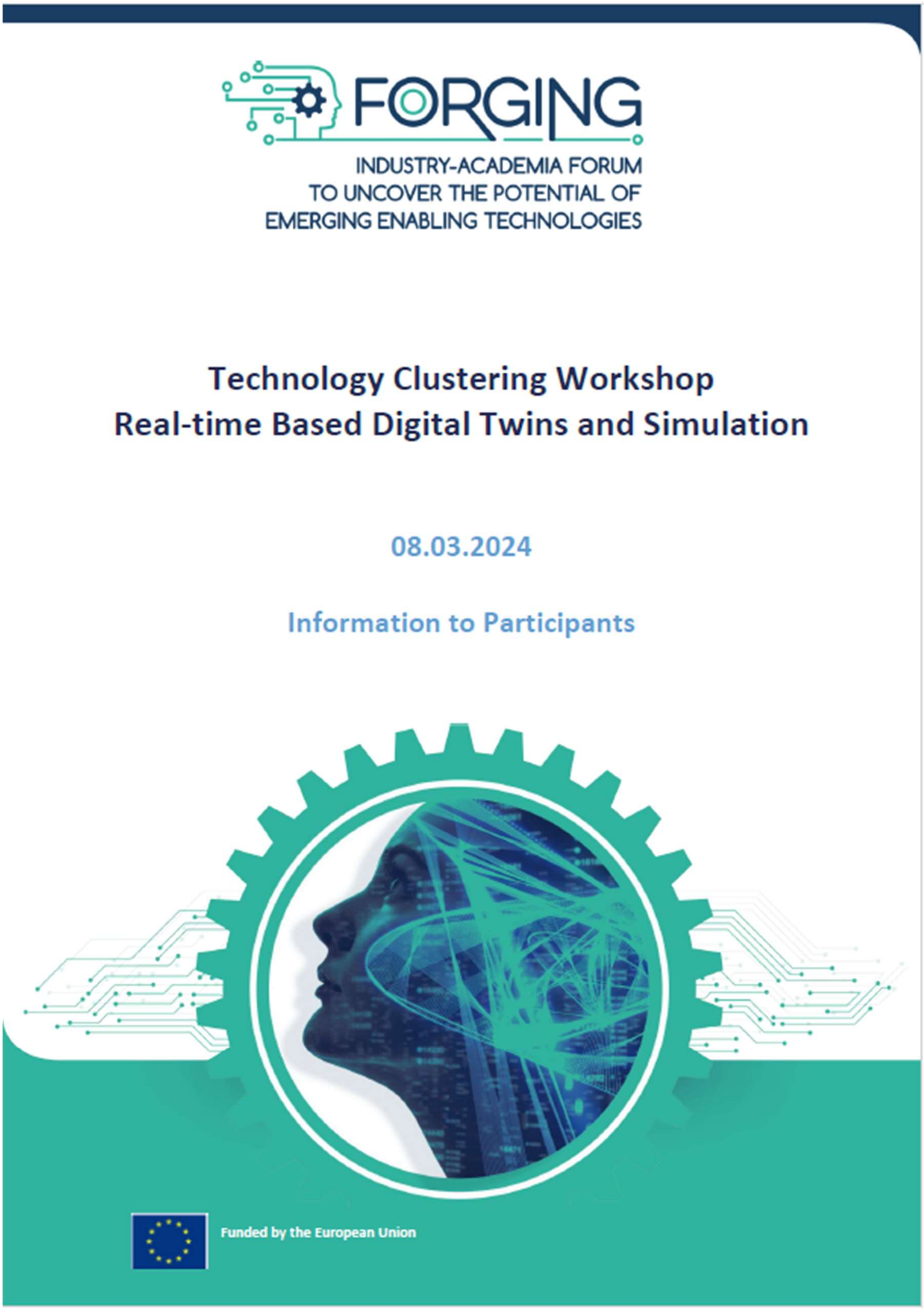
Table 2 – Results in a nutshell

Finally, Table 3 presents the reader a summary of assessment criteria to be taken into account when evaluating emerging enabling technologies. Such summary, based on expert participants' feedback gathered during the Technology Clustering workshop series, is intended to enhance FORGING's efforts to integrate social and environmental considerations in the development, market uptake and evaluation on novel technologies of Industry 5.0.

Technical criteria	Environmental criteria	Social criteria
- Open data - Open algorithm - Reality checking - Compliance with regulatory standards - Scalability - Interoperability - Scalability - Resilience - Usability - End-user design - Transparency - Lifecycle assessment - Integration capability	- Efficient use of resources - Good ecological performance - Circular design - Carbon footprint - Energy consumption - Use of renewable energy - Sustainable production - Environmental impact assessment	- Positive cognitive impact - Positive workforce transformation - Accessibility - Inclusivity - Transparency - Explainability - Fairness - Universal design - Impact on employment - Fair working conditions - Personal data management - Equity - Affordability

Table 3 – Assessment criteria for emerging enabling technologies

Annex: Information Packages



FORGING
INDUSTRY-ACADEMIA FORUM TO UNCOVER THE POTENTIAL OF EMERGING ENABLING TECHNOLOGIES

Technology Clustering Workshop
Real-time Based Digital Twins and Simulation

08.03.2024

Information to Participants

Funded by the European Union

Dear Participant,

We are delighted to welcome you to the upcoming FORGING workshop focusing on **Real-time Based Digital Twins and Simulation**!

You may find below some useful information to make your participation as smooth as possible.

Date: March 8th

Time: 9.00 – 12.30 CET

Where: The workshop will be held online via Microsoft Teams. You will receive the link via email once your attendance is confirmed.

Agenda:

09:00 – 09:30	**Welcome and Introduction**
09:30 – 09:50	**FORGING results presentation – Perspective Cards** FORGING partner (VTT) will show the Perspective Cards as project tool aimed at exploring the potential of emerging technologies towards a sustainable and responsible innovation journey
09:50 – 10:45	**Session I: Co-definition of scoring criteria to select Emerging Technologies** Participants will collaborate to co-define scoring criteria to evaluate the technological portfolio
10:45 – 11:00	Coffee break
11.00 – 11.15	**FORGING results presentation – Strategic Matrix**

	FORGING partner (STAM) will illustrate the Strategic Matrix of technologies developed so far in the framework of FORGING
11:15 – 12:15	**Session II: Co-creation of the Priority Clustering** Based on the selected criteria, participants will revise the initial technological portfolio and create a priority cluster of the technologies
12:15 - 12:30	**Final discussion and Conclusions**

Aim and objectives:

1. Co-define evaluation/scoring **criteria to prioritise responsible emerging technologies**, weighing aspects such as societal aspects, sustainable considerations, feasibility, and human desirability.
2. Establish a priority **clustering of the technologies**.

Role of participants:

Participants will have the opportunity to provide feedback on the FORGING technological portfolio, and to co-define criteria on the basis of which select the most promising technologies.

The workshop will be based on a **co-creation process** enhancing collaboration among participants.

Participation guidelines for successful co-creation:

- **Be fully present and avoid multitasking.** Your undivided attention is essential throughout the workshop.
- **Engage and collaborate with fellow participants.** Active participation is key. Use the Miro board to interact with fellow experts and project partners.
- **Trust the process and facilitation.** Adhere to the scheduled time limits, as you will achieve your goals by doing so.
- **Stay curious and have fun.** Co-creation is an exciting opportunity – let's make the most of it!

Tools:

We will use the Miro board throughout the workshop. If you are not familiar with this collaboration tool, you may find instructions at the below links:

a) Short video explaining how to use Miro; b) Miro basics: a guide for new participants.

Background:

FORGING is a new flagship initiative funded by the European Commission to assist the growth and manifestation of emerging enabling technologies and to accelerate their uptake by industry and society.

The aim of FORGING is to initiate a sustainable and interactive multi-sector and multi-stakeholder Forum that actively supports the co-creation and the uptake of enabling technologies in support to the digital and green transitions through human-centred technologies and innovations, respecting the boundaries of the planet, and maximising benefits for society as a whole.

FORGING focuses on six technological frameworks in line with the Industry 5.0 framework:

1. Human-centric solutions and human-machine-interaction
2. Bio-inspired technologies and smart materials
3. Real time-based digital twins and simulation
4. Cyber safe data transmission, storage, and analysis technologies
5. Artificial Intelligence
6. Technologies for energy efficiency and trustworthy autonomy.

The project consists of three main phases:
(1) technology uncovering through the **identification of emerging technologies** and of expected economic, societal and environmental effects;
(2) **analysing future societal scenarios** for the enabling technologies;
and (3) **co-creating concrete use cases** for the uncovered technologies.

The FORGING consortium includes six European partners: *INL – International Iberian Nanotechnology Laboratory* (Project Coordinator), *G.A.C. Group*, *STAM SRL*, *I2CAT – The Internet Research Centre*, *APRE – Agency for the Promotion of European Research*, and *VTT – Technical Research Centre of Finland*.

FORGING started in October 2022 and has produced relevant results so far. Partners and experts from across the EU analysed existing factors and implications of the technological frameworks, as well as unwanted and unintended consequences for society and the environment. By combining co-creation events with in-depth desk research, we analysed technological opportunity areas and associated challenges to be addressed in the next stages of the project.

By partaking in this workshop, you will contribute first-hand to further enhance FORGING mission.

We are looking forward to shaping the future together!

FORGING

INDUSTRY-ACADEMIA FORUM
TO UNCOVER THE POTENTIAL OF
EMERGING ENABLING TECHNOLOGIES

Technology Clustering Workshop
Real-time Based Digital Twins and Simulation

08.03.2024

Information to Participants (Part II)

Funded by the European Union

Dear Participant,

Welcome on board!

In view of your participation in the **Technology Clustering Workshop on Real-time Based Digital Twins and Simulation** to be held on March 8th, we are pleased to provide you with more specific information about the event.

Date: March 8th

Time: 9.00 – 12.30 CET

Where: Microsoft Teams – Link available here[5].

How: We will engage in a co-creation process through the Miro board. If you are not familiar with this collaboration tool, you may find a short presentation in this video. You may also consult this guide for additional tips on how to use the tool.

Workshop Agenda:

09:00 – 09:30	**Welcome and Introduction**

[5] *Please note that the workshop will be recorded for the purposes of the analysis of results. Check the FORGING privacy policy.*

	FORGING partners (APRE) will present the project context, illustrate the workshop goals, go through the agenda, and conduct an icebreaker session
09:30 – 09:50	**FORGING results presentation – Perspective Cards** FORGING partners (VTT) will show the Perspective Cards as project tools aimed at exploring the potential of emerging technologies towards a sustainable and responsible innovation journey.
09:50 – 10:45	**Session I: Co-definition of scoring criteria to select Emerging Technologies** Participants will collaborate to co-define scoring criteria to evaluate the technological portfolio.
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11:15 – 12:15	**Session II: Co-creation of the Priority Clustering** Based on the selected criteria, participants will revise the initial technological portfolio and create a priority cluster of the technologies.
12:15 - 12:30	**Final discussion and Conclusions**

FORGING Project Results: The Technological Portfolio

In the upcoming workshop, the following technologies will be discussed:

Definition of Technologies:

- **Predictive maintenance**: as well explain by IBM, predictive maintenance "can identify, detect, and address issues as they occur, as well as predict the potential future state of equipment, and so reduce risk" (Retrieved from IBM online)
- **Decision making process**: refers to the capability to identify the solutions of specific problems, or as explained by Taylor (2013)[6], "decision making is that thinking which results in the choice among alternative courses" (p.48).
- **Geographic information systems (GIS)**: refers to a system which gathers, storages data referring to a specific geographic place. Types of data may include not latitude, longitude, but also information on the landscape (e.g. vegetation).
- **Building Information Modelling (BIM)**: as also recalled in Kubba (2012)[7] "BIM is the virtual representation of the physical and functional characteristics of a facility from inception onward. As such, it serves as a shared information repository for collaboration throughout a facility's life cycle" (p.201).

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[6] *Taylor, D. W. (2013). Decision making and problem solving. Handbook of organizations, p. 20, pp. 48-86.*

[7] *Kubba, S. (2012). Handbook of green building design and construction: LEED, BREEAM, and Green Globes. Butterworth-Heinemann.*

- **Enterprise BIM (EBIM)**: refers to BIM concept focusing on the enterprise dimension.
- **Prognostic and health management (PHM)**: refers to a "cutting-edge integrated technology, which takes knowledge, information and data of system performance, control, operation and maintenance as input to: i) detect the initiation of anomalies, ii) isolate/diagnose the occurring failures, iii) predict the health state of the system in the future and estimate its remaining useful life to dynamically support the maintenance decisions" (Hu, Miao, Si, Pan and Zio, 2022)[8].
- **Cognitive digital twins**: is related to an extension of the concept of Digital Twin and it refers to "a digital representation of a physical system that is augmented with certain cognitive capabilities and support to execute autonomous activities; comprises a set of semantically interlinked digital models related to different lifecycle phases of the physical system including its subsystems and components; and evolves continuously with the physical system across the entire lifecycle" (Zheng, Lu and Kiritsis, 2022, p. 7614)[9].

[8] *Hu, Y; Miao, X; Si,Y.; Pan, E.; Zio, E.; "Prognostics and health management: A review from the perspectives of design, development and decision" in Reliability Engineering & System Safety, Vol. 217, 2022.*

[9] *Xiaochen Zheng, Jinzhi Lu & Dimitris Kiritsis (2022) The emergence of cognitive digital twin: vision, challenges and opportunities, International Journal of Production Research, 60:24, pp. 7610-7632.*

Annex II?
FORGING Project Results: Perspective Cards

INSTRUCTIONS

Industry 5.0 takes humans to the centre industry. These perspective cards are aimed to generate empathy for and understanding of the world views for the perspective holder when designing applications of an emerging technology.

They are best used in a role-playing game, where each player takes the perspective of the key stakeholder and examines the set of questions with a particular technology in focus. The card deck includes perspectives and a technology card. The technology card provides a set of emerging technologies and their priority application areas that are to be discussed individually on each round of the game. The six perspectives provide detailed prompts around the interests of the actors, providing ground for the exploration of considerations about the societal impacts of technology.

The six perspectives are:

- **Developer** (the entity that creates, designs and releases an application)
- **Citizen** (including perspectives of agency, education and activism)
- **User** (individual, company)
- **Regulator** (different levels of governance, including non-traditional regulation actors)
- **Investor/venture capitalist** (funder of companies and start-ups)
- **Malicious agent** (interest group, organized crime, state, individual)

This is a game with no individual winner or losers, but a good game will typically generate new ideas, contribute to identifying potential problems, and the solutions for those problems.

You can take multiple rounds and change the perspectives, and you can start the game over with a new technology.

Have fun!

DEVELOPER – Questions to Consider

- How can my solutions support better quality decision-making based on high-quality data?
- Can I create solutions that reduce the need for physical travel?
- How are my solutions supporting environmental sustainability and social fairness?
- Am I making sure that I am developing solutions that are inclusive and create opportunities for everyone, e.g. for those who have restrictions in moving in the physical world?
- Are my solutions discouraging people from being active in the physical world?
- How do I ensure that my use of data preserves individuals’ privacy?

New Questions?

CITIZEN – Questions to Consider

- Will I be able to maintain human contacts if I am hospitalized or placed in elderly care?
- Will some of the services I depend on be offered only in virtual spaces or will I have the possibility to select an option in the physical world?
- Will the use of digital twins and simulations offer me more opportunities to get involved in the development of my neighbourhood or city?
- Will the use of digital twins and simulations enhance my capabilities to participate in the working life?
- Can I trust that my privacy is always ensured even with the increased use of data?
- Are the services I am being offered optimized for economic rationality or human needs?

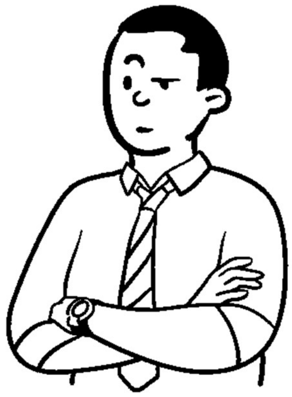
New Questions?

USER – Questions to Consider

- Is my job being threatened by my activities being modelled for simulations?
- Will someone notice and help if I get too involved in virtual spaces and start to suffer mentally because of it?
- What are the risks that I should be concerned about regarding the possible monopolization of digital twin and simulation technologies?
- Is the usability, functionality and affordability of the solutions I use ensured to all groups as well as possible?
- Is moving between the virtual and the real world seamless from all perspectives (economic, social, political, psychological etc.)?
- Do I understand enough about the solutions that I am using to make informed decisions about their use, for instance regarding their energy use or privacy related issues?

New Questions?

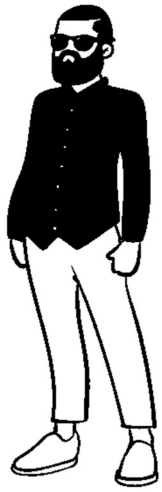
REGULATOR – Questions to Consider



- How can I promote energy-efficient algorithms and infrastructure to mitigate the environmental impact of digital twins and simulation, while ensuring sufficient computational power for complex models?
- How can I ensure responsible data collection, storage, and utilisation in digital twin and simulation applications, especially through clear frameworks for data ownership, privacy, and transparency?
- How can I address potential negative societal impacts of digital twins and simulation, including social isolation, job displacement, and the influence of biased algorithms in decision-making processes?
- How can I champion the development of inclusive digital twin and simulation technology, ensuring affordability and usability for all social groups, regardless of income, disability, or technological literacy?
- How can I make use of foresight within regulatory bodies to anticipate the potential long-term social, economic, and environmental consequences of large-scale digital twin and simulation implementations?
- How can I develop regulations that establish ethical guidelines for the evolving relationship between the physical and virtual worlds facilitated by digital twins and simulations?

New Questions?

INVESTOR – Questions to Consider



- How can I identify early-stage digital twin and simulation applications with disruptive potential, considering not only technological breakthroughs but also integration with existing infrastructure and workforce capabilities?
- How can I prepare for the potential disruption of quantum computing in the digital twin and simulation space?
- How can I balance the benefits of open-source data and simulation platforms with the need for intellectual property protection for proprietary algorithms and functionalities?
- How can I ensure that I prioritise companies with strong data privacy practices, accessibility considerations, and focus on solutions that address societal challenges beyond economic gains?
- How can I make sure that my investment decisions prioritise companies with robust methodologies for bias detection and mitigation, ensuring fair and equitable outcomes?
- How can I ensure my portfolio is adaptable and focused on modular and interoperable solutions that can be easily adapted to changing user needs and advancements in related fields such as AI and augmented reality?

New Questions?

MALICIOUS AGENT – Questions to Consider

- How can I exploit the complexity of real-time simulations to mask my activities and make it difficult to detect or attribute malicious actions?
- How can I manipulate real-time data streams within digital twin simulations to disrupt decision-making in critical infrastructure or financial markets?
- Am I able to weaponize personalised avatars and deepfakes within simulations to create discord, manipulate behaviour, or spread misinformation?
- Can I manipulate user perception or introduce delays to lead to critical errors in human-machine interface of real-time simulations?
- Can I use real-time social simulations to exacerbate societal tensions, polarise public opinion, or incite violence?
- Can I exploit potential blind spots in regulations or bypass ethical and security measures designed to prevent malicious manipulation of real-time simulations?

New Questions?

FORGING is a new flagship initiative funded by the European Commission to assist the growth and manifestation of **emerging enabling technologies** and accelerate their uptake by industry and society.

We invite you to find out more from our **video** that you can watch **here!**

Looking forward to shaping the future together!