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Weak signals in Science and Technologies - 2024

Technologies at an early stage of development that could impact our future

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Contents

Abstract

Detecting emerging technologies is crucial for policymaking as it helps to anticipate future trends and address their potential societal, economic, and security impacts. Early identification also allows policymakers to support strategic industries, orient research and innovation, and guide regulation to ensure competitiveness.

The present report presents a comprehensive analysis of 221 weak signals in technology development, distributed in twelve clusters, which were detected over the course of 2024. These signals were spotted using text mining, clustering techniques and scientometric indicators applied to peer-reviewed scientific publications (Scopus) and patent documents (Patstat).

Executive summary

Detecting emerging technologies is crucial for policymaking as it helps to anticipate future trends and address their potential societal, economic, and security impacts. Early identification also allows policymakers to support strategic industries, orient research and innovation, and guide regulation to ensure competitiveness.

The present report presents a comprehensive analysis of 221 weak signals in technology development. These early-stage emerging technologies were detected over the course of 2024 and are distributed in twelve clusters. These emerging technologies were spotted using text mining, clustering techniques and scientometric indicators applied to peer-reviewed scientific publications (Scopus) and patent documents (Patstat).

Key findings

— **The United States and China are at the forefront** of producing scientific knowledge across most clusters of emerging technologies. Although it does not lead, **Europe holds a strong position in research** for emerging technologies in the clusters of Digital Twin, Artificial Intelligence and Machine Learning, Therapeutics and Biotechnologies, Energy, and Environment and Agriculture, contributing a significant share of scientific publications. European organisations also contribute significantly to top 1% most impactful scientific articles.

— **China and the US are leading in patenting** for all twelve categories. European organisations consistently file fewer patent applications compared to their counterparts in China and the United States. This trend holds even in areas where European organizations lead in scientific research, reaffirming findings from previous JRC weak signal reports and other recent studies. These reports highlight that **European R&D organisations file less patents** on their research results than organisations in China or in the United States.

— The **European R&D ecosystem appears fragmented**. While Europe serves as a key global hub for the exchange of scientific knowledge in most of the emerging technologies covered in this report, the presence of European organizations among the top-performing entities is limited. This suggests a lack of critical mass with many strong scientific actors of small size.

— Overall, the **European R&D ecosystem does not show specialization** across most clusters of emerging technologies, except for Artificial Intelligence and Machine Learning. In this area, Europe demonstrates a certain degree of specialization, though to a lesser extent than China. This indicates that European organizations are more focused on these technologies and contribute a proportionally larger share of scientific knowledge in this domain compared to other emerging technology clusters.

1 Introduction

Emerging technologies

Technology emergence refers to the transition of novel technologies from early stages of development to widespread adoption across industries and society. This dynamic process is driven by the convergence of various factors, such as scientific breakthroughs, market demand, and sustained investment in research and development. Given that emerging technologies can profoundly reshape and disrupt societal structures and market dynamics, their early detection is crucial for the timely development of innovation policies aimed at promoting both a stable business environment and a safe, secure society for citizens. Monitoring technology emergence allows to anticipate opportunities and potential risks, thus enabling informed, proactive policymaking and strategic planning.

Detecting emerging technologies and assessing their potential future impacts pose methodological and analytical challenges. Various methods can be employed, including foresight techniques, such as horizon scanning, scenario planning or trend analysis. These techniques typically involve the use of both qualitative and quantitative methods to anticipate future technological developments and their potential implications for society and markets. The process implies gathering and analysing data from a wide range of sources, such as academic publications, patents, expert opinions, or market analysis reports.

Data from various sources can be used in data-driven technology foresight. For example, web scraping techniques can retrieve data online, such as news articles or social media posts. Other approaches call on more traditional databases to spot emerging technologies like venture capital investments data, research funding data, patent declarations or scientific publications. Data analytics using AI techniques like machine learning or large language models can be coupled to scientometrics to detect signals in these various databases. By combining these methods, policymakers and other stakeholders can gain a comprehensive understanding of emerging technologies and make informed decisions about their development and deployment. The insights gained from technology foresight activities are valuable for guiding policymaking in adapting regulatory frameworks, and for ensuring that all relevant stakeholders are ready to respond to or capitalize on future changes.

Technology foresight at the JRC

As one of the main providers of scientific and technical advice to the European Commission, the Joint Research has built its foresight capabilities to support policymakers to anticipate and better prepare for the future. The JRC technology foresight is a multidisciplinary activity that combines qualitative methods, including expert solicitation and scenario planning, with data analytics. Through its qualitative foresight activities, the JRC brings together relevant experts and stakeholders to develop anticipatory knowledge and collect insights on possible alternative futures. As many policy fields have a technological component, these scenarios for the future are used to support policy makers by assessing possible long-term implications and opportunities of technological development[1]. In 2018, the JRC started to develop a more quantitative approach to technology

1 See for example: European Parliament; General Secretariat of the Council of the European Union; European Commission, Secretariat-General; European Commission, Joint Research Centre; European External Action Service; European Economic and Social Committee; European Committee of the Regions, European Court of Auditors, European Investment Bank, EU Institute for Security Studies: *"Choosing Europe's future"*, Barry, G. (editor), Publications Office of the European Union, Luxembourg, 2024, https://data.europa.eu/doi/10.2760/180422, JRC137474.

foresight to complement the qualitative activities already in place. This new approach, relying on data, aims at detecting early signs of emerging technologies and scientific developments (the so-called "weak signals"[2]) relying on a mix of text mining techniques and scientometric indicators, applied on a corpus of peer-reviewed scientific publications, patents, and EU-funded R&D projects[3,4,5] (see chapter on methodology for more details).

In addition to previously published reports[6,7,8,9] on emerging technologies, weak signals of technology emergence have been used to feed various foresight processes in the Commission and related institutions (see for example the two public reports on border control technologies[10] and horizon scanning for nuclear safety and security[11]).

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3 G. Joanny, S. Perani, O. Eulaerts, Detection of disruptive technologies by automated identification of weak signals in technology development. Proceedings of the ISSI, International Society for Scientometrics and Informetrics (2019), pp. 2644-2645.

4 A. Moro, E. Boelman, G. Joanny, J.L. Garcia, A bibliometric-based technique to identify emerging photovoltaic technologies in a comparative assessment with expert review, Renewable Energy, 123 (2018), pp. 407-416

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6 Eulaerts O., Joanny G., Giraldi J., Fragkiskos S., Perani S., Weak signals in Science and Technologies - 2019 Report, EUR 29900 EN, Publications Office of the European Union, Luxembourg, ISBN 978-92-76-12386-6.

7 Eulaerts O., Joanny G., Perani S., Weak signals in Science and Technologies 2019 - Analysis and recommendations, EUR 30061 EN, Publications Office of the European Union, Luxembourg.

8 Eulaerts et al, Weak signals in Science and Technologies –Weak signals in 2020, EUR 30714 EN, Publications Office of the European Union, Luxembourg.

9 Eulaerts et al., Weak signals in Science and Technologies in 2021, Publications Office of the European Union, Luxembourg, doi:10.2760/700257, JRC129501

10 Eulaerts, O. and Joanny, G., Weak Signals in Border Management and Surveillance Technologies, EUR 31126 EN, Publications Office of the European Union, Luxembourg, 2022.

11 Tanarro Colodron, J., Simola, K., Simic, Z., Cihlar, M., Gerbelova, H., Liessens, A. and Joanny, G., Horizon Scanning for Nuclear Safety, Security and Safeguards Yearly Report - 2020, EUR 30607 EN, Publications Office of the European Union, Luxembourg, 2021.

2 Methodological approach

Tools and data

The list of weak signals of emerging technologies presented in this report is the result of several detection processes ran during 2024 on specific topics including energy, quantum computing, food and agriculture, security, mobility, medical imaging, advanced materials, space technologies, and electronics. The software used for the detection of Weak Signals, created and developed by the JRC, is an advanced monitoring system called TIM Technology. This system integrates science, technology and innovation data from several data sources including Scopus, PATSTAT and Cordis. Two sets of data have been used to detect early-stage technologies: scientific publications (Scopus database of scientific publications from Elsevier[12] covering 01/1996 to 06/2023) and patents (Spring 2023 edition of Patstat[13] from the European Patent Office). When signals are reconstructed in TIM Technology (see below), a third database is used in addition to Scopus and Patstat: Cordis[14], the repository of EU funded R&D projects and activities.

Thematic clusters and dashboards

To facilitate the presentation of the weak signals, these were classified into the following 12 thematic clusters: advanced materials and advanced manufacturing, aerospace, artificial intelligence and machine learning, digital twin, e-health, energy, environment and agriculture, ICT, medical imaging, mobility and transport, quantum and cryptography, therapeutics and biotechnologies. Thematic dashboards, one per cluster, are available online for deeper exploration of the weak signals. Each dashboard includes several visualizations for each weak signal, providing information on its main characteristics such as top active organizations, countries, as well as most frequent associated keywords and journal categories. The dashboards have been set up in the TIM Technology system and can be accessed here:

Advanced Materials and Advanced Manufacturing

Aerospace

Mobility and Transport

Digital Twin

Artificial Intelligence and Machine Learning

ICT

Medical Imaging

Therapeutics and Biotechnologies

e-Health

Environment and Agriculture

Energy

Quantum and Cryptography

[12] https://www.elsevier.com/products/scopus/data

[13] https://www.epo.org/en/searching-for-patents/business/patstat

[14] https://cordis.europa.eu/

Visualisations

Scientific publications, patents and EU projects are retrieved for each weak signal, and indicators are calculated for each dataset. This report presents a selection of indicators and visualizations, while the full set is available in the dedicated dashboard. Throughout the report, "Europe" is used in various visualisations or tables and always means the 27 Member States of the European Union.

The following information is given for each signal, within each category:

1. An **overview** of the main characteristics and common trends of the weak signals grouped within the cluster.

2. A technology **radar** for each weak signal, illustrating 4 key dimensions:

   — **Share of scientific publications** for the WS. A high share of scientific publications may indicate foundational research, theoretical developments, or the exploration of novel applications.

   — **Share of patents** for the WS. A substantial share suggests that the technology may be transitioning toward commercialization and highlights its potential for proprietary value capture.

   — **Activeness** (in %, on a scale from 0% to 100%). This metric is defined as the ratio between the number of documents retrieved for a certain period and the total number of documents retrieved for the total period, here 1996 to 2023. We have used activeness21-23, which represents the percentage of documents published in the past three years (2021-2023) relative to the total number of documents available for the full period (1996-2023). A high activeness score indicates that a significant portion of documents in the dataset were produced in the most recent years, indicating recent research activity or interest in the topic. This indicator is considered as a proxy of signal novelty within a given research field or topic area. The underlying assumption is that promising technological developments in a specific domain are typically accompanied by a noticeable surge in the number of scientific publications or patents fillings in the most recent years, which can often be associated with new developments, emerging trends, or renewed interest in that area.

   — **Persistence.** This indicator is defined as the span of years over which relevant documents have been published. The metric is considered as a proxy for novelty: the higher the persistence, the longer the technology has been under development. It is worth noting that the persistence metric is field specific, reflecting different development timelines within different fields. For instance, a WS in the field of Information and Communication Technologies (ICT) might evolve more rapidly towards maturity, resulting in a lower persistence score, whereas in areas like quantum technology or engineering, this maturation might be slower, leading to a higher persistence score. This metric can vary from 0 to 28 years, corresponding to the data range available in TIM at the moment of analysis.

3. The **Revealed Technology Advantage** (RTA) for the focal technology in key economies, including the United States, Japan, China, South Korea, India, the United Kingdom, and the European Union (27 Member States). This index serves as an indicator of an economy's

relative specialization in the focal technology and is calculated as the proportion of the economy's scientific publications[15] in the focal technology, divided by the share of scientific publications across all fields. An RTA value greater than 1 indicates that the country has a relative specialization or advantage in the technology field compared to the world average. An RTA value less than 1 suggests that the country or region is less specialized in that area, while an RTA value of exactly 1 indicates that the country's share in the specific technology field is exactly proportional to its share in the global technological activities.

4. Three lists to capture the **main actors** active in the field:

   — The top 20 organizations by scientific output.

   — The top 20 organizations by citation count, normalized by Scopus category and publication year.

   — The top 10 organizations by patent filings.

5. **International collaborations** are analysed through a table and a network graphic. The table shows the rate of collaborations in their scientific outputs for the main territorial actors and for the EU, US, China triangle. The graphic shows the collaboration network between countries, where each node represents a country (The 27 EU Member States are aggregated into one node), and a metric called "betweenness centrality" is used to colour the nodes. Betweenness centrality is a measure of a node's "bridging" characteristics in a network, based on the proportion of shortest paths between all pairs of nodes that pass through it. In a network graph where nodes represent countries and connections represent co-publications, a node with high betweenness centrality indicates is a node acting as a "bridge" or "bottleneck" for the flow of scientific knowledge between other nodes. The nodes are color-coded from red (low betweenness centrality) to green (high betweenness centrality),

In addition, a description of each weak signal, together with its novel aspects and the top 5 organisations in terms of total output, can be found in the annex. The descriptions of the technology were obtained using a Large Language Model[16] based on the abstracts of the top 10 most cited publications in the dataset normalized by field and publication year.

[15] While the RTA index is commonly derived from patent data, for the purpose of assessing emerging technologies in their early stage of development, we adapted the index using scientific publications. This adjustment acknowledges that, at these early stages, academic output is a more accurate reflection of a region's focus and capabilities in these cutting-edge areas.

[16] The descriptions were obtained using the GPT-4-32K model, one of the models available in the GPT@JRC AI platform.

3 Weak Signals

The 221 weak signals, also called emerging technologies in this report, have been clustered into 12 categories using journal categories: advanced materials and advanced manufacturing; aerospace; digital twins; medical imaging; artificial intelligence and machine learning; ICT; e-health; mobility and transport; environment and agriculture; energy; therapeutics and biotechnologies; and quantum and cryptography.

Figure 1. Weak signals organized by clusters

Advanced materials and advanced manufacturing

additive Friction Stir Deposition	monolayer MoSi2N4	quasi-solid-state Li-Metal battery
anion exchange membrane electrolyzer	mxene nanosheet	reconfigurable intelligent surface
argyrodite electrolyte	nano fungicide	scaffold for cultivated meat
biphenylene network	organoid on a chip	self-healing ionogel
engineered living material	patient derived organoid	solid-state lithium metal batteries
flexible Zinc ion batteries	photocatalytic N2 reduction	terahertz intelligent surfaces
high entropy carbides	photonic synapses	ternary hybrid nanofluid
industry 5.0	photothermal superhydrophobic coating	ti3c2tx mxene
janus transition metal dichalcogenide	piezo photocatalysis	twisted 2D materials
laser direct energy deposition	polyetherimide for energy storage	urea electrosynthesis
laser powder bed fusion	potassium hybrid ion capacitor battery	volumetric additive manufacturing
memtransistor	precision fermentation	zinc metal battery

Aerospace

6G in space	edge computing for UAV	sustainable aviation fuel
advanced air mobility	evtol aircraft	truck drone
edge computing for satelittes	space-Air-Ground Integrated network	urban air mobility
	spaceborne computing	vertiport

Mobility and Transport

15 minutes city	lidar odometry	oriented object detection
3d multi object tracking	lidar slam	pedestrian trajectory prediction
6G V2X	marine fuel - ammonia	urban micromobility
AI for smart charging	monocular 3d object detection	vehicle integrated photovoltaic
charging strategy for electric buses	multi modal fusion for autonomous car	

Digital twins

city digital twin	digital twin for buildings	digital twin in healthcare
cyber twin architecture	digital twin for real estate	digital twin in transportation
digital twin for connected vehicle simulation	digital twin in agriculture	digital twin of quantum systems

Artificial intelligence & Machine learning

Artificial Intelligence of Things	federated reinforcement learning	multimodal hate speech detection
asynchronous federated learning	human AI interface	privacy-preserving machine learning
attention mechanisms in CNN	human centric AI	scientific machine learning
decentralized federated learning	large language models	self supervised learning CNN
epistemic AI	machine unlearning	tiny machine learning
evolutionary Neural Architecture Search	masked face recognition	trustworthy AI
explainable AI	masked language model	trustworthy machine learning
federated deep learning	multimodal AI	vertical federated learning
federated machine learning		

Information and Communication Technologies

adversarial defense	metaverse	secure decentralized finance
blockchain in supply chain	MITRE ATT&CK	self sovereign identity
confidential computing	multi key fully homomorphic encryption	single chip neuromorphic computing
deepfake detection	non-fungible tokens	smart contracts supply chain
few shot learning	open RAN	vehicular edge computing
human cyber physical system	practical byzantine fault tolerance blockchain	zero Trust architecture
intrusion Dectection BoT-IoT	redactable blockchain	

Medical imaging

deuterium metabolic imaging	optoretinography	red dichromatic imaging
Line-field confocal optical coherence tomography	Pix2Pix GAN	Total body positron emission tomography
MRI radiomics	radiomics nomogram	Vesical Imaging-Reporting and Data Syst

Therapeutics and Biotechnologies

3D printing for wound management	CRISPR-Cas13	postbiotic
biology-guided radiotherapy	fragmentomics	proteolysis targeting chimeras
boron proton capture therapy	gastruloid technology	robotic bronchoscopy
CAR macrophage therapy	immunotherapy cold tumor	spatial omics
CAR NK cells	intermittently scanned continuous glucose monitoring	tele neuropsychology
CRISPR-Cas12	metagenome assembled genome	transcatheter edge to edge
	mRNA vaccines	

e-Health

AI classified histopathology images	AI Instance Segmentation	explainable AI in medical imaging
AI disease prediction	Automated Tumor characterization by AI	explainable anomaly detection
AI driven neurodegenerative dis detect	blockchain 4 electronic health record	Few-shot learning in medical imaging
AI for Abdominal lesion detect/character	bowel pathology analysis with AI	internet of health things
AI for medical diagnosis	digital therapeutics	virtual care

Environment and agriculture

agrophotovoltaic	decarbonized chemicals	microplastic biodegradation
atmospheric water harvesting	direct seawater electrolysis	PFAs removal
building decarbonization	edge computing in agriculture	regenerative agriculture
circular construction	e-dna metabarcoding	sustainable last mile delivery
circular food system	food upcycling	urea electrolysis
cultivated meat	hemispherical solar distiller	

Energy

5th generation district heating	green hydrogen	positive energy district
blue hydrogen	grey hydrogen	smart local energy systems
direct recycling of batteries	hydrogen geological storage	sustainable ammonia
electrochromic energy storage	levelized cost of hydrogen	sustainable aviation fuel
gravity energy storage	osmotic energy harvesting	turquoise hydrogen
green ammonia	personal thermal management	zinc hybrid supercapacitor

Quantum and Cryptography

Classic McEliece encryption	quantum blockchain	quantum reservoir computing
gate based quantum computing	quantum classifier	quantum resistant algorithm
HHL algorithm	quantum cloud computing	quantum sdk
kyber digital signature algorithm	quantum compiler	quantum support vector
lattice-based quantum cryptography	quantum drug discovery	quantum transduction
NISQ devices	quantum generative adversarial network	Quantum Variational Algorithms
Parameterized quantum circuits	Quantum microscopy	shallow quantum circuits
quantum autoencoders	Quantum neural networks	superconducting quantum processors
quantum battery	quantum phase estimation algorithms	variational quantum circuits
	quantum reinforcement learning	

Source: JRC

3.1 Advanced Materials and Advanced Manufacturing

Dashboard: Advanced Materials and Advanced Manufacturing

Advanced materials and advanced manufacturing		
additive Friction Stir Deposition	monolayer MoSi2N4	quasi-solid-state Li-Metal battery
anion exchange membrane electrolyzer	mxene nanosheet	reconfigurable intelligent surface
argyrodite electrolyte	nano fungicide	scaffold for cultivated meat
biphenylene network	organoid on a chip	self-healing ionogel
engineered living material	patient derived organoid	solid-state lithium metal batteries
flexible Zinc ion batteries	photocatalytic N2 reduction	terahertz intelligent surfaces
high entropy carbides	photonic synapses	ternary hybrid nanofluid
industry 5.0	photothermal superhydrophobic coating	ti3c2tx mxene
janus transition metal dichalcogenide	piezo photocatalysis	twisted 2D materials
laser direct energy deposition	polyetherimide for energy storage	urea electrosynthesis
laser powder bed fusion	potassium hybrid ion capacitor battery	volumetric additive manufacturing
memtransistor	precision fermentation	zinc metal battery

Source: JRC

The sector of advanced materials and manufacturing encompasses a wide range of emerging technologies. Despite this heterogeneity, several key trends can be highlighted. Notably, a number of multifunctional advanced materials are being developed, including Engineered Living Materials, High Entropy Carbides, and MXene Nanosheets. These materials display multiple properties and functions at once. Nano-scale design and engineering is another common trait in this cluster. This precise approach to material creation, where atoms and molecules are manipulated, is applied in the development of Biphenylene Network, Janus Transition Metal Dichalcogenides, and Monolayer MoSi2N4. Additionally, the ability to self-repair and adapt to the environment characterize materials such as Self-Healing Ionogels and Reconfigurable Intelligent Surfaces.

Some emerging technologies are developed to address energy efficiency and environmental impact, such as Solid-State Lithium Metal Batteries and Potassium Hybrid Ion Capacitor Batteries. Some materials are also developed to replicate to or interface with biological systems, as illustrated by Engineered Living Materials and Organoid on a Chip. Furthermore, advancements in sensing and monitoring are evident in Reconfigurable Intelligent Surfaces and Photonic Synapses, while MXene Nanosheets highlights the potential for tunability and programmability in material applications.

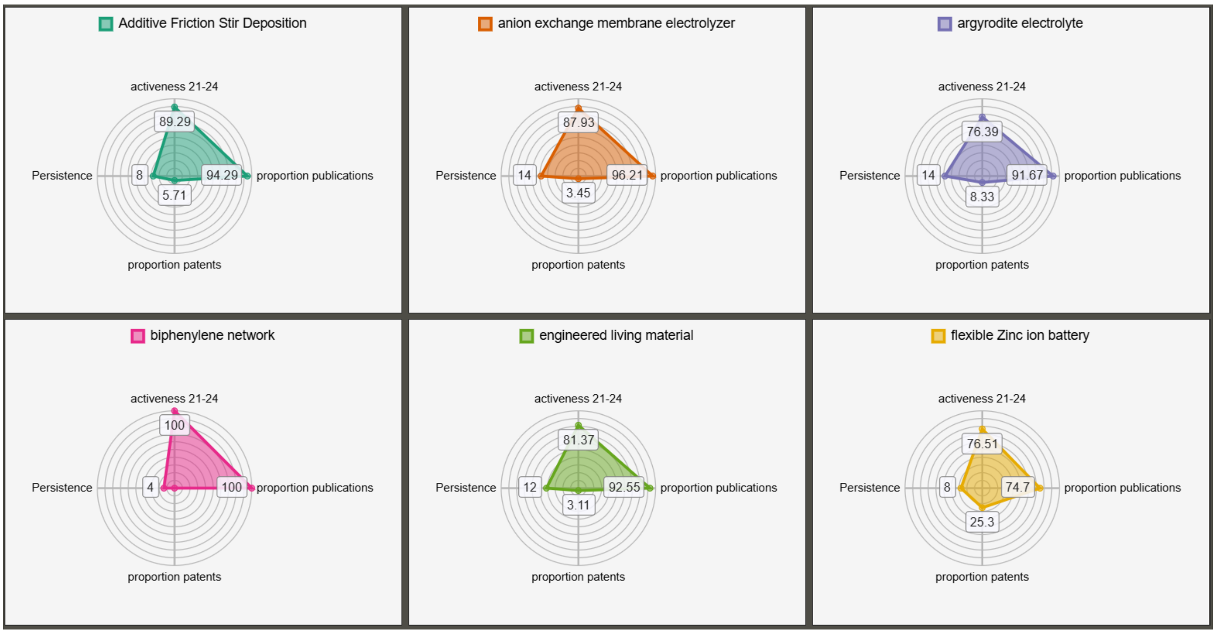
In the realm of manufacturing, additive processes such as Additive Friction Stir Deposition, Laser Direct Energy Deposition, Laser Powder Bed Fusion, and Volumetric Additive Manufacturing are notable. These methods construct objects in a layer-by-layer fashion, which is recognized for its potential to increase precision, reduce material waste, and minimize the need for extensive post-processing.

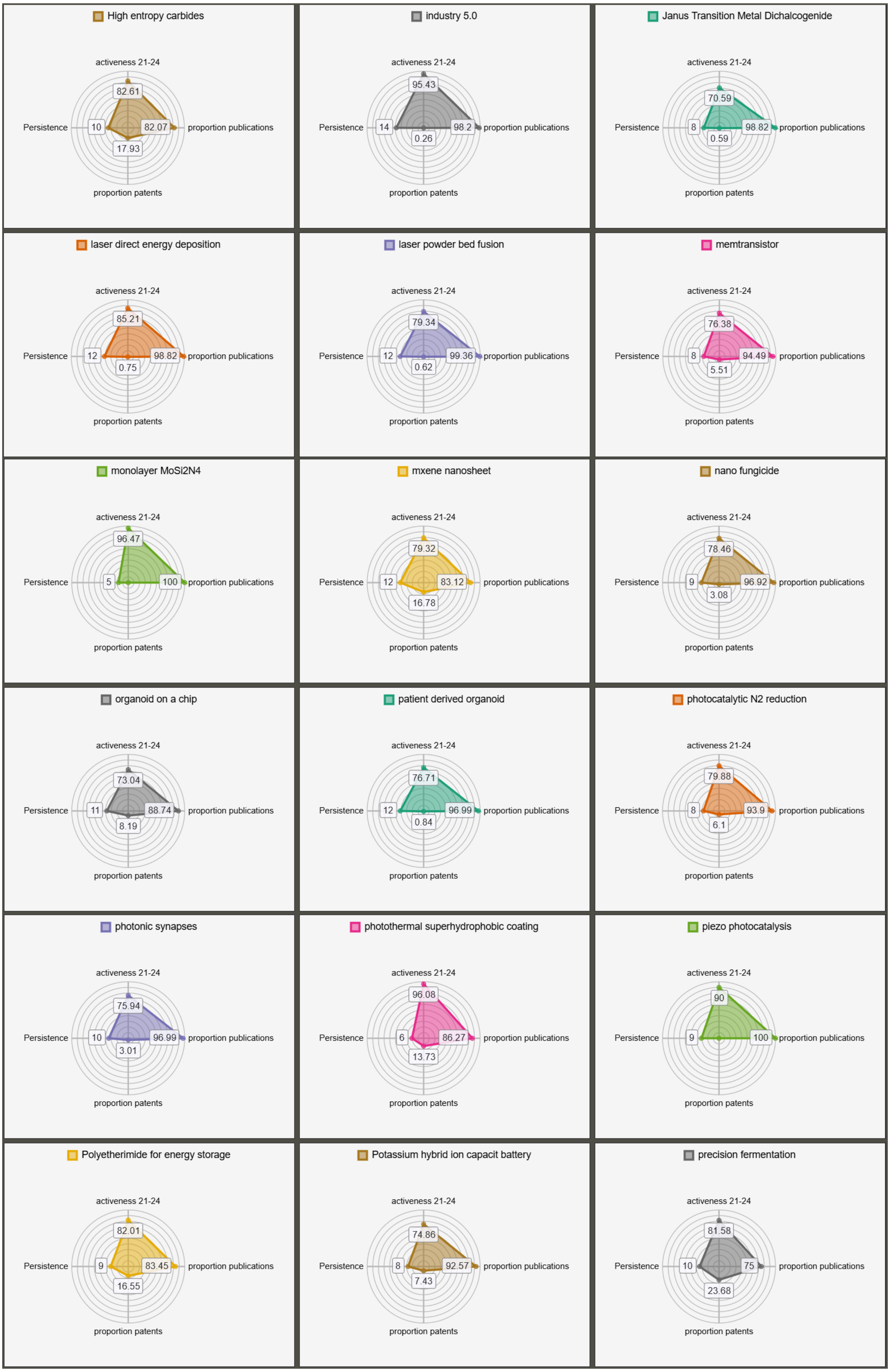
The concept of Industry 5.0 is also emerging. Not a technology as such, Industry 5.0 is a transformative manufacturing paradigm that seamlessly merges human ingenuity with artificial intelligence, prioritizing a more sustainable, resilient, and people-centric approach to industrial production and manufacturing. Its primary goal is to harmonize technological advancements with human values, ensuring that innovation benefits both individuals and the environment and offering a multitude of advantages like the creation of customized, high-quality products, a more circular economy, and a renewed focus on social responsibility and environmental stewardship.

Technology radars

Most of the technologies in this category show a low share of patents, confirming their early stage of developments. Notable exceptions include “volumetric additive manufacturing”, “high entropy carbides’, and ‘flexible zinc ion batteries’, indicating a more mature state of development and commercial interest for these technologies. The technologies in this cluster have been under development for about ten years on average, with the notable exception of “reconfigurable intelligent surfaces”, which development time spans over two decades. Despite its lengthy period of research, it has only recently seen a surge in activity, as suggested by an activeness score of 95%. This is indicative of a technology that has only recently begun to approach maturity, highlighting a common pattern in the field where technologies can undergo prolonged periods of incremental progress before reaching a tipping point that drives widespread research and commercial interest. This pattern underscores the often-slow evolution of new technologies within advanced materials and manufacturing. Breakthroughs can be sporadic and unpredictable, but when they do occur, they have the potential to rapidly attract the attention of the scientific community and industry.

Figure 2. Technology radars for emerging technologies in Advanced Materials and Advanced Manufacturing.




High entropy carbides
activeness 21-24
82.61
Persistence
10
82.07
proportion publications
17.93
proportion patents
industry 5.0
activeness 21-24
95.43
Persistence
14
98.2
proportion publications
0.26
proportion patents
Janus Transition Metal Dichalcogenide
activeness 21-24
70.59
Persistence
8
98.82
proportion publications
0.59
proportion patents
laser direct energy deposition
activeness 21-24
85.21
Persistence
12
98.82
proportion publications
0.75
proportion patents
laser powder bed fusion
activeness 21-24
79.34
Persistence
12
99.36
proportion publications
0.62
proportion patents
memtransistor
activeness 21-24
76.38
Persistence
8
94.49
proportion publications
5.51
proportion patents
monolayer MoSi2N4
activeness 21-24
96.47
Persistence
5
100
proportion publications
proportion patents
mxene nanosheet
activeness 21-24
79.32
Persistence
12
83.12
proportion publications
16.78
proportion patents
nano fungicide
activeness 21-24
78.46
Persistence
9
96.92
proportion publications
3.08
proportion patents
organoid on a chip
activeness 21-24
73.04
Persistence
11
88.74
proportion publications
8.19
proportion patents
patient derived organoid
activeness 21-24
76.71
Persistence
12
96.99
proportion publications
0.84
proportion patents
photocatalytic N2 reduction
activeness 21-24
79.88
Persistence
8
93.9
proportion publications
6.1
proportion patents
photonic synapses
activeness 21-24
75.94
Persistence
10
96.99
proportion publications
3.01
proportion patents
photothermal superhydrophobic coating
activeness 21-24
96.08
Persistence
6
86.27
proportion publications
13.73
proportion patents
piezo photocatalysis
activeness 21-24
90
Persistence
9
100
proportion publications
proportion patents
Polyetherimide for energy storage
activeness 21-24
82.01
Persistence
9
83.45
proportion publications
16.55
proportion patents
Potassium hybrid ion capacit battery
activeness 21-24
74.86
Persistence
8
92.57
proportion publications
7.43
proportion patents
precision fermentation
activeness 21-24
81.58
Persistence
10
75
proportion publications
23.68
proportion patents

Source: JRC

Revealed Technology Advantage

China and, to some extent, South Korea exhibit strong specialization in the emerging technologies within this cluster, indicating a strategic focus and investment in this sector compared to other areas of science and technology. On the other hand, Europe, Japan, and, to some extent, the United States show RTAs below 1, implying that these regions are under-specialized in the field of advanced materials and manufacturing relative to their broader technological efforts. This may suggest that these regions allocate their research and development resources more evenly across different fields or that they have a stronger focus on other technology areas. This specialization pattern is corroborated by the dominance of Chinese organizations in the emerging technologies of this category.

Figure 3. Revealed Technological Advantage for WS in Advanced Materials and Advanced Manufacturing.

Weak Signals	China	US	Europe	UK	Japan	South Korea	India
Additive Friction Stir Deposition	1.26	2.96	0.15	0.45	0.00	0.00	1.18
anion exchange membrane electrolyzer	2.50	0.86	0.52	0.42	0.41	10.78	0.24
argyrodite electrolyte	2.24	0.88	1.05	0.45	2.59	4.62	0.00
biphenylene network	3.43	0.87	0.88	0.27	1.06	2.26	0.41
engineered living material	1.32	1.93	1.14	1.58	0.26	0.55	0.15
flexible Zinc ion battery	5.27	0.38	0.13	0.83	0.00	1.64	0.18
High entropy carbides	3.62	0.81	0.68	1.37	0.13	0.40	0.37
industry 5.0	0.61	0.38	1.77	0.17	0.24	0.98	3.19
Janus Transition Metal Dichalcogenide	3.75	0.69	0.52	0.35	0.91	0.97	1.99
laser direct energy deposition	2.48	1.03	0.80	1.01	0.25	1.10	1.91
laser powder bed fusion	1.62	1.09	1.27	1.24	0.80	1.12	0.59
memtransistor	2.21	1.39	0.46	0.61	0.63	8.80	0.74
monolayer MoSi2N4	4.65	0.30	0.37	0.35	0.00	1.91	1.05
mxene nanosheet	4.92	0.48	0.26	0.45	0.31	2.67	0.81
nano fungicide	1.47	0.07	0.44	0.47	0.30	1.29	9.22
organoid on a chip	2.06	1.29	1.07	0.79	0.44	2.66	1.12
patient derived organoid	1.70	1.51	1.44	1.16	1.41	2.11	0.31
photocatalytic N2 reduction	5.33	0.39	0.21	0.48	0.25	1.85	0.14
photonic synapses	3.40	0.70	0.34	1.37	0.29	6.93	0.52
photothermal superhydrophobic coating	5.75	0.49	0.36	0.33	0.86	0.92	0.00
piezo photocatalysis	4.69	0.47	0.36	0.70	0.17	1.94	0.97
Polyetherimide for energy storage	5.32	0.55	0.17	0.25	0.00	0.00	0.00
Potassium hybrid ion capacit battery	5.56	0.32	0.29	0.64	0.35	0.75	0.69
precision fermentation	0.87	0.83	1.25	1.29	0.33	0.71	1.18
quasi-solid-state Li-Metal battery	4.81	0.15	0.74	0.75	0.64	3.44	1.51
reconfigurable intelligent surface	2.81	0.56	0.85	2.27	0.34	2.37	1.12
scaffold for cultivated meat	1.83	0.85	0.43	0.49	0.21	7.14	0.98
self-healing ionogel	5.09	0.35	0.33	0.27	0.00	2.24	0.82
self-healing ionogel	5.09	0.35	0.33	0.27	0.00	2.24	0.82
solid-state lithium metal batteries	4.59	0.63	0.36	0.37	0.59	2.07	0.32
terahertz intelligent surfaces	3.37	0.59	0.36	1.34	0.86	1.85	4.06
ternary hybrid nanofluid	0.97	0.34	0.31	1.27	1.98	2.77	6.64
ti3c2tx mxene	4.50	0.59	0.34	0.56	0.39	3.31	1.14
twisted 2D materials	3.65	1.17	0.66	1.79	2.02	1.23	1.01
urea electrosynthesis	5.22	0.91	0.46	0.57	0.37	0.00	1.29
volumetric additive manufacturing	0.74	1.86	0.95	0.44	0.28	0.00	0.67
Zinc metal battery	4.88	0.62	0.27	0.38	0.58	2.65	0.24
Average for all weak signals	3.31	0.76	0.61	0.75	0.52	2.56	1.34

Source: JRC

Main actors

Chinese organizations exhibit a high level of activity in the field, with a significant presence among the top 20 organizations by document volume. The prominence of these organizations is likely a reflection of targeted investment, government support, and a concerted national strategy to acquire competitive advantage in the field. This strategic focus is consistent with China's broader ambitions to lead in high-tech sectors and to transition from a manufacturing-based economy to one driven by innovation and high-value industries. In contrast, the average citation per article, which can be considered as an indicator of research impact or quality, suggests a more diverse representation of the innovation landscape for these technologies. European and U.S.-based universities each account for five of the top20 organizations, followed by three in China, with the remainder spread across countries like Singapore, the UK, and Turkey. This indicates that while Chinese organizations are prolific in terms of publication numbers, research from institutions in other regions remains influential in the field.

Patenting activity further highlights the competitive landscape in advanced materials and manufacturing. Chinese organizations are at the forefront of patenting within these technologies, showcasing their commitment to not only conducting research but also to securing value appropriation mechanisms. U.S.-based organizations are also significant contributors to patent filings (as illustrated by the leading role of Qualcomm) indicating their substantial roles in technological development and commercialization in this sector. European innovation in this field, as represented by patent filings, appears to be less pronounced, with only Ericsson being in the top 40 in terms of patent filing volume (10 patents), ranking 11th.

Figure 4. Main actors for WS in Advanced Materials and Advanced Manufacturing

(Top20 organisations in terms of number of documents + Top20 organisations in terms of mean citation by article, normalized by field and year + Top 10 patenting organisations).

Organisations	Country	#Documents
Chinese Academy Of Sciences	China	1023
Southeast University	China	453
Tsinghua University	China	426
South China University of Technology	China	336
Huazhong University of Science and Technology	China	323
NORTHWESTERN POLYTECHNICAL UNIVERSITY	China	295
University of Electronic Science and Technology of China	China	289
Zhejiang University	China	283
University of Science and Technology of China	China	270
Nanyang Technological University	Singapore	243
Zhengzhou University	China	239
Central South University	China	236
Shanghai Jiao Tong University	China	231
Queen Mary University of London	United Kingdom	211
University of California	United States of America	205
Drexel University	United States of America	204
XI'AN JIAOTONG UNIVERSITY	China	197
Shenzhen University	China	186
Nanjing University of Information Science and Technology	China	176
Shandong University	China	173

Organisations	Country	Mean normalized citation per article
National and Kapodistrian University of Athens	Greece	20.56
Université Paris-Saclay	France	18.22
Singapore University of Technology and Design	Singapore	17.98
University of Texas at Dallas	United States of America	16.82
Princeton University	United States of America	14.13
King Abdullah University of Science and Technology	Saudi Arabia	14.00
Koç University	Turkey	12.68
Yangzhou University	China	12.19
Queen Mary University of London	United Kingdom	11.98
Friedrich-Alexander-Universität Erlangen-Nürnberg	Germany	10.85
China University of Petroleum	China	10.61
Qingdao University	China	10.32
University of Luxembourg	Luxembourg	10.06
Hong Kong University of Science and Technology	Hong Kong	9.93
Missouri University of Science and Technology	United States of America	9.85
Linköping University	Sweden	9.72
University of Pennsylvania	United States of America	9.44
Drexel University	United States of America	9.43
National University of Defense Technology	China	9.28
University of Surrey	United Kingdom	9.11

Organisations	#Patents	Country
QUALCOMM INC	116	United States of America
China University of Mining and Technology	75	China
CSIC HAIZHUANG WINDPOWER EQUIPMENT CO., LTD.	33	China
Northwestern University	26	United States of America
Tsinghua University	16	China
CHINA ACADEMY OF SPACE TECHNOLOGY	16	China
University of Electronic Science and Technology of China	15	China
HUAWEI TECH CO LTD	12	China
CHINA TELECOM CORPORATION LIMITED	12	China
DAJIU MANUFACTURING CO., LTD.	11	China

Source: JRC

International collaborations

The United Kingdom stands out as the most collaborative country in this cluster, with 81% of its scientific outputs involving at least one organization from outside the UK. In comparison, European organizations collaborate with institutions from other regions in 48% of their scientific production, which aligns with the average for the countries analysed. China exhibits the lowest proportion of international collaboration, with only 27% of its scientific outputs including contributions from organizations outside of China.

The European Union collaborates similarly with the United States and China, with 28% of EU outputs involving U.S.-based organizations and 36% involving Chinese organizations. Notably, China and the United States collaborate with each other more frequently than either does with the EU, with 35% of Chinese outputs involving U.S. organizations and 51% of U.S. outputs including Chinese organizations.

Figure 5. International collaborations between countries and macro-regions for the cluster Advanced Manufacturing and Advanced Materials.

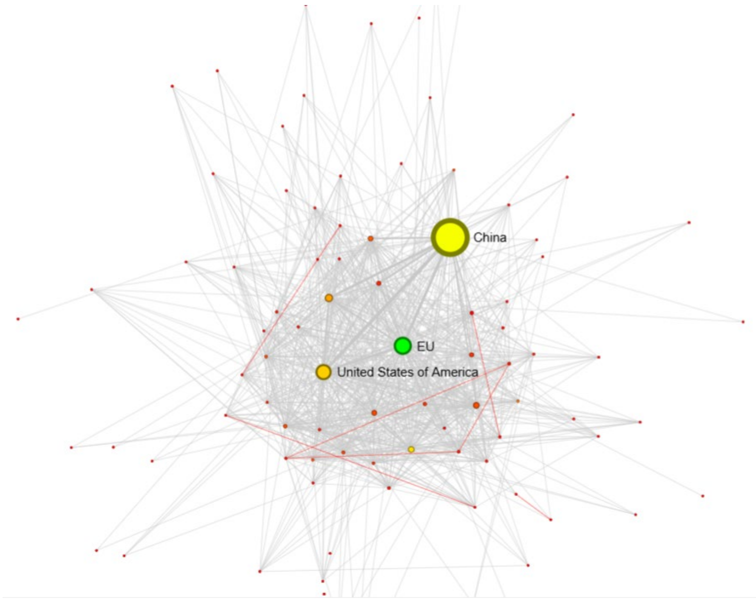
Share of international collaboration		Share of collaboration between EU, US, CN			
United Kingdom	81%				
Japan	57%		EU	US	CN
South Korea	49%	EU with	/	28%	36%
United States	49%	US with	33%	/	51%
Europe	48%	CN with	29%	35%	/
India	48%				
China	27%				

Source: JRC

Europe, and China to a lesser extent, play a key role in the distribution of knowledge flows in this cluster, as can be seen in the figure below.

Figure 6. Collaborative networks between countries for the cluster Advanced Manufacturing and Advanced Materials.

The size of the nodes = number of documents and edges = number of joint publications/patents. Colour coding according to betweenness centrality (from red (low) to green (high)).

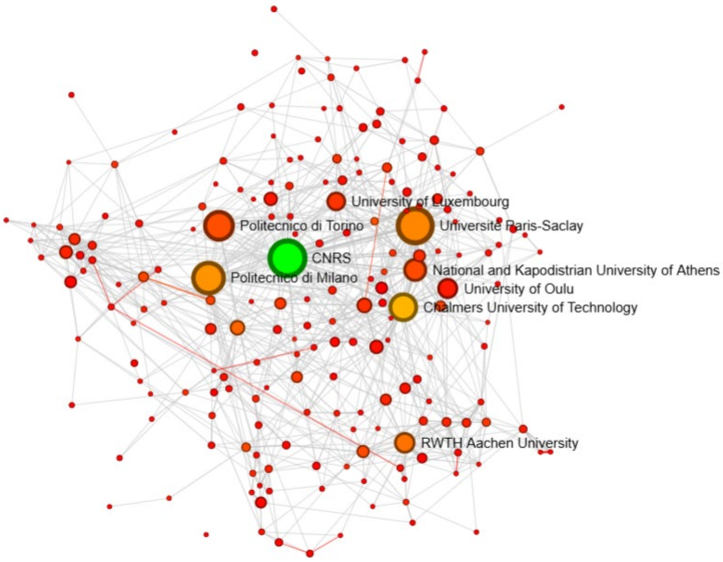


Source: JRC

Within Europe, CNRS is the pivotal organisations for the exchange of knowledge between European organisations.

Figure 7. Collaborative networks for top200 European organisations in the cluster Advanced Manufacturing and Advanced Materials.

The size of the nodes = number of documents and edges = number of joint publications/patents. Colour coding according to betweenness centrality (from red (low) to green (high)).



Source: JRC

3.2 Aerospace

Dashboard: Aerospace

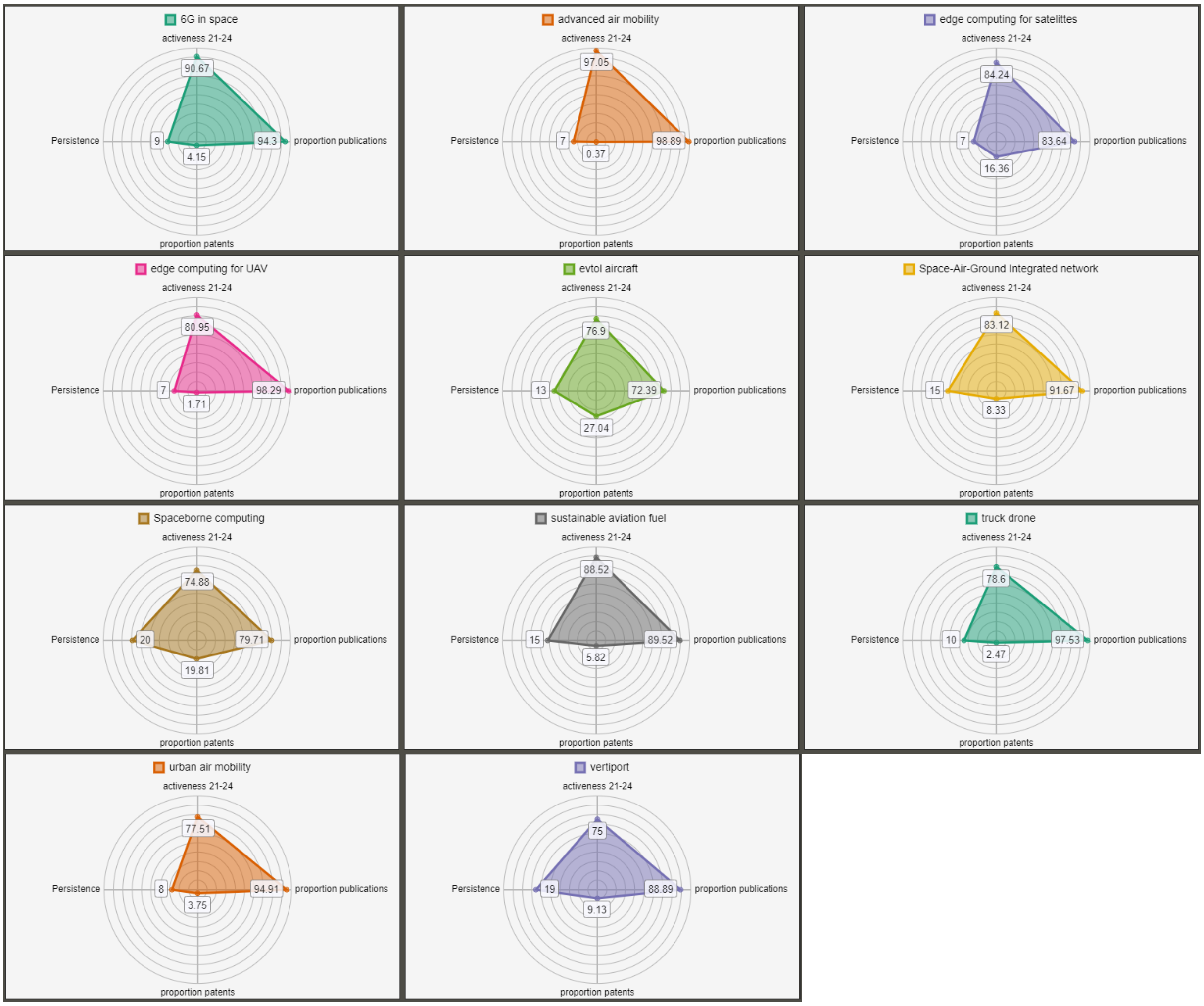
Aerospace		
6G in space	edge computing for UAV	sustainable aviation fuel
advanced air mobility	evtol aircraft	truck drone
edge computing for satelittes	space-Air-Ground Integrated network	urban air mobility
	spaceborne computing	vertiport

The emerging technologies within this cluster are characterized by their transformative potential and share a reliance on interdisciplinary expertise, drawing from fields such as aerospace engineering, computer science, and materials science. One of their key features is the integration of advanced communication systems, which are essential for ensuring seamless connectivity and data exchange between vehicles in air and space environments. Examples include the deployment of next-generation telecommunications like 6G in space and integrated networks that span space, air, and ground to enhance communication capabilities. Edge computing is another technological focus, particularly for its application in satellites. By processing data closer to the point of collection, edge computing enables real-time data analysis, reducing latency and improving the efficiency of decision-making processes in air and space operations. Automation is another significant theme, with the development of autonomous systems and AI-driven algorithms aimed at enhancing the safety, efficiency, and sustainability of air transportation. Technologies such as advanced air mobility, electric Vertical Take-Off and Landing (eVTOL) aircraft, and urban air mobility are indicative of the industry's move towards automated transport solutions. In the quest for sustainability, electrification and sustainable propulsion are critical areas of research. The development of eVTOL aircraft and the pursuit of sustainable aviation fuel are driven by the need to minimize carbon emissions and the environmental footprint of aviation. These efforts include exploring hybrid-electric propulsion systems and alternative fuels that could offer an eco-friendlier approach to air travel. Safety and efficiency remain overarching concerns, with the goal of not only reducing environmental impact but also enhancing the passenger experience and the overall performance of air and space transportation systems. Through a combination of advanced technology and innovative design, these emerging technologies aim to reshape the future of mobility both within Earth’s atmosphere and beyond.

Technology radars

No clear pattern can be observed between the four dimensions of the radar for the technologies in this cluster, indicating substantial variation in technological development within the Aerospace Technologies sector. For instance, emerging signals like advanced air mobility exhibit low persistence and high activeness, suggesting rapid recent growth in interest from the research community. Conversely, technologies such as spaceborne computing and vertiport show the opposite pattern, with a longer development time (high persistence) but lower activity levels in the most recent years (relative low activeness). Notably, the eVTOL aircraft segment demonstrates a higher proportion of patents compared to other technologies (reflecting significant efforts to secure intellectual property in a potentially disruptive market) but a lower activeness score, which might be indicative of a more mature development stage. Overall, these examples underscore the non-linear and multifaceted nature of technological progress in the aerospace industry, which depends on various factors such as technology maturation and the rate of innovation, the potential for commercialization, as well as the development of regulatory frameworks.

Figure 8. Technology radars for emerging technologies in Aerospace.



Source: JRC

Revealed Technology Advantage

South Korea and China show strong specialization in most of the technologies in this category. This specialization pattern is consistent with the ambition of these countries to establish themselves as leaders in high-tech industries, including aerospace. The specialization of the United States, although less pronounced than that of South Korea and China, confirms a considerable focus on maintaining and advancing its capabilities in a sector in which it established a long-standing tradition of leadership. In contrast, both Europe and Japan show under-specialization in most emerging aerospace technologies. On the one hand, the specialization of Europe in sustainable aviation fuels may suggest that European efforts are currently more concentrated on environmental aspects of aviation, such as reducing aircraft emissions and researching alternative fuels, rather than on new aerospace technologies. On the other hand, with RTA index values above one in space-air-ground integrated network technologies and 6G in space, Japan demonstrates a focus on advanced communication technologies that bridge space-based and terrestrial networks. In line with its strong electronics and telecommunications sector. Japan's specialization in these areas suggests a strategic emphasis on developing infrastructure and capabilities that support seamless connectivity across space, air, and ground.

Figure 9. Revealed Technological Advantage for WS in Aerospace.

Weak Signals	China	US	Europe	UK	Japan	South Korea	India
6G in space	2.47	0.66	0.80	0.66	1.25	3.13	1.72
advanced air mobility	0.12	2.66	0.74	2.66	0.21	1.21	0.17
edge computing for satelittes	4.60	0.28	0.37	0.28	0.00	1.47	0.49
edge computing for UAV	4.53	0.47	0.25	0.47	0.63	1.57	0.91
evtol aircraft	0.60	1.99	0.79	1.99	0.59	3.16	0.43
Space-Air-Ground Integrated network	4.52	0.49	0.20	0.49	1.24	1.33	0.88
Spaceborne computing	4.19	0.49	0.38	0.49	0.12	1.23	0.54
sustainable aviation fuel	0.46	1.51	1.23	1.51	0.46	0.38	0.62
truck drone	2.26	1.14	0.92	1.14	0.32	1.20	0.38
urban air mobility	0.33	1.99	1.03	1.99	0.20	3.95	0.33
vertiport	0.30	1.99	1.02	1.99	0.08	4.90	0.20
Average for all weak signals	2.22	1.24	0.70	1.24	0.46	2.14	0.61

Source: JRC

Main actors

Consistently with the historical leading role of the US in the aerospace industry, NASA is the leading organisation in terms of number of documents produced. European organisations like the Technical University of Munich, Delft University, or the think-tank Bauhaus Luftfahrt are also prominent amongst the top20 organizations in terms of volume of research output. However, when it comes to impact, a different picture emerges as Chinese and British organizations lead the ranking of most cited publications, while no EU27 organization is present on the list. The landscape of intellectual property rights in aerospace is prominently shaped by entities from the US, Japan, China, and South Korea. These organizations' strategic efforts to secure patents for early-stage technologies demonstrate their focus on capitalizing on their research and maintaining a competitive edge through technological innovation.

Figure 10, Main actors for WS in Aerospace.

(Top20 organisations in terms of number of documents + Top20 organisations in terms of mean citation by article, normalized by field and year + Top 10 patenting organisations).

Organisations	Country	#Documents
NASA	United States of America	260
Beijing University of Posts and Telecommunications	China	93
XIDIAN UNIVERSITY	China	86
Beihang University	China	74
University of California	United States of America	67
Chinese Academy Of Sciences	China	67
Technical University of Munich	Germany	65
Cranfield University	United Kingdom	54
Tsinghua University	China	50
Nanjing University of Aeronautics and Astronautics	China	50
University of Electronic Science and Technology of China	China	48
Central South University	China	42
Purdue University	United States of America	39
Massachusetts Institute of Technology	United States of America	39
Nanyang Technological University	Singapore	35
Southeast University	China	35
Delft University of Technology	Netherlands	34
National University of Defense Technology	China	34
Bauhaus Luftfahrt e.V.	Germany	33
University of Waterloo	Canada	32

Organisations	Country	Mean normalized citation per article
Zhejiang University of Technology	China	20.29
Rolls-Royce plc	United Kingdom	19.12
University of New South Wales	Australia	17.39
Southwest Jiaotong University	China	15.57
University of Essex	United Kingdom	14.56
Queen Mary University of London	United Kingdom	14.13
Memorial University	Canada	13.71
China Academy of Information and Communications Technology	China	13.60
Dalian University of Technology	China	13.13
University of Manchester	United Kingdom	12.61
Northumbria University	United Kingdom	12.57
Zayed University	United Arab Emirates	11.55
School of Information and Electronics	China	10.95
University of Technology Sydney	Australia	10.70
University College London	United Kingdom	10.68
Nanjing University of Information Science and Technology (NUST)	China	10.64
University of Macau	Macao	10.25
Zhejiang University	China	10.18
University of Science and Technology Beijing	China	10.15
Korea University	South Korea	10.13

Organisations	#Patents	Country
BETA Air LLC	25	United States of America
China University of Mining and Technology	12	China
Rolls-Royce plc	11	United Kingdom
Honeywell International Inc	11	United States of America
DENSO Corp	10	Japan
CHINA ACADEMY OF SPACE TECHNOLOGY	8	China
HYUNDAI MOTOR CO	6	South Korea
KIA CORP	6	South Korea
Beihang University	5	China
NTN CORP	5	Japan

Source: JRC

International collaborations

The level of international collaboration in scientific publications and patenting varies significantly within this cluster. The United Kingdom leads with 67% of its output produced in partnership with organizations in other countries, while South Korea records the lowest rate at just 20%. Europe occupies a middle position, with 34% of its scientific output involving collaboration with entities outside the EU. Europe maintains strong collaborative ties with the United States, with one-third of EU publications involving U.S.-based organizations. Collaboration with China is less frequent; 23% of EU collaborative outputs include Chinese partners, whereas only 11% of China's collaborative outputs involve EU entities. China and the United States exhibit a higher degree of mutual collaboration, with 40% of U.S. collaborative scientific output including Chinese organizations.

Figure 11. International collaborations between countries and macro-regions for Aerospace.

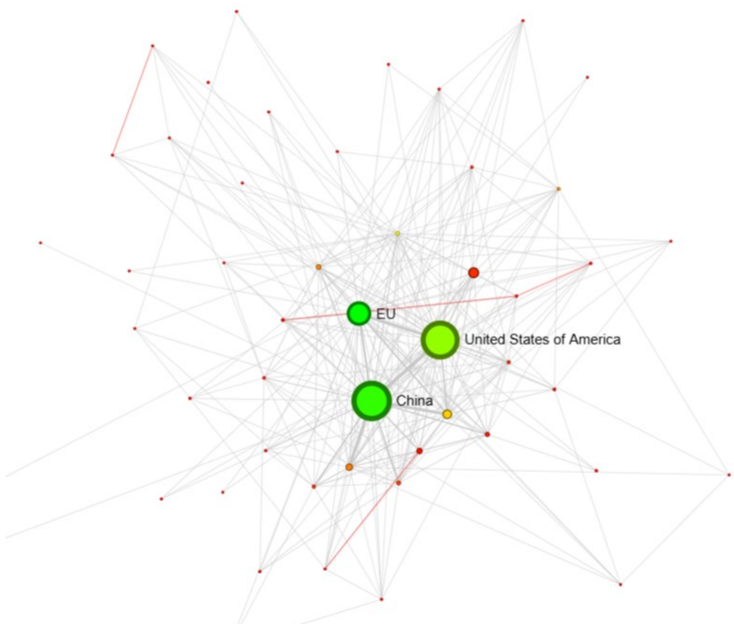
Share of international collaboration		Share of collaboration between EU, US, CN			
United Kingdom	67%				
India	48%		EU	US	CN
Japan	44%	EU with	/	35%	23%
China	38%	US with	29%	/	40%
Europe	34%	CN with	11%	24%	/
United States	24%				
South Korea	20%				

Source: JRC

Based on the properties of the network graph in figure 12 it appears that the EU, China, and the US are contributing equally to the flow of knowledge for this cluster.

Figure 12. Collaborative networks between countries for the cluster aerospace.

The size of the nodes = number of documents and edges = number of joint publications/patents. Colour coding according to betweenness centrality (from red (low) to green (high)).



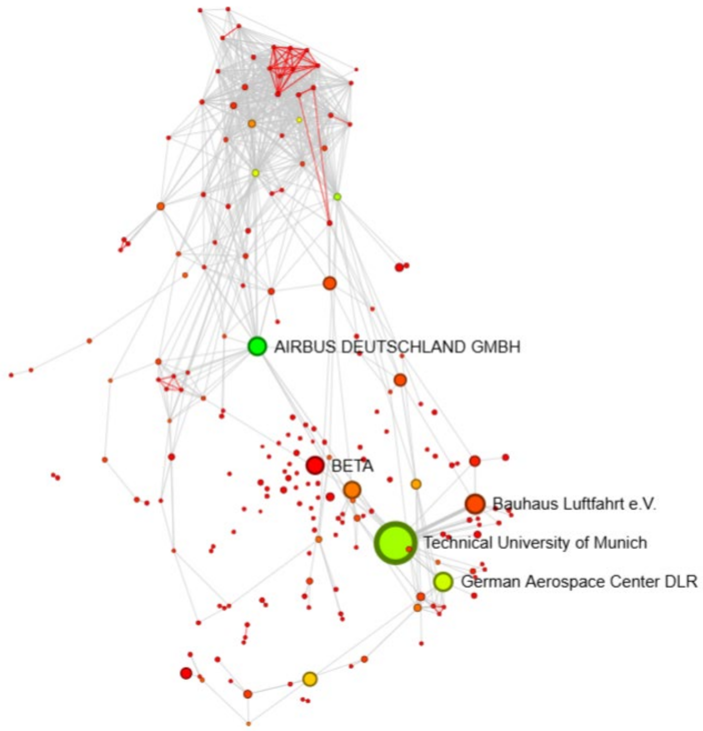
Source: JRC

Within this cluster of emerging aerospace technologies, Airbus plays as a central hub for the flow of knowledge in Europe. Additionally, the Technical University of Munich and the German Aerospace

Center play significant roles, though smaller, as key contributors to the dissemination of scientific knowledge.

Figure 13. Collaborative networks for top200 European organisations in the Aerospace cluster.

The size of the nodes = number of documents and edges = number of joint publications/patents. Colour coding according to betweenness centrality (from red (low) to green (high)).



Source: JRC

3.3 Mobility and Transport

Dashboard: Mobility and Transport

Mobility and Transport		
15 minutes city	lidar odometry	oriented object detection
3d multi object tracking	lidar slam	pedestrian trajectory prediction
6G V2X	marine fuel - ammonia	urban micromobility
AI for smart charging	monocular 3d object detection	vehicle integrated photovoltaic
charging strategy for electric buses	multi modal fusion for autonomous car	

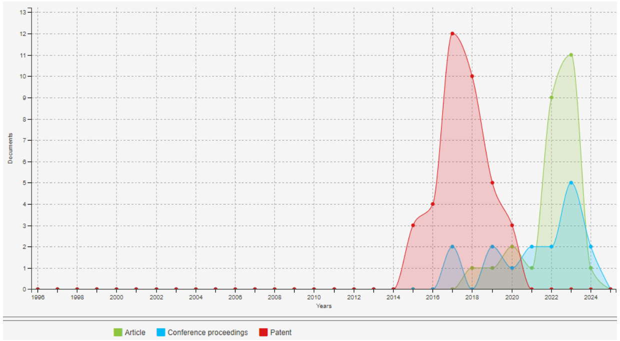
Emerging technologies in the mobility and transport sector are predominantly utilizing artificial intelligence (AI) and machine learning (ML) to enhance the functionality and sustainability of transportation systems. Applications such as AI-enabled smart charging, multimodal sensor fusion for autonomous vehicles, and pedestrian trajectory prediction are prime examples of this trend. These technologies aim to facilitate more efficient, safer, and environmentally friendly mobility solutions. AI and ML play a pivotal role in advancing the sensing and perception capabilities of autonomous vehicles. Techniques like lidar odometry, monocular 3D object detection, and oriented object detection are critical for the accurate and timely recognition of surrounding objects, which is essential for the dependable navigation of autonomous vehicles in diverse settings. The importance of real-time data processing and analytics cannot be overstated in the context of automated mobility. Emerging technologies, including 6G Vehicle-to-Everything (V2X) communication and pedestrian trajectory prediction systems, depend on the swift and decentralized processing of data to make informed and reliable decisions in the moment. In parallel, there is a concerted effort to address the environmental challenges associated with transportation. Technologies geared towards smarter charging protocols for electric buses and the integration of photovoltaic systems into vehicles are directed at diminishing carbon emissions and promoting the use of renewable energy sources. These initiatives are part of a broader movement to incorporate electrification and sustainable energy solutions into the transport sector, furthering the pursuit of green mobility.

Technology radars

Most of the technologies in this cluster share a common profile, characterized by average persistence of 6 to 12 years, high activeness, and a large share of scientific publications (figure 11). While persistence suggests a steady continuation of research and development over time, the high activity level in the most recent years reflects a generalized trend towards autonomous and efficient mobility solutions. No correlation between the four dimensions of the chart was found.

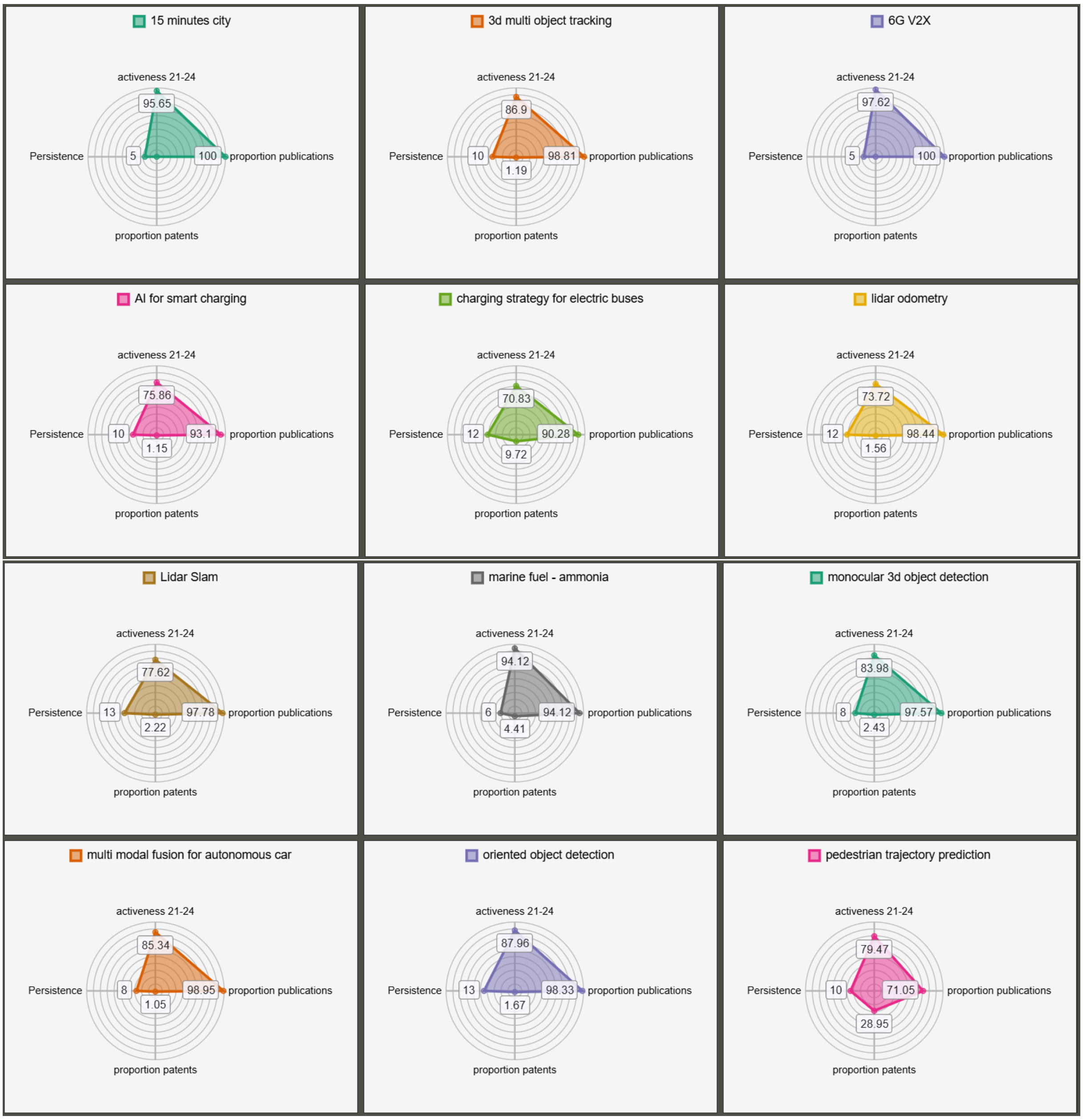
Two emerging technologies in this cluster, however, stand out due to their high proportion of patents. This suggests significant commercial interest and efforts to secure intellectual property rights, indicating that these technologies are seen as having substantial market potential. The technology of wireless charging for drones, despite exhibiting lower recent activity (activeness 21-24 of 41), is retained in the list of emerging technologies. The decision to maintain focus on this technology is informed by its document distribution, which shows two separate peaks, one for patent filings and another for scientific publications. A peak of patents preceding a peak of scientific publications is sometimes observed for new technologies that have significant commercial potential or that consists in the integration of various existing technologies. This can also be observed in certain fields, like in biotech or in pharmaceuticals, where patent protection is crucial for securing funding and investment, providing a clear path to commercialization. Patenting before publishing is therefore a widespread practice to safeguard the inventor's or company's interests.

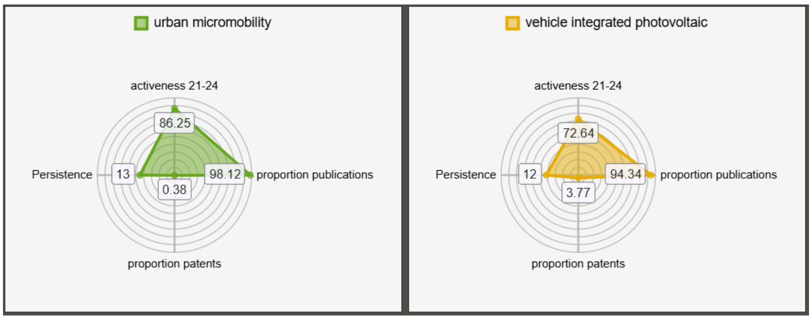
Figure 14. Distribution of documents for the technology “drone wireless charging”.



Source: JRC

Figure 15. Technology radars for emerging technologies in Mobility and Transport.





Source: JRC

Revealed Technology Advantage

China's and, to some extent, South Korea's specialization in most of the emerging technologies in this cluster underscores their strategic commitment to becoming key players in the development and deployment of autonomous driving solutions. On the other hand, European specialization in the mobility and transport sector, albeit more modest, is notably influenced by its focus on holistic and integrated urban planning concepts like the "15-minute city" or "urban micromobility". These concepts emphasize the importance of creating urban environments where essential services and amenities are accessible within a 15-minute walk or bike ride, which can significantly impact urban design, sustainability, and residents' quality of life. While these signals may not represent technological advancements in the traditional sense, they are indicative of Europe's commitment to addressing transportation and mobility challenges through comprehensive, system-level approaches that prioritize sustainability and liveability. Finally, India's specialization in technologies related to the efficient use of energy and renewable energy sources is in line with country's goal of promoting electric vehicles and low-carbon transportation systems[17].

[17] https://e-amrit.niti.gov.in/national-level-policy

Figure 16. Revealed Technological Advantage for WS in Mobility and Transport.

Weak Signals	China	US	Europe	UK	Japan	South Korea	India
15 minutes city	0.00	0.56	2.58	0.56	0.00	0.00	0.00
3d multi object tracking	2.53	0.93	1.38	0.93	0.46	1.47	0.00
6G V2X	2.20	0.41	1.13	0.41	0.00	1.93	2.66
AI for smart charging	0.30	0.85	1.81	0.85	0.47	0.00	2.48
charging strategy for electric buses	2.56	0.59	1.10	0.59	1.02	0.00	0.34
drone wireless charging	2.50	0.41	0.19	0.41	0.91	4.84	2.13
lidar odometry	3.50	0.52	0.59	0.52	0.22	1.75	0.10
marine fuel - ammonia	1.45	0.54	1.42	0.54	0.30	3.17	0.70
monocular 3d object detection	3.44	0.73	0.53	0.73	0.28	2.83	0.11
multi modal fusion for autonomous car	3.56	0.34	0.88	0.34	0.30	1.07	0.00
oriented object detection	5.20	0.26	0.28	0.26	0.45	0.69	0.30
pedestrian trajectory prediction	3.62	0.74	0.45	0.74	0.77	0.82	0.32
urban micromobility	0.31	1.13	1.89	1.13	0.44	0.78	0.30
vehicle integrated photovoltaic	0.62	0.64	1.58	0.64	3.99	2.84	2.01
Average for all weak signals	2.27	0.62	1.13	0.62	0.69	1.59	0.82

Source: JRC

Main actors

Chinese universities and companies are highly active in emerging technologies within this category, with most of the top20 organizations in terms of output volume being based in China. However, when considering mean citations per article, the top20 ranking features a more diverse range of institutions from the US, UK, China, and other countries. European institutions such as Eindhoven University of Technology, University of Catania, CNRS, and Politecnico di Milano also rank in the top20 by both number of publications and mean normalized citations. Chinese organizations dominate patent filings, while Bosch is the only European company in the top 10.

Figure 17. Main actors for WS in Mobility and Transport.

(Top20 organisations in terms of number of documents + Top20 organisations in terms of mean citation by article, normalized by field and year + Top 10 patenting organisations).

Organisations	Country	#Documents
Chinese Academy Of Sciences	China	96
Tsinghua University	China	70
Shanghai Jiao Tong University	China	48
Zhejiang University	China	47
Wuhan University	China	46
Tongji University	China	45
Beihang University	China	37
University of California	United States of America	34
XI'AN JIAOTONG UNIVERSITY	China	32
Hong Kong Polytechnic University	Hong Kong	31
Southeast University	China	31
NORTHWESTERN POLYTECHNICAL UNIVERSITY	China	27
China University of Mining and Technology	China	26
University of Michigan	United States of America	26
Nanyang Technological University	Singapore	25
University of Science and Technology of China	China	25
Dalian University of Technology	China	24
Tianjin University	China	24
Fudan University	China	23
Eindhoven University of Technology	Netherlands	22

Organisations	Country	Mean normalized citation per article
Carnegie Mellon University	United States of America	37.64
National Engineering Laboratory	United Kingdom	22.40
Massachusetts Institute of Technology	United States of America	20.63
University of Catania	Italy	19.12
Michigan State University	United States of America	18.20
Rutgers University	United States of America	16.74
Toyota Motor Corp	Japan	16.14
University of Sydney	Australia	16.11
Chinese University of Hong Kong	Hong Kong	14.75
KAIST	South Korea	14.45
University of Glasgow	United Kingdom	14.10
Ford Motor Company	United States of America	13.69
CNRS	France	13.65
University of Toronto	Canada	13.40
Beijing Institute of Technlogy	China	13.02
University of Illinois at Urbana-Champaign	United States of America	12.53
Baidu Inc.	China	12.06
Politecnico di Milano	Italy	11.81
NORTHWESTERN POLYTECHNICAL UNIVERSITY	China	11.57
Shanghai Jiao Tong University	China	11.47

Organisations	#Patents	Country
China University of Mining and Technology	15	China
NANJING AEROSPACE UNIV	6	China
Bosch Corp	5	Germany
CHONGQING CHANGAN AUTOMOBILE CO., LTD.	5	China
CSIC HAIZHUANG WINDPOWER EQUIPMENT CO., LTD.	4	China
Tsinghua University	3	China
DAJIU MANUFACTURING CO., LTD.	3	China
Science and Technology Corporation	3	United States of America
University of Michigan	2	United States of America
Industrial Technology Research Institute	2	Taiwan

Source: JRC

International collaborations

The degree of international collaboration in scientific publications and patenting varies within this cluster. The United Kingdom leads in collaboration, with 68% of its output involving partnerships with organizations in other countries. In contrast, China has the lowest rate of international collaboration at 27%. Europe falls in the middle, with 34% of its scientific output linked to entities outside the EU. Europe has strong collaborative ties with the United States, with one-third of EU publications including U.S.-based organizations. However, collaboration with China is less common, with 23% of EU collaborative outputs involving Chinese partners, while only 11% of China's collaborative outputs include EU entities. China and the United States collaborate more with each other than with the EU, with up to 52% of U.S. scientific outputs involving at least one Chinese organization.

Figure 18. Internal collaborations between countries and macro-regions for Mobility and Transport.

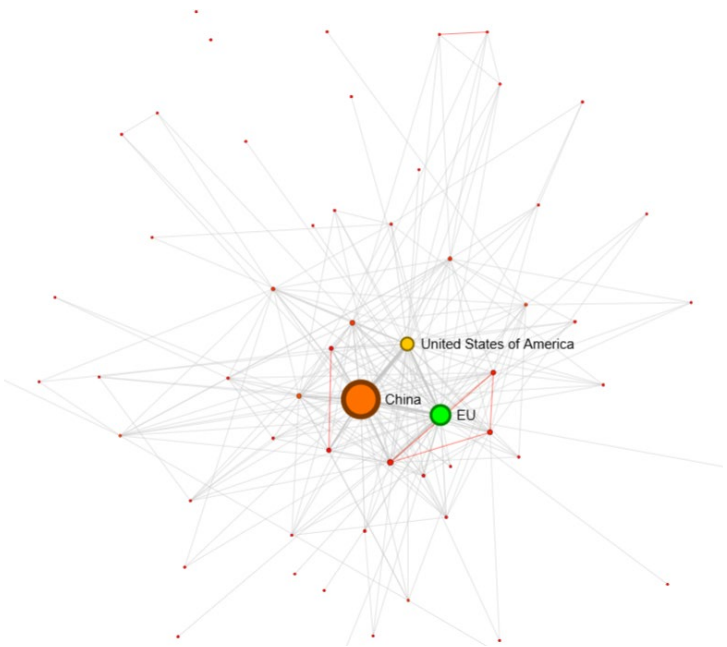
Share of international collaboration		Share of collaboration between EU, US, CN			
United Kingdom	68%				
United States	46%		EU	US	CN
India	40%	EU with	/	24%	33%
Europe	34%	US with	27%	/	52%
South Korea	32%	CN with	21%	29%	/
Japan	29%				
China	27%				

Source: JRC

Europe has a central position in facilitating the flow of knowledge within this cluster, as illustrated in the figure below. While the United States and China also contribute to the dissemination of scientific knowledge, their roles are comparatively smaller.

Figure 19. Collaborative networks between countries for the cluster Mobility and Transport.

The size of the nodes = number of documents and edges = number of joint publications/patents. Colour coding according to betweenness centrality (from red (low) to green (high)).

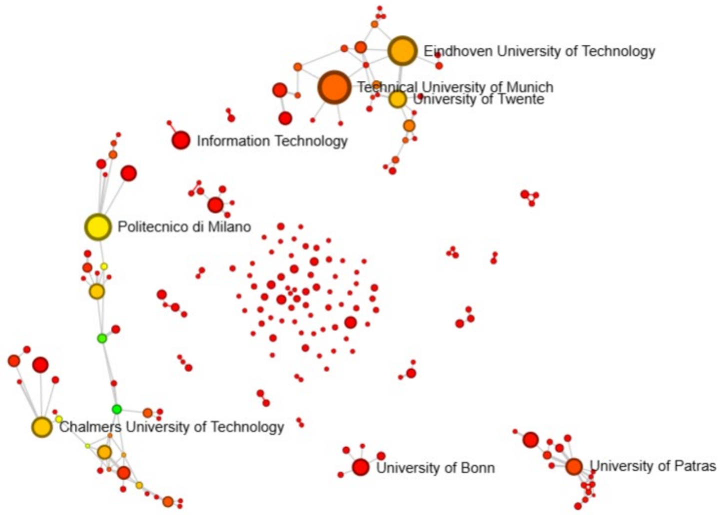


Source: JRC

The flow of knowledge within Europe for emerging technologies in Mobility and Transport is relatively restricted, characterized by a low number of connections and limited network density. Many organizations are linked to only one or two others, creating a fragmented landscape. Within this cluster, two smaller players, the University of Rome II (Italy) and TNO (Netherlands), serve as intermediaries, bridging two otherwise isolated clusters of organizations: one centred around Politecnico di Milano and the other around Chalmers University of Technology.

Figure 20. Collaborative networks for top200 European organisations in the Mobility and Transport cluster.

The size of the nodes = number of documents and edges = number of joint publications/patents. Colour coding according to betweenness centrality (from red (low) to green (high)).



Source: JRC

3.4 Digital Twin

Dashboard: Digital Twin

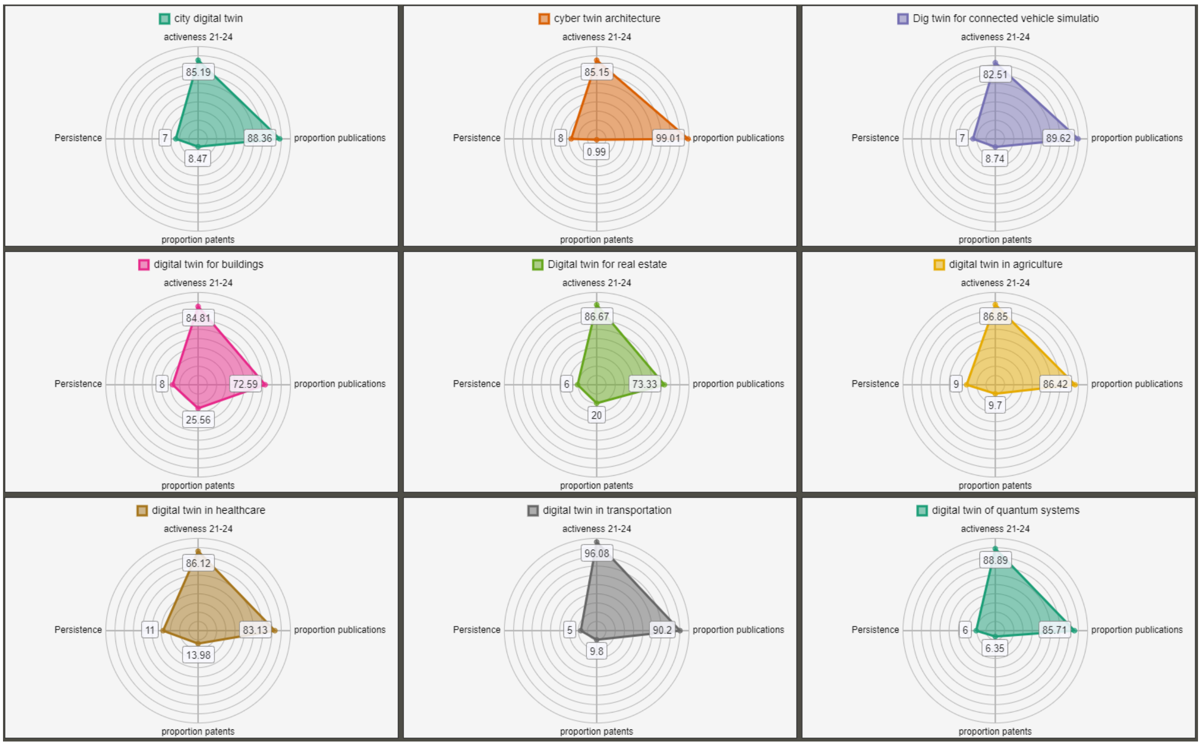
Digital twin		
city digital twin	digital twin for buildings	digital twin in healthcare
cyber twin architecture	digital twin for real estate	digital twin in transportation
digital twin for connected vehicle simulation	digital twin in agriculture	digital twin of quantum systems

Common novel aspects include the integration of multiple data sources, such as for City Digital Twin, Digital Twin for Buildings, and Digital Twin for Real Estate. This novelty aims at integrating multiple data sources to create a dynamic, self-updating digital replica of a physical entity. Real-time monitoring and control of physical systems through their digital twins is another novelty present in some of the technologies, such as in Digital Twin for Transportation or Digital Twin of Quantum Systems. In some emerging technologies, e.g. in Digital Twin for Agriculture and Digital Twin for Healthcare, an emphasis is made on taking a holistic approach to digital twin development, considering the entire lifecycle of the physical system and its interactions with other systems. Finally, emerging technologies such as Digital Twin for Buildings, Digital Twin for Real Estate, or Digital Twin for Agriculture, feature predictive capabilities, enabling the simulation of various scenarios, prediction of future trends, and real-time monitoring and control of physical systems. These novel aspects are driving the development of more sophisticated and effective digital twin solutions that can transform various industries and domains.

Technology radars

All emerging technologies related to digital twins exhibit high activeness 21-24 and low persistence. The proportion of patents varies between 1% and 25%. Here too, no correlation could be found between the four dimensions of the radar.

Figure 21. Technology radars for emerging technologies in Digital Twin.



Source: JRC

Revealed Technology Advantage

For the emerging technologies related to digital twin, South Korea, China, Europe, and India are similarly specialized. It is surprising to see that US is under specialized in this category. As US organisations are usually strong in digital technologies, the under specialization observed here might be a coincidence related either to the field of digital twin or to the small number of technologies considered. This under specialization is consistent with the small number of US organisations in the two top20 lists (figure 23).

Figure 22. Revealed Technological Advantage for WS in Digital Twin.

Weak Signals	China	US	Europe	UK	Japan	South Korea	India
city digital twin	0.96	0.59	1.30	1.59	1.03	3.41	1.20
cyber twin architecture	3.08	0.51	0.51	1.62	0.57	2.84	3.80
Dig twin for connected vehicle simulatio	1.32	0.89	1.35	0.90	0.58	1.98	1.09
digital twin for buildings	0.69	0.48	1.60	1.73	0.97	1.87	0.23
Digital twin for real estate	0.56	0.65	2.04	0.45	0.00	0.00	0.68
digital twin in agriculture	0.91	0.50	1.62	1.32	0.19	1.11	1.45
digital twin in healthcare	1.20	0.92	1.34	1.35	0.31	1.22	1.51
digital twin in transportation	2.15	1.03	0.86	0.64	0.00	0.00	0.00
digital twin of quantum systems	1.14	1.11	1.39	1.64	0.35	0.75	1.65
Average for all weak signals	1.33	0.74	1.33	1.25	0.44	1.47	1.29

Source: JRC

Main actors

Organizations in Europe play a significant role in emerging technologies related to digital twins, often taking a leading position. Politecnico di Milano stands out for producing the highest volume of scientific knowledge in this cluster. Additionally, six other European institutions are among the top 20 organizations by the number of publications: Politecnico di Torino, Delft University of Technology, Aarhus University, Uppsala University, RWTH Aachen University, and Siemens. In terms of research impact, two EU entities rank among the top 20 organizations by mean normalized citations per article: Wageningen University (Netherlands) and the University of West Bohemia (Czech Republic). While no European company or university is among the top 10 patent filers in this area, Siemens (Germany) and Philips (Netherlands) make the top 20 list, each with three patents filed.

Figure 23. Main actors for WS in Digital Twin.

(Top20 organisations in terms of number of documents + Top20 organisations in terms of mean citation by article, normalized by field and year + Top 10 patenting organisations).

Organisations	Country	#Documents
Politecnico di Milano	Italy	50
China University of Mining and Technology	China	38
Beihang University	China	35
University of California	United States of America	32
University of Cambridge	United Kingdom	28
Norwegian University of Science and Technology	Norway	28
Politecnico di Torino	Italy	24
University College London	United Kingdom	23
Tsinghua University	China	22
Aarhus University	Denmark	21
Tongji University	China	20
Delft University of Technology	Netherlands	20
Shanghai Jiao Tong University	China	19
Chinese Academy Of Sciences	China	19
University of Ottawa	Canada	18
Zayed University	United Arab Emirates	18
STIFTELSEN SINTEF	Norway	17
Uppsala University	Sweden	17
RWTH Aachen University	Germany	17
SIEMENS AG	Germany	17

Organisations	Country	Mean normalized citation per article
University of Texas at Austin	United States of America	43.40
NASA Langley Research Center	United States of America	40.23
School of Information Technology and Engineering	Canada	36.54
Pusan National University	South Korea	27.40
University of British Columbia	Canada	20.62
Lebanese American University	Lebanon	20.58
University of New South Wales	Australia	19.26
Nanjing University of Aeronautics and Astronautics	China	19.10
Singapore University of Technology and Design	Singapore	18.39
University of West Bohemia	Czech Republic	17.83
Chongqing University	China	17.74
Deakin University	Australia	17.36
Oak Ridge National Laboratory	United States of America	16.89
National University of Singapore	Singapore	16.86
Sungkyunkwan University	South Korea	16.20
Wageningen University	Netherlands	15.44
China University of Mining and Technology	China	15.32
Guangdong University of Technology	China	14.75
University of Houston	United States of America	14.66
Northeastern University	China	14.57

Organisations	#Patents	Country
China University of Mining and Technology	35	China
STATE GRID	9	China
IBM Corp	9	United States of America
Johnson Controls	9	United States of America
General Electric Co	9	United States of America
CSIC HAIZHUANG WINDPOWER EQUIPMENT CO., LTD.	7	China
Toyota Motor Corp	6	United States of America
Northwestern University	5	United States of America
CHINA ACADEMY OF SPACE TECHNOLOGY	5	China
Tata Consultancy Services	4	India

Source: JRC

International collaborations

The UK is the most collaborative within this cluster of emerging technologies, with 68% of its output involving partnerships with organizations from other countries. European and Chinese organizations show lower levels of international collaboration, with 35% and 34% of their scientific articles and patents, respectively, involving foreign partners. Collaboration between the US and Europe is slightly more frequent than with China.

Figure 24. International collaborations between countries and macro-regions for Digital twin.

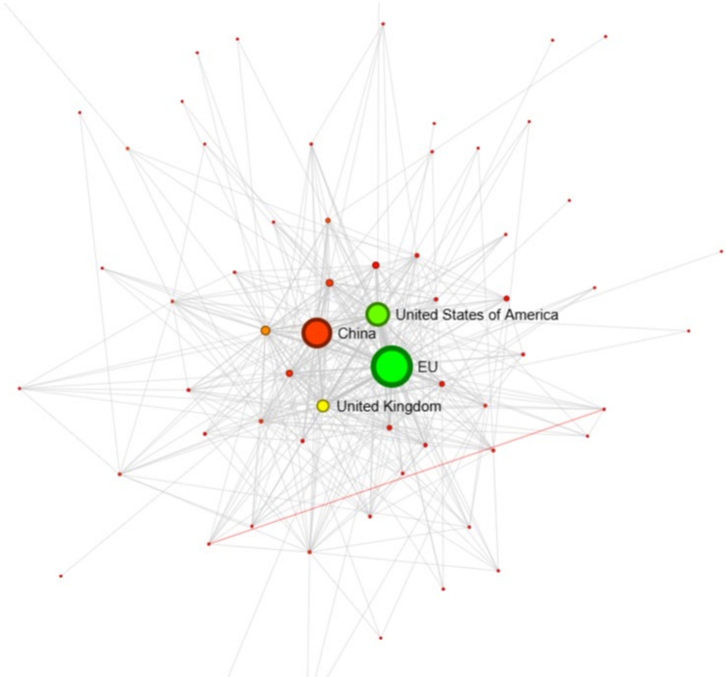
Share of international collaboration		Share of collaboration between EU, US, CN			
United Kingdom	68%				
Japan	54%		EU	US	CN
India	47%	EU with	/	27%	25%
United States	45%	US with	38%	/	22%
South Korea	37%	CN with	23%	23%	/
Europe	35%				
China	34%				

Source: JRC

Organisations from Europe, the US and, to a lesser extent, from the UK, are pivotal in the flow of knowledge in this cluster of emerging technologies, as can be observed in the figure below.

Figure 25. Collaborative networks between countries for the cluster Mobility and Transport.

The size of the nodes = number of documents and edges = number of joint publications/patents. Colour coding according to betweenness centrality (from red (low) to green (high)).

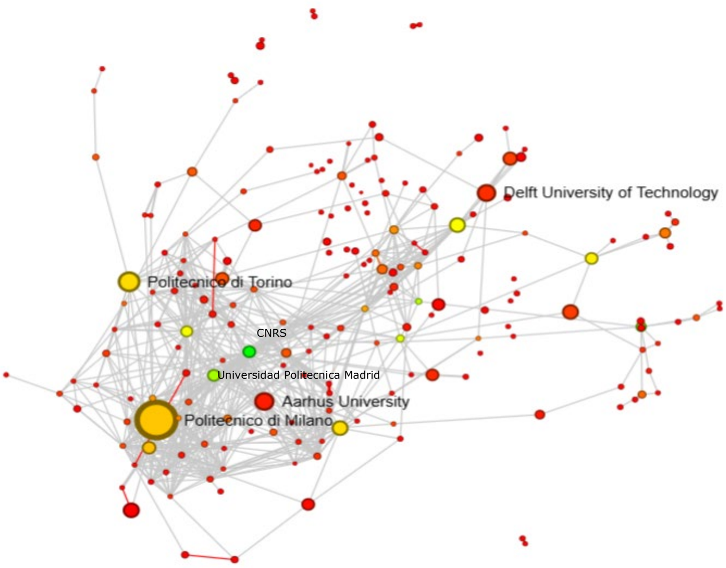


Source: JRC

Two of the mid-range players play a role in facilitating the flows of knowledge in Europe: CNRS and the Universidad Politecnica de Madrid.

Figure 26. Collaborative networks for top200 European organisations in Digital Twin.

The size of the nodes = number of documents and edges = number of joint publications/patents. Colour coding according to betweenness centrality (from red (low) to green (high)).



Source: JRC

3.5 Artificial intelligence and machine learning

Dashboard: [Artificial Intelligence and Machine Learning]()

Artificial intelligence & Machine learning		
Artificial Intelligence of Things	federated reinforcement learning	multimodal hate speech detection
asynchronous federated learning	human AI interface	privacy-preserving machine learning
attention mechanisms in CNN	human centric AI	scientific machine learning
decentralized federated learning	large language models	self supervised learning CNN
epistemic AI	machine unlearning	tiny machine learning
evolutionary Neural Architecture Search	masked face recognition	trustworthy AI
explainable AI	masked language model	trustworthy machine learning
federated deep learning	multimodal AI	vertical federated learning
federated machine learning		

The emerging technologies related to artificial intelligence and machine learning show a strong emphasis on addressing challenges related to data privacy, security, and explainability. Common novel aspects among these technologies include:

— Decentralized and Federated Approaches: technologies such as Federated Machine Learning, Federated Deep Learning, and Vertical Federated Learning, adopt decentralized and federated approaches to enable collaborative model training while preserving data privacy and security.

— Explainability and Transparency: Technologies like Explainable AI, Trustworthy AI, and Human-Centric AI, focus on providing transparent and interpretable decision-making processes, addressing the need for accountability and trust in AI systems.

— Advanced Cryptographic Methods and Secure Multi-Party Computation: Privacy-Preserving Machine Learning and other technologies leverage advanced cryptographic methods and secure multi-party computation to ensure data security and regulatory compliance during model training and inference.

— Integration of Domain Knowledge and Physical Laws: Scientific Machine Learning and other approaches combine data-driven methods with domain knowledge and physical laws to enhance predictive accuracy, solve inverse problems, and provide uncertainty quantification in modelling physical systems.

— Adaptability to Heterogeneous Data and Environments: Technologies like Multimodal AI, Masked Face Recognition, and Tiny Machine Learning demonstrate adaptability to diverse data types, environments, and edge devices, enabling more comprehensive and nuanced understanding in complex domains.

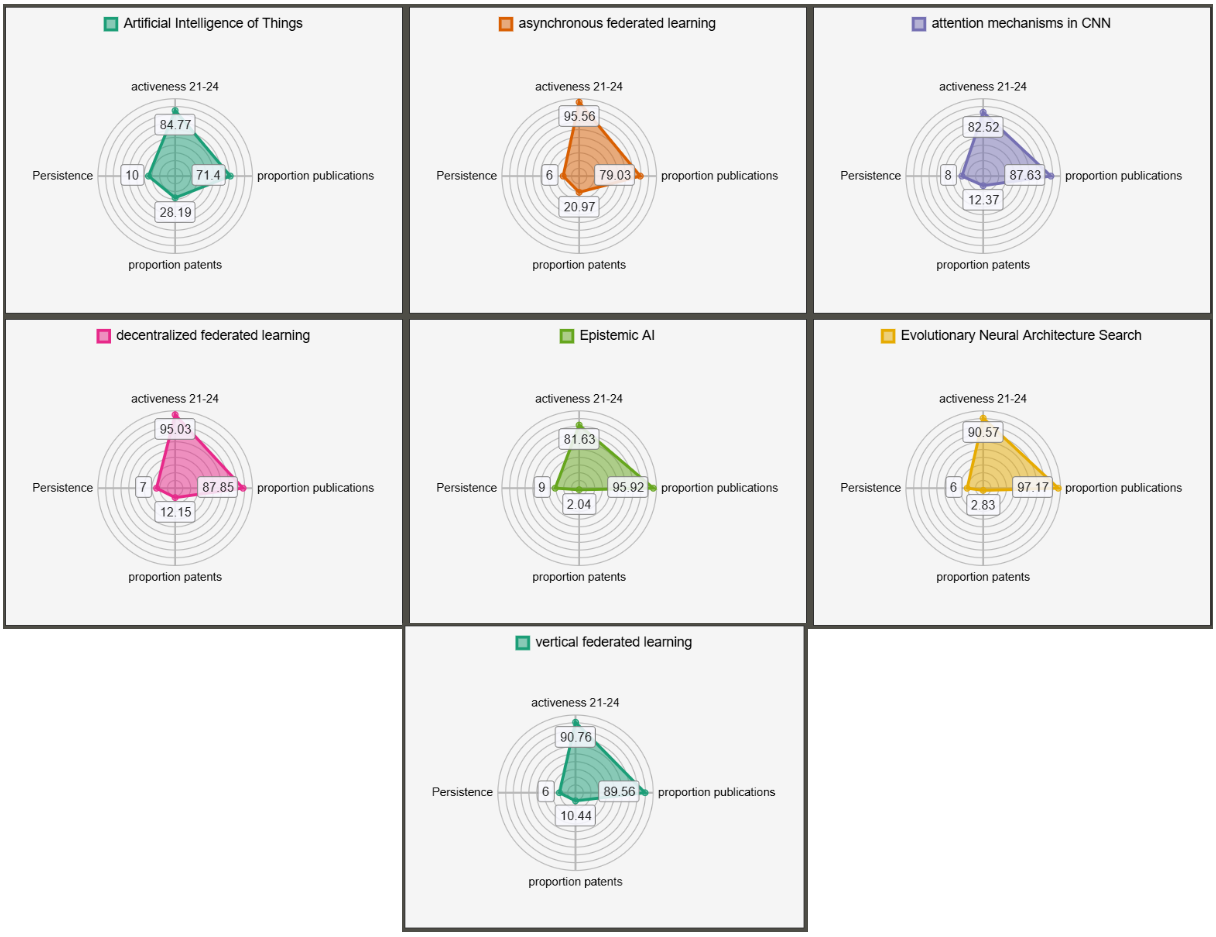
— Emphasis on Human-AI Collaboration and Ethics: Human-Centric AI, Ethical AI, and Human AI Interface technologies prioritize human-AI collaboration, ethics, and inclusivity, striving for more accountable, fair, and transparent AI systems.

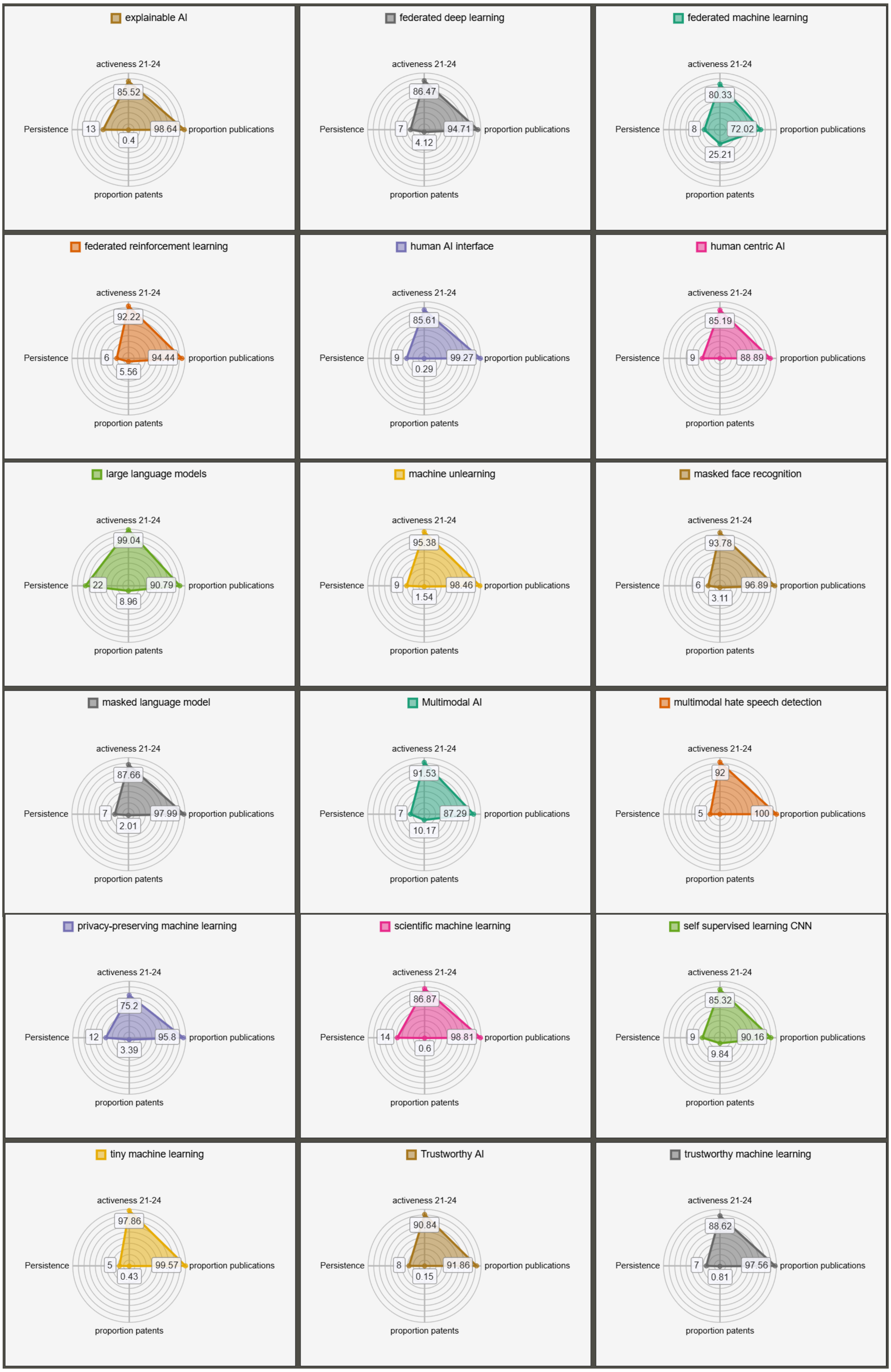
These novel aspects reflect the current trends and challenges in the field of AI and ML, where researchers and developers are actively working to address concerns related to data privacy, security, explainability, and ethics, while also exploring innovative approaches to integrate domain knowledge, physical laws, and human-centric design principles.

Technology radars

The emerging technologies related to AI and ML share a similar shape in the radar visualisation. The share of patents in the document sets is on average low, which is expected for the field of AI and Machine learning. Indeed, this is a field with a strong open-source collaboration, which evolves too quickly for the patent processes, and relies on algorithms that are hard to patent. Companies often use trade secrets instead of patents and focus on patenting specific applications rather than foundational technologies. A few notable exceptions, such as “federated machine learning” and “asynchronous federated learning”, stand out with a share of patents above 20%, signalling the development of applications with perceived market potential. Emerging technologies in this field have been under development on average for over 8 to 9 years, with the exception of “large language models”, which include documents dating back to 1996. This long development timeline reflects the cumulative nature of advancements in the field of artificial intelligence and natural language processing, with foundational work stretching back nearly three decades. Despite this long persistence, the “large language models” technology has a very high activeness of almost 100% (99.04%), showing the recent surge of interest for these models following the recent developments and the launch of commercial products in the past two years. Many other of the emerging technologies in AI and ML have such a high activeness (11 of the 22 technologies have activeness 21-24 > 90%).

Figure 27. Technology radars for emerging technologies in AI and Machine learning.





explainable AI
activeness 21-24
Persistence
proportion publications
proportion patents
85.52
13
98.64
0.4
federated deep learning
activeness 21-24
Persistence
proportion publications
proportion patents
86.47
7
94.71
4.12
federated machine learning
activeness 21-24
Persistence
proportion publications
proportion patents
80.33
8
72.02
25.21
federated reinforcement learning
activeness 21-24
Persistence
proportion publications
proportion patents
92.22
6
94.44
5.56
human AI interface
activeness 21-24
Persistence
proportion publications
proportion patents
85.61
9
99.27
0.29
human centric AI
activeness 21-24
Persistence
proportion publications
proportion patents
85.19
9
88.89
large language models
activeness 21-24
Persistence
proportion publications
proportion patents
99.04
22
90.79
8.96
machine unlearning
activeness 21-24
Persistence
proportion publications
proportion patents
95.38
9
98.46
1.54
masked face recognition
activeness 21-24
Persistence
proportion publications
proportion patents
93.78
6
96.89
3.11
masked language model
activeness 21-24
Persistence
proportion publications
proportion patents
87.66
7
97.99
2.01
Multimodal AI
activeness 21-24
Persistence
proportion publications
proportion patents
91.53
7
87.29
10.17
multimodal hate speech detection
activeness 21-24
Persistence
proportion publications
proportion patents
92
5
100
privacy-preserving machine learning
activeness 21-24
Persistence
proportion publications
proportion patents
75.2
12
95.8
3.39
scientific machine learning
activeness 21-24
Persistence
proportion publications
proportion patents
86.87
14
98.81
0.6
self supervised learning CNN
activeness 21-24
Persistence
proportion publications
proportion patents
85.32
9
90.16
9.84
tiny machine learning
activeness 21-24
Persistence
proportion publications
proportion patents
97.86
5
99.57
0.43
Trustworthy AI
activeness 21-24
Persistence
proportion publications
proportion patents
90.84
8
91.86
0.15
trustworthy machine learning
activeness 21-24
Persistence
proportion publications
proportion patents
88.62
7
97.56
0.81

Source: JRC

Revealed Technology Advantage

China exhibits specialization in 11 out of 20 emerging technologies. This specialization pattern shows once more China's commitment to grow its high-tech sector by steering the research and development direction towards a wide range of technology fields. Interestingly, the areas of under specialization cover all the technologies related to the ethical aspects of AI as well as LLMs. On the contrary, US and European's research communities appear to be more concerned by ethical considerations, as shown by their specialization in emerging technologies like human-centric AI and trustworthy AI. The EU also exhibits clusters of strong specialization in security related applications and decentralized and federated approaches to machine learning. India's specialization in half of the technologies in this cluster points at strategic considerations of leveraging its established IT sector to branch into more advanced technological domains. Although US entities are significantly represented among the leading organizations in publishing, the RTA for US suggests that their involvement in the field is proportional to their engagement across several technological fields. Dominating a field with an RTA that does not show a particular specialization demonstrates the influential position of US organisations in the R&D landscape in this field, illustrating the depth and breadth of the US's technological base.

Figure 28. Revealed Technological Advantage for WS in AI and Machine Learning.

Weak Signals	China	US	Europe	UK	Japan	South Korea	India
artificial intelligence of Things	1.88	0.52	0.51	1.95	0.55	1.76	2.06
asynchronous federated learning	3.53	0.36	0.46	0.90	0.87	1.24	0.90
attention mechanisms in CNN	4.83	0.23	1.04	0.52	0.35	0.76	0.22
decentralized federated learning	2.64	0.72	1.05	0.65	0.84	1.15	0.94
Epistemic AI	0.79	1.60	0.48	3.45	0.00	0.00	1.64
evolutionary Neural Architecture Sea	2.70	0.54	0.54	1.72	0.55	0.39	0.87
explainable AI	0.30	1.67	1.72	1.54	0.65	1.86	0.97
federated deep learning	2.18	1.08	2.36	2.20	0.00	0.76	0.83
federated machine learning	0.93	1.26	2.58	1.76	0.15	0.47	0.92
federated reinforcement learning	2.90	0.42	1.05	1.91	1.01	4.30	0.66
human AI interface	0.46	1.71	1.29	1.26	0.42	2.52	0.50
human centric AI	0.09	2.25	0.78	2.35	1.32	0.56	0.51
large language models	0.90	0.92	0.68	1.26	0.63	1.15	1.79
machine unlearning	2.17	0.46	0.87	0.81	0.59	0.63	1.41
masked face recognition	1.67	0.42	3.07	0.41	0.35	1.30	0.37
masked language model	1.84	0.55	0.85	0.69	1.38	1.29	1.38
Multimodal AI	1.14	0.85	2.60	1.00	1.29	3.16	1.42
multimodal hate speech detection	0.99	0.63	8.93	0.59	0.00	0.00	0.34
privacy-preserving machine learning	1.78	0.80	1.48	0.94	1.02	1.61	1.23
scientific machine learning	0.71	0.93	0.88	0.62	0.29	0.86	2.83
self supervised learning CNN	2.66	0.60	0.73	1.06	0.99	2.85	0.85
tiny machine learning	0.53	1.39	1.15	0.76	0.24	1.92	0.64
Trustworthy AI	0.40	2.00	0.49	1.54	0.18	0.96	1.11
trustworthy machine learning	1.03	1.09	1.67	0.98	0.00	0.34	1.54
vertical federated learning	4.21	0.30	0.30	0.59	0.60	0.18	0.79
Average for all weak signals	1.73	0.93	1.50	1.26	0.57	1.28	1.07

Sources: JRC

Main actors

In the sphere of emerging technologies related to Artificial Intelligence and Machine Learning, organizations from the United States clearly demonstrate their leadership. This is evidenced by their substantial volume of publications and the significant impact of their research, as reflected in the average number of citations per article. The US's leading position is further reinforced in the domain of patenting, where it shares prominence with Chinese organizations, indicating a competitive focus on innovation and securing intellectual property rights within this high-tech sector. European entities also make a notable appearance in the landscape of AI and ML technologies, although limited to research. Prestigious research institutions such as CNRS (National Centre for Scientific Research, France), University College Dublin (Ireland), Aalto University (Finland), INRIA (National Institute for Research in Digital Science and Technology, France), and RWTH Aachen University (Germany) have secured spots in the top20 for their scientific contributions to the field. While these organizations' presence in this echelon underscores the strength and quality of European research in AI and ML, this does not seem to be translated into patentable innovations. Only Nokia (Finland) makes it into the top20 in patenting (11th, with 8 patents), while a second company makes it into the top50: Ericsson (Sweden) with 4 patents.

Figure 29. Main actors for WS in AI and Machine Learning.

(Top20 organisations in terms of number of documents + Top20 organisations in terms of mean citation by article, normalized by field and year + Top 10 patenting organisations).

Organisations	Country	#Documents
University of California	United States of America	328
Microsoft Corp	United States of America	269
Chinese Academy Of Sciences	China	264
GOOGLE INC	United States of America	239
IBM Corp	United States of America	238
Tsinghua University	China	229
Carnegie Mellon University	United States of America	213
Stanford University	United States of America	208
China University of Mining and Technology	China	186
Nanyang Technological University	Singapore	160
Harvard University	United States of America	159
National University of Singapore	Singapore	158
Massachusetts Institute of Technology	United States of America	150
University of Washington	United States of America	145
Zhejiang University	China	141
Peking University	China	134
Shanghai Jiao Tong University	China	115
CNRS	France	113
Hong Kong University of Science and Technology	Hong Kong	111
Amazon	United States of America	107

Organisations	Country	Mean normalized citation per article
UC Berkeley	United States of America	87.86085969
University of Auckland	New Zealand	79.67666082
GOOGLE INC	United States of America	72.7647914
Yale University	United States of America	69.39743644
NVIDIA CORP	United States of America	51.60590334
Google DeepMind	United Kingdom	51.09163446
University College Dublin	Ireland	45.22196049
University of Virginia	United States of America	42.06362182
Aalto University	Finland	40.71418291
Brown University	United States of America	38.62854175
University of Toronto	Canada	34.54725775
INRIA	France	32.13663557
University of Technology	Australia	30.88391091
New York University	United States of America	30.43215302
Stanford University	United States of America	30.34806852
University of Washington	United States of America	30.26525996
Microsoft Corp	United States of America	29.17719748
Cornell University	United States of America	29.16906138
University of Illinois	United States of America	28.4715553
RWTH Aachen University	Germany	27.98263038

Organisations	#Patents	Country
China University of Mining and Technology	171	China
GOOGLE INC	24	United States of America
TENCENT TECHNOLOGY CO., LTD.	17	China
IBM Corp	15	United States of America
CSIC HAIZHUANG WINDPOWER EQUIPMENT CO., LTD.	13	China
SOURCE PHOTONICS INC.	13	China
Microsoft Corp	10	United States of America
DIGITAL TECH CO LTD	10	South Korea
IFLYTEK CO., LTD.	10	China
Tsinghua University	9	China
NOKIA TECH LTD	8	Finland
Chinese Academy Of Sciences	7	China
DAJIU MANUFACTURING CO., LTD.	7	China
HUAWEI TECH CO LTD	6	China
University of Electronic Science and Technology of China	5	China
STATE GRID	5	China
BANK OF CHINA CO., LTD.	5	China
CHINA ACADEMY OF SPACE TECHNOLOGY	4	China
MINBAO ENERGY AND EQUIPMENT CO., LTD.	4	China
Accenture	4	United States of America

Source: JRC

International collaborations

Organizations from the EU, the US, Japan, South Korea, and India collaborate internationally in approximately 40% of their scientific output. The UK stands out as the most collaborative country, with a collaboration rate of 68%, while China follows with a scientific collaboration rate of 35%. Among the EU's collaborations, 35% involve U.S.-based organizations, whereas only 12% include partners from China. A similar pattern is observed for China, where only 15% of collaborations involve an EU organization, but 40% include at least one partner from the United States.

Figure 30. International collaborations between countries and macro-regions for AI and Machine Learning.

Share of international collaboration		Share of collaboration between EU, US, CN			
United Kingdom	68%				
Japan	44%		EU	US	CN
United States	42%	EU with	/	35%	12%
India	42%	US with	31%	/	27%
Europe	39%	CN with	15%	40%	/
South Korea	38%				
China	35%				

Source: JRC

Figures 21 and 22 highlight that the United States attract more collaboration in artificial intelligence and machine learning than any other region. The significant role of U.S. organizations is further confirmed by their central position in the flow of knowledge within this cluster of emerging technologies (Figure 31). Europe also plays a crucial role in this context, although this influence is not reflected in a substantial presence of European organizations among the top producers of scientific outputs or patents.

Figure 31: Collaborative networks between countries for the cluster Mobility and Transport.

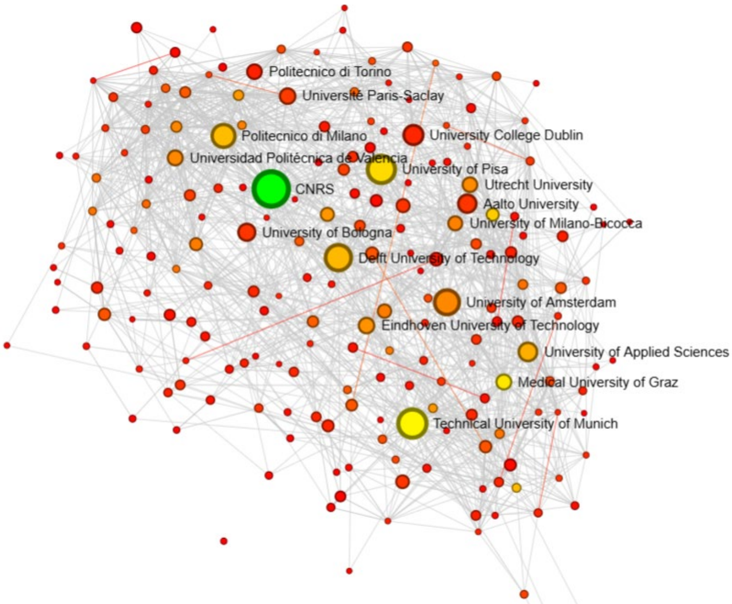
The size of the nodes = number of documents and edges = number of joint publications/patents. Colour coding according to betweenness centrality (from red (low) to green (high)).

Souce: JRC

Knowledge flows in Europe are intense, as can be seen on figure 32 below, with CNRS playing a central role.

Figure 32. Collaborative networks for top200 European organisations in AI and Machine Learning.

The size of the nodes = number of documents and edges = number of joint publications/patents. Colour coding according to betweenness centrality (from red (low) to green (high)).



Source: JRC

3.6 Information and Communication Technologies

Dashboard: ICT

Information and Communication Technologies		
adversarial defense	metaverse	secure decentralized finance
blockchain in supply chain	MITRE ATT&CK	self sovereign identity
confidential computing	multi key fully homomorphic encryption	single chip neuromorphic computing
deepfake detection	non-fungible tokens	smart contracts supply chain
few shot learning	open RAN	vehicular edge computing
human cyber physical system	practical byzantine fault tolerance blockchain	zero Trust architecture
intrusion Dectection BoT-IoT	redactable blockchain	

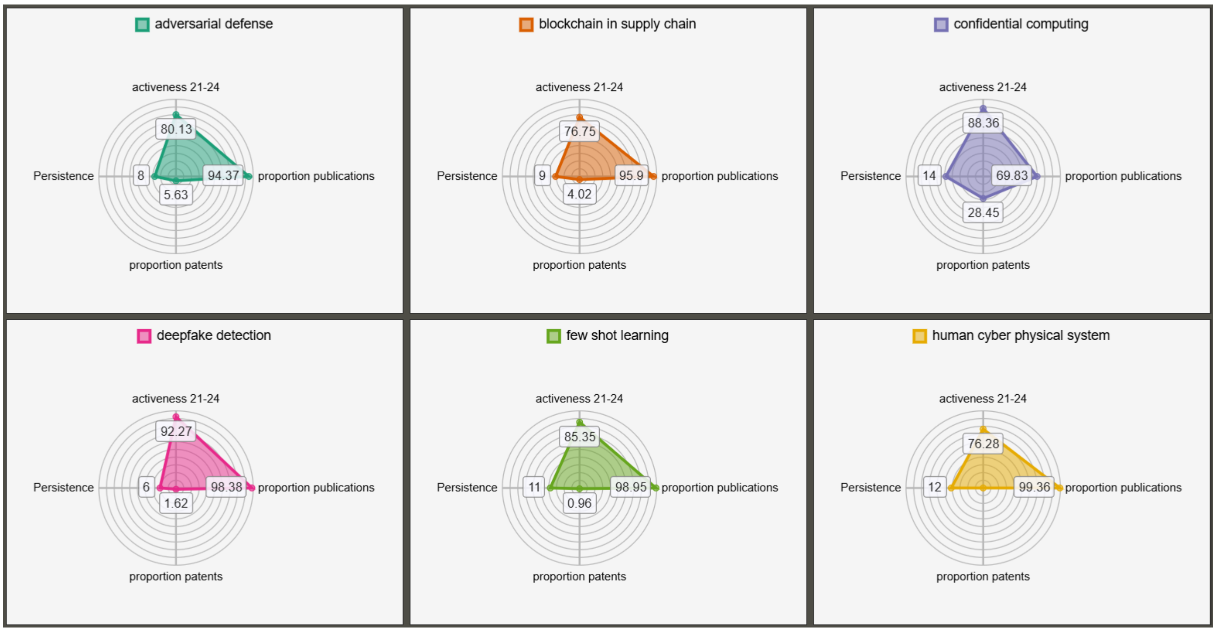
The detected emerging technologies share several common traits that reflect current trends and priorities in the ICT industry. A significant and anticipated theme is the application of AI and ML to push the boundaries of performance, security, and efficiency. Technologies such as adversarial defense, deepfake detection, few-shot learning, and single-chip neuromorphic computing exemplify the diverse ways in which AI and ML are being harnessed to enhance various aspects of computing and data handling. In the realm of blockchain and decentralized technologies, there is a clear focus on ensuring the security and reliability of transactions. Similarly, innovations like blockchain in supply chain, redactable blockchain, and secure decentralized finance are all centred around making decentralized systems more transparent and trustworthy. These technologies aim to bolster the integrity and efficiency of transactions while maintaining user privacy and confidence in the system. Security and privacy also emerge as prevailing trends across a range of other technologies. Confidential computing, multi-key fully homomorphic encryption, self-sovereign identity, and Zero Trust architecture are all geared towards safeguarding data and interactions in the digital space. These technologies are critical in an era where data breaches and cybersecurity threats are increasingly common, and they play a pivotal role in protecting sensitive information and maintaining user trust. Another trend that stands out is interoperability and integration, which focuses on enabling seamless interactions among disparate systems, networks, and devices. Technologies like Open RAN (Radio Access Network), the metaverse, and vehicular edge computing are designed to facilitate compatibility and communication across various platforms and infrastructures, enhancing the user experience and enabling new functionalities. Lastly, the need for real-time processing is a theme that spans multiple ICT applications. Technologies such as single-chip neuromorphic computing and vehicular edge computing represent the industry's push towards faster, on-the-spot data processing capabilities. This is especially important for applications that require immediate response and analysis, such as those in autonomous vehicles or smart infrastructure. These common trends among emerging technologies underscore a broader shift towards more intelligent, secure, interconnected, and efficient systems. As these trends continue to develop, they are poised to bring about significant advancements and reshape the technological landscape in various domains.

Technology radars

The emerging technologies within the ICT cluster present varied profiles, reinforcing the observation made for previous technology radars that no apparent correlation across the four radar dimensions can be made. As the landscape of ICT emerging technologies exhibits a wide range of characteristics, it points at the complex interplay between innovation, commercialization potential, and research interest, with each technology following its own unique path of development. The heterogenous profiles emerging from the four dimensions of the radar reflect the industry's adaptive response to the evolving needs and challenges of the digital age, as well as strategic priorities of innovation and market positioning.

Several emerging technologies in ICT, including multi key fully homomorphic encryption, confidential computing, non-fungible tokens (NFTs), and the metaverse, display long development time (high persistence) and a substantial share of patents in the document sets. This profile is indicative of the long-term vision of the industry towards secure, transparent, and interconnected virtual environments, as well as the steady maturation of these technologies towards commercial applications and market adoption. Conversely, emerging technologies, such as deepfake detection, intrusion detection BoT-IoT, MITRE ATT&CK, and secure decentralized finance, align with the industry's urgent need to address rapidly evolving security threats following recent developments in AI and ML. These technologies are characterized by a low share of patents and low persistence but high activeness, reflecting their nascent status and the immediate relevance that has prompted a spike in research and development activities. Finally, technologies like Open RAN and Zero Trust Architecture, with short persistence, high activeness, and significant patent shares, suggest the development of innovative cybersecurity solutions and open communication standards with considerable market potential despite the relatively short development timeframe. While these patterns highlight a broader industry shift toward systems that are intelligent, secure, and capable of seamless integration and real-time processing, the varying degrees of patenting activity and research persistence reflect differing stages of technological maturity and market readiness.

Figure 33. Technology radars for emerging technologies in ICT.




intrusion Dectection BoT-IoT
activeness 21-24
92.57
Persistence
6
100
proportion publications
proportion patents
metaverse
activeness 21-24
96.17
Persistence
21
81.72
proportion publications
18.23
proportion patents
MITRE ATT&CK
activeness 21-24
94.53
Persistence
7
99.5
proportion publications
0.5
proportion patents
multi key fully homomorphic encryption
activeness 21-24
73.43
Persistence
10
79.72
proportion publications
20.28
proportion patents
Non-fungible tokens
activeness 21-24
93.99
Persistence
12
53.18
proportion publications
46.7
proportion patents
open RAN
activeness 21-24
91.01
Persistence
9
87.27
proportion publications
11.61
proportion patents
practical byzantine fault tolerance
activeness 21-24
71.46
Persistence
16
95.21
proportion publications
4.79
proportion patents
redactable blockchain
activeness 21-24
86.41
Persistence
7
98.06
proportion publications
1.94
proportion patents
secure decentralized finance
activeness 21-24
96.08
Persistence
7
97.06
proportion publications
1.96
proportion patents
self sovereign identity
activeness 21-24
76.82
Persistence
11
90.69
proportion publications
7.66
proportion patents
single chip neuromorphic computing
activeness 21-24
90
Persistence
5
90
proportion publications
5
proportion patents
Smart contracts supply chain
activeness 21-24
79.73
Persistence
8
97.13
proportion publications
2.12
proportion patents
vehicular edge computing
activeness 21-24
77.56
Persistence
8
99.7
proportion publications
0.15
proportion patents
Zero Trust architecture
activeness 21-24
92.91
Persistence
5
78.74
proportion publications
21.26
proportion patents

Souce: JRC

Revealed Technology Advantage

The RTA index values highlight the strategic focus of India, South Korea, and China, as these economies demonstrate strong specialization across most of the emerging technologies within this cluster. Their targeted R&D investment in ICT as well as AI and ML is indicative of a concerted effort to lead in the high-tech sector. Conversely, the EU and US exhibit balanced involvement rather than specialized focus within this cluster, with an average RTA index value close to one. Japan clearly shows under specialization, with an average RTA value well below one.

Figure 34. Revealed Technological Advantage for WS in ICT.

Weak Signals	China	US	Europe	UK	Japan	South Korea	India
adversarial defense	2.97	1.04	0.35	0.62	0.60	1.71	1.41
blockchain in supply chain	1.53	0.56	0.81	1.74	0.19	0.80	3.93
confidential computing	1.64	1.72	0.90	1.00	0.23	1.50	0.69
deepfake detection	1.84	0.75	0.53	0.49	0.39	2.01	3.68
few shot learning	3.38	0.92	0.47	0.90	0.39	1.12	0.78
human cyber physical system	3.34	1.08	0.94	0.38	0.74	0.79	0.29
intrusion Dectection BoT-IoT	0.67	0.49	0.27	1.75	0.00	0.80	4.64
metaverse	1.13	0.64	0.84	1.14	0.71	3.91	1.70
MITRE ATT&CK	0.19	1.05	1.11	1.33	1.05	2.23	1.12
multi key fully homomorphic encryption	3.14	0.60	0.59	0.52	1.00	1.43	1.76
Non-fungible tokens	0.78	0.71	1.01	1.20	0.43	1.77	2.55
open RAN	0.66	0.83	1.56	1.08	0.33	1.40	1.05
practical byzantine fault tolerance	3.88	0.49	0.38	0.90	0.20	1.62	1.87
redactable blockchain	4.52	0.81	0.51	0.29	0.75	0.40	0.88
secure decentralized finance	1.12	1.39	0.64	2.53	0.00	0.00	2.03
self sovereign identity	0.36	0.60	1.70	1.45	0.65	1.14	1.57
single chip neuromorphic computing	2.74	0.95	0.44	0.82	1.06	4.51	2.48
Smart contracts supply chain	1.21	0.45	0.68	1.56	0.18	0.63	6.23
vehicular edge computing	3.83	0.62	0.50	1.02	0.57	1.96	1.15
Zero Trust architecture	1.26	1.18	0.51	0.52	0.67	1.22	1.67
Average for all weak signals	2.01	0.84	0.74	1.06	0.51	1.55	2.07

Source. JRC

Main Actors

The ranking of top organizations highlights the dominance of Chinese organizations in terms of output volume, while the landscape is more diverse when considering research impact (normalized citations value). Despite the United States displaying a slight under-specialization, American entities are well-represented among the leading actors in this sector, indicating a strong and balanced research output across various technological domains. Chinese organisations, while producing a lot of scientific outputs related to the emerging technologies in this field, struggle to have impactful publications in the field: only two Chinese organisations are in the top 50 most impactful organisations in terms of citations (Shenzhen University, 25th, and Guangdong University of Technology, 39th). Conversely, European organizations face challenges, to say the least, in matching the prominence of their peers in the United States, China, and South Korea. In terms of volume of scientific outputs, the first European organisation is the CNRS (National Centre for Scientific Research) in France, at the 59th place with 55 documents, while it is slightly better in terms of impact, as University of Zilina from Slovakia is in the top20 (14th place) and another organisation makes the top 50 (Technical University of Munich, 35th place). When it comes to securing intellectual property rights, the absence of European organizations in the top 50 patent filers is notable. Conversely, organizations from the other major economies except India are actively seeking patent protection for their innovations.

Figure 35. Main actors for WS in ICT.

(Top20 organisations in terms of number of documents + Top20 organisations in terms of mean citation by article, normalized by field and year + Top 10 patenting organisations).

Organisations	Country	#Documents
Chinese Academy Of Sciences	China	431
Nanyang Technological University	Singapore	176
Beijing University of Posts and Telecommunications	China	176
Tsinghua University	China	175
XIDIAN UNIVERSITY	China	171
University of Electronic Science and Technology of China	China	170
Zhejiang University	China	151
Shanghai Jiao Tong University	China	129
University of California	United States of America	129
Beihang University	China	126
Beijing Jiaotong University	China	126
Fudan University	China	124
Hong Kong Polytechnic University	Hong Kong	118
IBM Corp	United States of America	114
University of Science and Technology	China	112
Peking University	China	110
National University of Defense Technology	China	109
NORTHWESTERN POLYTECHNICAL UNIVERSITY	China	108
Nanjing University of Information Science and Technology (NUST)	China	106
XI'AN JIAOTONG UNIVERSITY	China	103

Organisations	Country	Mean normalized citation per article
Johns Hopkins University	United States of America	95.98916967
Google Research	United States of America	44.93201689
University of Hong Kong	Hong Kong	43.0408267
University of Tokyo	Japan	39.18459881
National Institute of Industrial Engineering	India	27.27345808
University of Toronto	Canada	21.87745433
Carnegie Mellon University	United States of America	21.34932478
Kyung Hee University	South Korea	21.01779077
University of Washington	United States of America	20.50187393
Business School	United Kingdom	19.93444957
University of Waterloo	Canada	19.19020849
University of Edinburgh	United Kingdom	18.3772616
Singapore University of Technology and Design	Singapore	17.37824051
University of Zilina	Slovakia	17.21311578
King Abdulaziz University	Saudi Arabia	17.02861067
Sejong University	South Korea	16.49686319
Samsung Corp	South Korea	16.48897278
Stanford University	United States of America	16.45526978
University of Southampton	United Kingdom	16.34047248
University of Michigan	United States of America	16.11527888

Organisations	#Patents	Country
BANK OF AMERICA CORP	54	United States of America
IBM Corp	46	United States of America
China University of Mining and Technology	32	China
LG Corp	21	South Korea
SONY Corp	14	Japan
Samsung Corp	10	South Korea
AT&T CORP	10	United States of America
ELECT&TELECOMUNICATIONS RES INST	8	South Korea
UNIVERSAL CITY STUDIOS LLC	8	United States of America
QUALCOMM INC	7	United States of America

Source. JRC

International collaborations

The United Kingdom has the highest rate of international collaboration at 73%, indicating a strong global engagement in its research and innovation activities. The United States follows with 64%, while Europe collaborates internationally in 45% of its outputs, which is slightly higher than Japan at 42%. India and China demonstrate similar levels of international collaboration, with 39% and 35%, respectively, while South Korea has the lowest rate at 19%. When examining specific collaboration between the EU, US, and China, 27% of the EU's collaborations involve US-based organizations, while 24% include Chinese partners. For the US, 22% of its collaborations are with European organizations, while 41% involve China, demonstrating a strong bilateral relationship between the US and China. For China, 33% of its collaborations include the US, while only 16% involve European organizations.

Figure 36. International collaborations between countries and macro-regions for the cluster ICT.

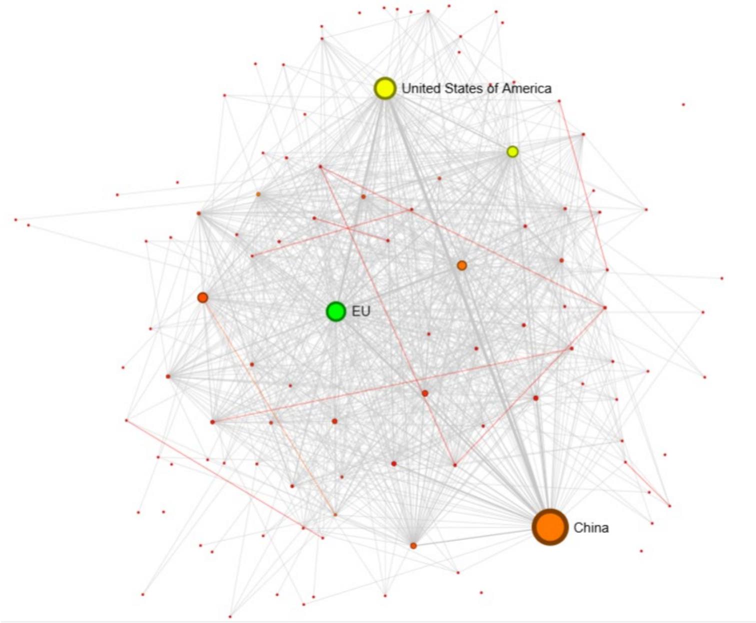
Share of international collaboration		Share of collaboration between EU, US, CN			
United Kingdom	73%				
United States	64%		EU	US	CN
Europe	45%	EU with	/	27%	24%
Japan	42%	US with	22%	/	41%
India	39%	CN with	16%	33%	/
China	35%				
South Korea	19%				

Source. JRC

Europe has a key role in the flows of knowledge in this cluster, as illustrated by the collaboration network between all countries (figure 37). Unfortunately, this connectivity of European organisations does not allow them to be in the top positions when it comes to scientific outputs or patenting.

Figure 37. Collaborative networks between countries for the cluster ICT.

The size of the nodes = number of documents and edges = number of joint publications/patents. Colour coding according to betweenness centrality (from red (low) to green (high)).



Source. JRC

Within Europe, a few academic institutions play a central role in disseminating scientific knowledge in the emerging technologies related to ICT: University of Paris-Saclay (France), University of Oulu (Finland), University of Torino (Italy), Universidad Politecnica de Madrid (Spain), and to a lesser extent: University of Munich (Germany), Politecnico di Milano (Italy), and CNRS (France). This reflects that ICT is central to the research agenda of many EU actors.

Figure 38. Collaborative networks for top200 European organisations in ICT.

The size of the nodes = number of documents and edges = number of joint publications/patents. Colour coding according to betweenness centrality (from red (low) to green (high)).

Source. JRC

3.7 Medical imaging

Dashboard: Medical Imaging

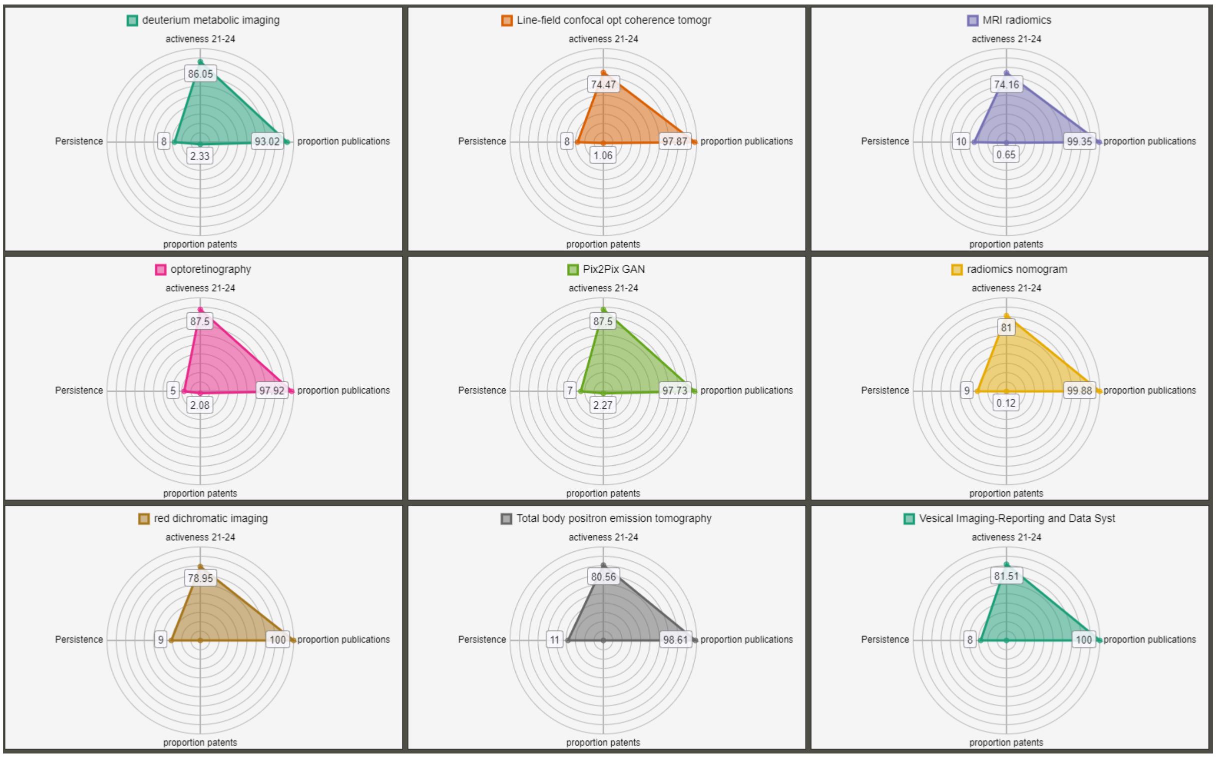
Medical imaging		
deuterium metabolic imaging	optoretinography	red dichromatic imaging
Line-field confocal optical coherence tomography	Pix2Pix GAN	Total body positron emission tomography
MRI radiomics	radiomics nomogram	Vesical Imaging-Reporting and Data Syst

These emerging technologies aim to address the challenges and opportunities presented by the increasing complexity and diversity of medical imaging applications. Common novel aspects reflect the current trends and developments in the field of medical imaging: enhanced visualization, advanced image analysis, non-invasive techniques, personalized medicine, and multimodal imaging. Enhanced Visualization and Imaging technologies like Red Dichromatic Imaging, Line-Field Confocal Optical Coherence Tomography, or Optoretinography, aim at improving visualization and imaging capabilities, thus enabling better diagnosis and treatment of various medical conditions. Other technologies, such as Pix2Pix GAN, radiomics nomogram, and MRI Radiomics, leverage machine learning and deep learning to analyse medical images and facilitate the identification of patterns and markers that may not be discernible through traditional analysis techniques. Multimodal integration of imaging and data, as seen in Total Body-PET and Deuterium Metabolic Imaging, is also helping to provide a more comprehensive understanding of complex medical conditions and enabling more accurate diagnoses. Finally, there is an observed trend towards developing non-invasive and minimally invasive techniques aimed at reducing the risks and discomfort associated with conventional medical imaging procedures. The pursuit of personalized medicine and precision diagnostics also reflects an intent to create treatment strategies that are more tailored to individual patient needs, with the potential for improving patient outcomes.

Technology radars

While the radar analysis for emerging technologies in medical imaging reveals no clear correlations across the four dimensions of patent share, persistence, activeness, and novelty, it is noteworthy that the nine technologies within this category display a consistent profile characterized by a remarkably low proportion of patents. Simultaneously, the other three dimensions fall within a similar range for these technologies. This uniformity may hint at an inherent attribute of the medical imaging field, where the focus on research and development could potentially outweigh the emphasis on securing patents. However, with only nine technologies under consideration in this category, drawing definitive conclusions remains challenging, and further investigation would be required to substantiate any trends specific to this domain of medical technology.

Figure 39. Technology radars for emerging technologies in Medical Imaging.



Source. JRC

Revealed Technology Advantage

The RTA index reveals a diverse and competitive landscape in medical imaging technologies, with different regions exhibiting varying degrees of specialization. China demonstrates strong specialization in five out of nine technologies, with particularly high RTAs in Line-field confocal optical coherence tomography and Total Body Positron Emission Tomography, signifying a strategic emphasis on advanced imaging modalities. The United States shows specialization in three technologies, with MRI Radiomics and Vesical Imaging-Reporting and Data System standing out with RTAs above 2, reflecting a focus on integrating quantitative imaging with clinical data for enhanced diagnostics. The European Union's specialization is evident in five technologies, with Pix2Pix GAN exhibiting an RTA above 2, indicating a substantial research interest in AI-powered image transformation. Japan, with strong specializations in Red Dichromatic Imaging and Vesical Imaging-Reporting and Data System, indicates focused advancements in endoscopy and standardized cancer imaging reporting. South Korea, while specializing in three technologies, shows a significant RTA in Deuterium Metabolic Imaging, pointing towards innovations in non-invasive metabolic tracking. India's specialization in Red Dichromatic Imaging is marked by an RTA greater than 4, highlighting a concentrated effort in endoscopic imaging technology.

Figure 40, Revealed Technological Advantage for WS in Medical Imaging.

Weak Signals	China	US	Europe	UK	Japan	South Korea	India
deuterium metabolic imaging	0.46	2.90	1.48	0.74	0.48	0.00	0.00
Line-field confocal opt coherence tomogr	0.13	0.51	3.48	0.32	0.21	0.00	0.00
MRI radiomics	3.11	1.17	1.22	0.75	0.42	1.22	0.12
optoretinography	0.13	3.47	1.01	0.00	0.00	0.00	0.00
Pix2Pix GAN	1.22	0.70	0.51	0.69	0.88	1.89	4.15
radiomics nomogram	6.01	0.67	0.38	0.14	0.11	0.28	0.10
red dichromatic imaging	0.32	0.34	0.31	0.00	16.52	0.00	1.18
Total body positron emission tomography	2.61	1.27	1.78	0.62	0.54	0.00	0.00
Vesical Imaging-Reporting and Data Syst	1.94	1.09	1.25	1.11	2.08	2.23	0.76
Average for all weak signals	1.77	1.35	1.27	0.49	2.36	0.62	0.70

Source: JRC

Main actors

Chinese organizations are at the forefront in terms of scientific article production, reflecting the country's substantial investment across a diverse set of technology fields. Only one European organisation appears in the top20 ranking based on the number of documents (Université Paris-Saclay, France). When it comes to research influence, as indicated by normalized citations per article, European organizations show a stronger impact. Notably, Italy contributes with four organizations—University of Catania, Regina Elena National Cancer Institute, Catholic University Sacro Cuore, and Policlinico Umberto—demonstrating the country's research quality and influence. Additionally, Siemens Healthcare from Germany and Instituto de Salud Carlos III in Spain stand out among the top20 most influential entities, suggesting that while European organizations may produce fewer articles overall, their research contributions are recognized for their significance within the scientific community. Patenting activity related to these emerging technologies is minimal, with filings stemming exclusively from Chinese or US-based organizations. This indicates a potential focus on not only advancing scientific knowledge but also securing intellectual property rights within these regions.

Figure 41. Main actors for WS in Medical.

(Top20 organisations in terms of number of documents + Top20 organisations in terms of mean citation by article, normalized by field and year + Top 10 patenting organisations).

Organisations	Country	#Documents
Chinese Academy Of Sciences	China	120
Fudan University	China	117
GE Healthcare	United States of America	98
People's Hospital	China	68
Affiliated Hospital of Qingdao University	China	65
Capital Medical University	China	62
Huazhong University of Science and Technology	China	54
GE Healthcare China	China	50
Southern Medical University	China	48
Beihang University	China	40
Sun Yat-sen University Cancer Center	China	40
First Affiliated Hospital of Nanjing Medical University	China	39
University of California	United States of America	39
Sun Yat-Sen University	China	38
Chinese Academy of Medical Sciences and Peking Union Medical College	China	38
Memorial Sloan-Kettering Cancer Center	United States of America	36
Shanghai Jiao Tong University School of Medicine	China	36
Université Paris-Saclay	France	36
Zhejiang University School of Medicine	China	33

Organisations	Country	Mean normalized citation per article
South China University of Technology	China	12.01
Guangdong General Hospital	China	11.62
Third Affiliated Hospital of Kunming Medical University	China	9.99
University of Texas Southwestern Medical Center	United States of America	9.14
Guangzhou Medical University	China	8.54
University of Sheffield	United Kingdom	8.52
University Health Network	Canada	8.47
University of Catania	Italy	7.88
Shantou University Medical College	China	7.79
Regina Elena National Cancer Institute	Italy	7.55
Yale University	United States of America	6.82
Hirslanden Clinic	Switzerland	6.66
Affiliated People's Hospital of Jiangsu University	China	6.60
Siemens Healthcare	Germany	6.47
Università Cattolica del Sacro Cuore	Italy	6.21
Policlinico Umberto I	Italy	5.98
University of North Carolina at Chapel Hill	United States of America	5.80
Southern Medical University	China	5.65
Instituto de Salud Carlos III	Spain	5.57
Hospital of Nantong University	China	5.51

Organisations	#Patents	Country
University of California	1	United States of America
Childrens hospital Medical Center	1	United States of America
Central South University	1	China
China University of Mining and Technology	1	China
Yale University	1	United States of America

Source: JRC

International collaborations

Figure 42 highlights that the United Kingdom exhibits the highest level of international collaboration at 90%, followed by the United States at 73%. Europe collaborates internationally in 56% of its scientific outputs, while Japan reaches 51%. India, China, and South Korea have lower collaboration rates, at 38%, 29%, and 21%, respectively.

In terms of collaboration between the EU, US, and China, 37% of EU collaborations involve the US, while 41% include Chinese partners. For the US, 30% of its collaborations are with European organizations, and 61% involve China, indicating a strong partnership between the US and China. Similarly, 31% of China's collaborations involve the EU, while 57% include the US. These figures demonstrate a clear preference of Chinese and US-based organisations to work together on the technologies in this cluster than with European organisations.

Figure 42. International collaborations between countries and macro-regions in Medical Imaging.

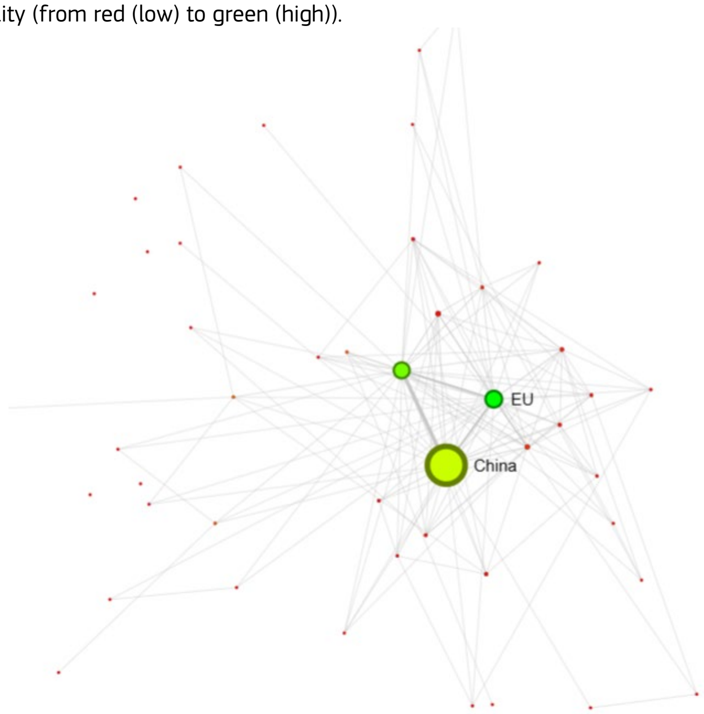
Share of international collaboration		Share of collaboration between EU, US, CN			
United Kingdom	90%				
United States	73%		EU	US	CN
Europe	56%	EU with	/	37%	41%
Japan	51%	US with	30%	/	61%
India	38%	CN with	31%	57%	/
China	29%				
South Korea	21%				

Source: JRC

Europe, the US and, to a lesser extent, China, are the three poles of knowledge dissemination for this cluster. Despite the low volume of scientific outputs by European organizations (fragmented ecosystem), Europe still plays a pivotal role in the knowledge flows.

Figure 43. Collaborative networks between countries for the cluster Medical Imaging.

The size of the nodes = number of documents and edges = number of joint publications/patents. Colour coding according to betweenness centrality (from red (low) to green (high)).

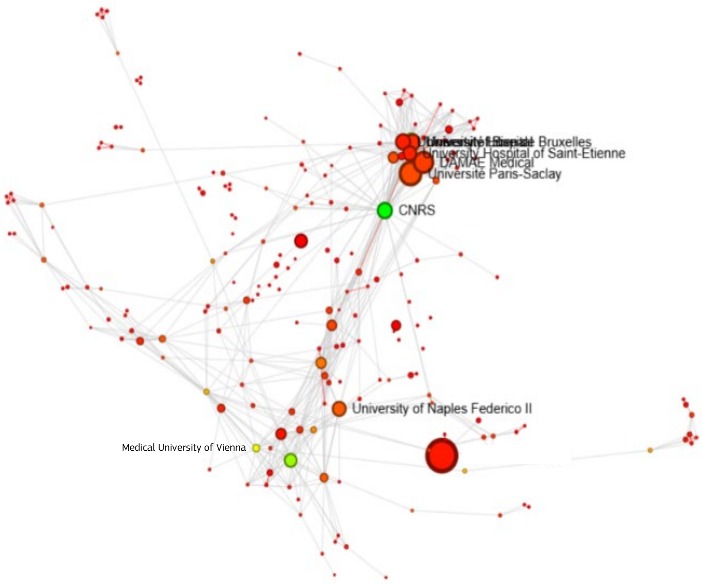


Source: JRC

Within Europe, two organisations stand out in their role of disseminating knowledge: CNRS (France) and the Medical University of Vienna (Austria).

Figure 44. Collaborative networks for top200 European organisations in Medical Imaging.

The size of the nodes = number of documents and edges = number of joint publications/patents. Colour coding according to betweenness centrality (from red (low) to green (high)).



Source: JRC

3.8 Therapeutics and biotechnologies

Dashboard: Therapeutics and Biotechnologies

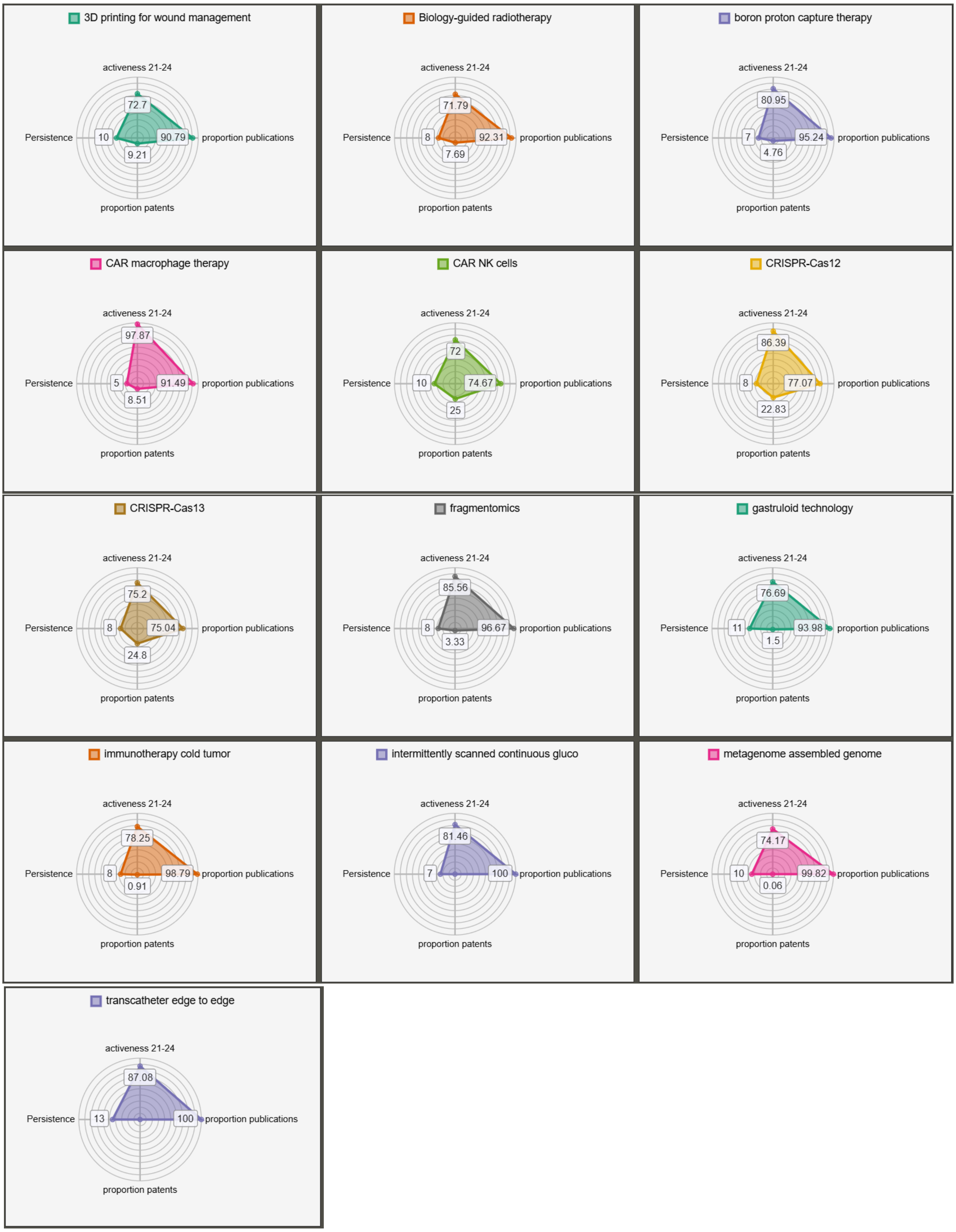
	Therapeutics and Biotechnologies	
3D printing for wound management	CRISPR-Cas13	postbiotic
biology-guided radiotherapy	fragmentomics	proteolysis targeting chimeras
boron proton capture therapy	gastruloid technology	robotic bronchoscopy
CAR macrophage therapy	immunotherapy cold tumor	spatial omics
CAR NK cells	intermittently scanned continuous glucose monitoring	tele neuropsychology
CRISPR-Cas12	metagenome assembled genome	transcatheter edge to edge
	mRNA vaccines	

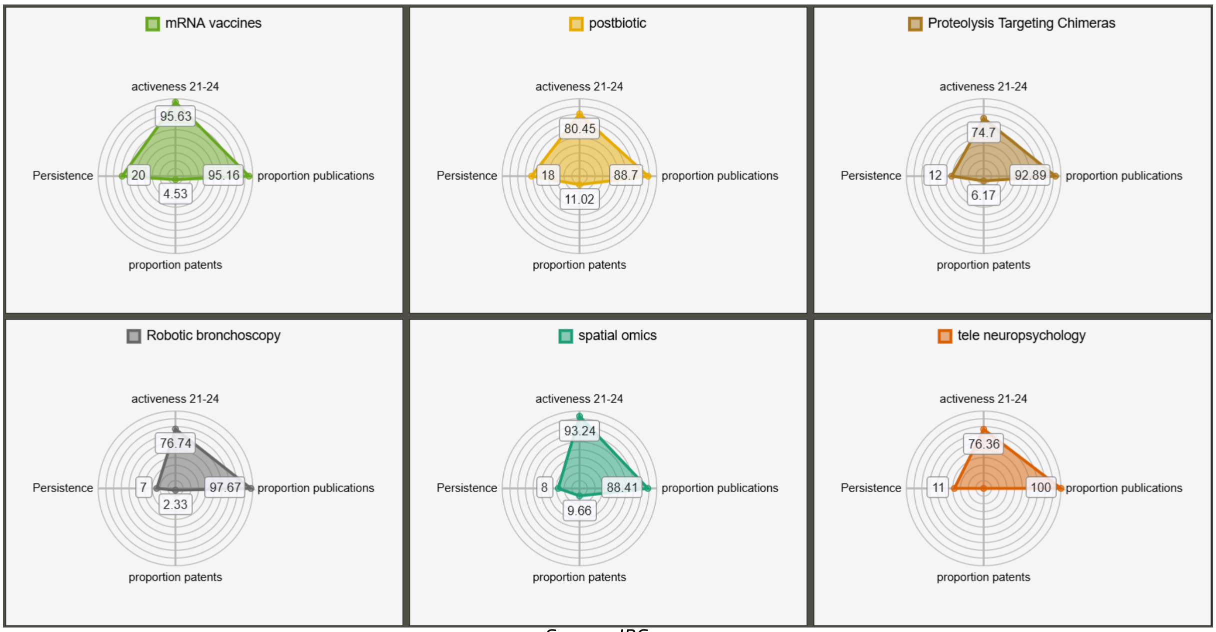
The emerging technologies in this cluster share several key themes aligned with the progression and innovation in precision medicine and personalized therapies. Technologies like CAR macrophage therapy and mRNA vaccines exemplify the industry's shift towards customized treatment strategies that cater to individual patient profiles, demonstrating the high-tech sector's commitment to revolutionizing healthcare. Immunotherapy technologies, including immunotherapy cold tumours and CAR NK cells, are at the forefront of harnessing the body's immune system to target and eliminate cancer cells, reflecting the growing importance of bioengineering in medical treatment. Similarly, technologies like Proteolysis Targeting Chimeras (PROTACs) are pioneering precise genomic and cellular modifications, expanding the therapeutic horizons in oncology and beyond. Regenerative Medicine and tissue engineering are also prominent, with innovations such as 3D printing for wound management and gastruloid technology leading the way in developing novel therapies for tissue repair and regeneration. These technologies are setting new benchmarks in the ability to mimic and restore complex biological structures and functions. Moreover, the focus on non-invasive or minimally invasive therapies is evident in advanced procedures like Transcatheter edge-to-edge repair (TEER), which seek to minimize patient risk and discomfort while delivering effective treatment outcomes. This trend underscores the sector's dedication to improving patient experiences and outcomes through technological advancements.

Technology radars

Most of the emerging technologies in this cluster share the same pattern: low persistence, high activeness, high proportion of articles and low proportion of patents. "mRNA vaccines" and "postbiotics" show a higher persistence than the average, but both technologies still have a high activeness (very high in the case of mRNA vaccines). The weak signal "CAR NK cells" has a higher proportion of patents (25%), associated to a higher persistence and a lower activeness, indicating potential commercial applications in this field.

Figure 45. Technology radars for emerging technologies in Therapeutics and Biotechnologies.





Source: JRC

Revealed Technology Advantage

The RTA index across the emerging technologies highlights the United States' broad and strong specialization in 13 out of 19 technologies, reflecting its comprehensive and strategic investment in a wide array of healthcare innovations. This wide-ranging specialization suggests a multidimensional approach to healthcare technology, with substantial R&D efforts spanning from precision medicine and regenerative therapies to advanced diagnostic and treatment technologies. Similarly to China (with noticeable RTAs in 8 of the 19 emerging technologies), the EU demonstrates a considerable range of specialization, with notable RTAs in 9 out of 19 technologies. This reflects the EU's strong commitment to healthcare innovation, likely driven by a combination of policy support, research funding, and a robust academic and clinical research environment. The emphasis on a diverse set of technologies may be aligned with the EU's focus on patient-centric healthcare and the integration of advanced technologies into public health systems. In contrast to the US, China and EU, Japan, South Korea, and India exhibit specialization in focused clusters.

Figure 46. Revealed Technological Advantage for WS in Therapeutics and Biotechnologies.

Weak Signals	China	US	Europe	UK	Japan	South Korea	India
3D printing for wound management	2.17	0.84	0.92	1.12	0.34	1.47	2.35
Biology-guided radiotherapy	0.17	2.15	0.44	0.41	0.00	0.00	0.00
boron proton capture therapy	0.00	0.86	2.18	2.21	1.90	0.00	0.00
CAR macrophage therapy	2.58	1.70	0.92	1.37	0.00	2.83	0.52
CAR NK cells	1.43	1.61	1.41	0.86	0.34	0.54	0.50
CRISPR-Cas12	4.45	0.80	0.51	0.16	0.23	1.30	0.38
CRISPR-Cas13	3.53	1.17	0.44	0.61	0.51	0.68	0.88
fragmentomics	1.28	0.89	1.59	0.51	0.44	2.34	0.26
gastruloid technology	0.25	1.89	1.58	3.30	0.30	0.98	0.00
immunotherapy cold tumor	2.23	1.93	0.80	0.54	1.16	1.62	0.34
intermittently scanned continuous glucose	0.24	1.08	2.02	2.07	3.10	0.68	0.13
metagenome assembled genome	1.66	1.72	1.45	1.31	0.72	0.72	0.44
mRNA vaccines	0.65	1.40	1.38	1.05	1.58	1.26	0.52
postbiotic	0.90	0.60	1.41	0.51	0.34	2.77	1.47
Proteolysis Targeting Chimeras	2.42	1.51	0.76	1.28	0.89	1.04	0.53
Robotic bronchoscopy	0.44	3.17	0.42	0.70	0.45	0.00	0.00
spatial omics	1.72	1.83	1.32	1.69	0.31	0.89	0.00
tele neuropsychology	0.06	2.73	0.61	0.94	0.35	0.00	0.41
transcatheter edge to edge	0.31	1.98	1.86	0.75	1.76	0.57	0.22
Average for all weak signals	1.39	1.57	1.16	1.13	0.78	1.04	0.47

Source: JRC

Main actors

Organisations from the US clearly dominate the landscape of emerging technologies in therapeutics and biotechnologies. The French National Centre for Scientific Research (CNRS) is among the top organisations in terms of scientific production. In patenting, Chinese and US-based organisations file most of the patents related to the technologies in this cluster.

Figure 47. Main actors for WS in Therapeutics and Biotechnologies.

(Top20 organisations in terms of number of documents + Top20 organisations in terms of mean citation by article, normalized by field and year + Top 10 patenting organisations).

Organisations	Country	#Documents
Chinese Academy Of Sciences	China	457
University of California	United States of America	405
Harvard University	United States of America	322
Sun Yat-Sen University	China	167
CNRS	France	165
Tel Aviv University	Israel	148
University of Pennsylvania	United States of America	139
Icahn School of Medicine at Mount Sinai	United States of America	136
Zhejiang University	China	129
University of Michigan	United States of America	123
Shanghai Jiao Tong University	China	122
Fudan University	China	116
Cornell University	United States of America	114
Sichuan University	China	114
University of Toronto	Canada	109
National University of Singapore	Singapore	103
National Institutes of Health	United States of America	100
Mayo Clinic	United States of America	100
Tsinghua University	China	100
University of Tokyo	Japan	97

Organisations	Country	Mean normalized citation per article
Baylor Scott and White Health	United States of America	29.51
London School of Hygiene and Tropical Medicine	United Kingdom	29.27
Ben-Gurion University of the Negev	Israel	27.66
Indiana University	United States of America	25.46
University of Texas Medical Branch	United States of America	22.90
Vanderbilt University Medical Center	United States of America	22.31
University College of Medicine	India	21.98
University of Oxford	United Kingdom	20.86
University of Colorado	United States of America	20.67
Washington University School of Medicine	United States of America	18.23
Ohio State University	United States of America	17.73
University of Iowa	United States of America	17.40
University of Utah	United States of America	17.35
University of Miami	United States of America	17.19
Imperial College London	United Kingdom	16.84
University of Arizona	United States of America	16.54
University of Maryland School of Medicine	United States of America	16.21
Cedars-Sinai Medical Center	United States of America	16.10
University of Michigan	United States of America	16.08
McMaster University	Canada	15.69

Organisations	#Patents	Country
China University of Mining and Technology	42	China
CSIC HAIZHUANG WINDPOWER EQUIPMENT CO., LTD.	21	China
THERAPEUTICS, INC.	14	United States of America
Chinese Academy Of Sciences	10	China
West China Hospital	9	China
Beijing Youan Hospital	8	China
Affiliated Hospital	7	China
BIOTECH CO LTD	7	South Korea
TRUSTEES OF THE UNIVERSITY OF PENNSYLVANIA	6	United States of America
Board of Regents, The University of Texas System	6	United States of America

Source: JRC

International collaborations

The United Kingdom demonstrates the highest level of international collaboration, with 77% of its research outputs involving partners from other countries. India follows with 57%, indicating a relatively strong global engagement. The United States and Europe show similar levels of international collaboration, at 47% and 46%. Japan, South Korea, and China exhibit lower collaboration rates, at 40%, 36%, and 32%, respectively.

In terms of specific collaborations between the EU, US, and China, 46% of the EU's collaborations include US-based organizations, whereas only 18% involve Chinese partners. Similarly, 42% of the US's collaborations include European organizations, while 23% involve Chinese entities. For China, 25% of its collaborations are with European organizations, while 41% involve partners from the US. These figures highlight the relatively strong collaborative ties between the EU and the US, as well as between the US and China, while collaborations between China and the EU are comparatively less prominent.

Figure 48. International collaborations between countries and macro-regions in Therapeutics and Biotechnologies.

Share of international collaboration		Share of collaboration between EU, US, CN			
United Kingdom	77%				
India	57%		EU	US	CN
United States	47%	EU with	/	46%	18%
Europe	46%	US with	42%	/	23%
Japan	40%	CN with	25%	41%	/
South Korea	36%				
China	32%				

Source: JRC

In this cluster of emerging technologies, Europe and the US share the role of knowledge disseminators.

Figure 49. Collaborative networks between countries for the cluster Therapeutics and Biotechnologies.

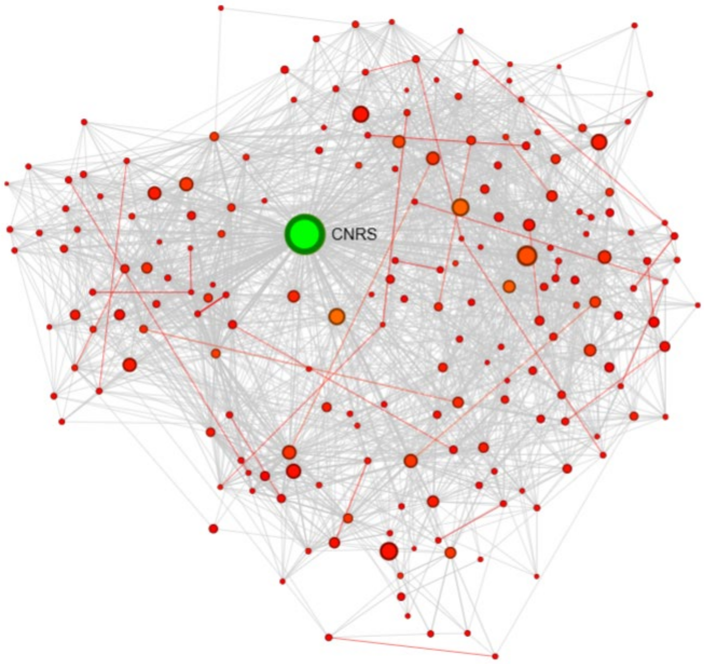
The size of the nodes = number of documents and edges = number of joint publications/patents. Colour coding according to betweenness centrality (from red (low) to green (high)).

Source: JRC

The central role of CNRS (France) in the flows of knowledge in Europe on emerging technologies related to Therapeutic and Biotechnologies appears clearly in figure 50 below.

Figure 50. Collaborative networks for top200 European organisations in Therapeutics and Biotechnologies.

The size of the nodes = number of documents and edges = number of joint publications/patents. Colour coding according to betweenness centrality (from red (low) to green (high)).



Source: JRC

3.9 e-Health

Dashboard: [e-Health]

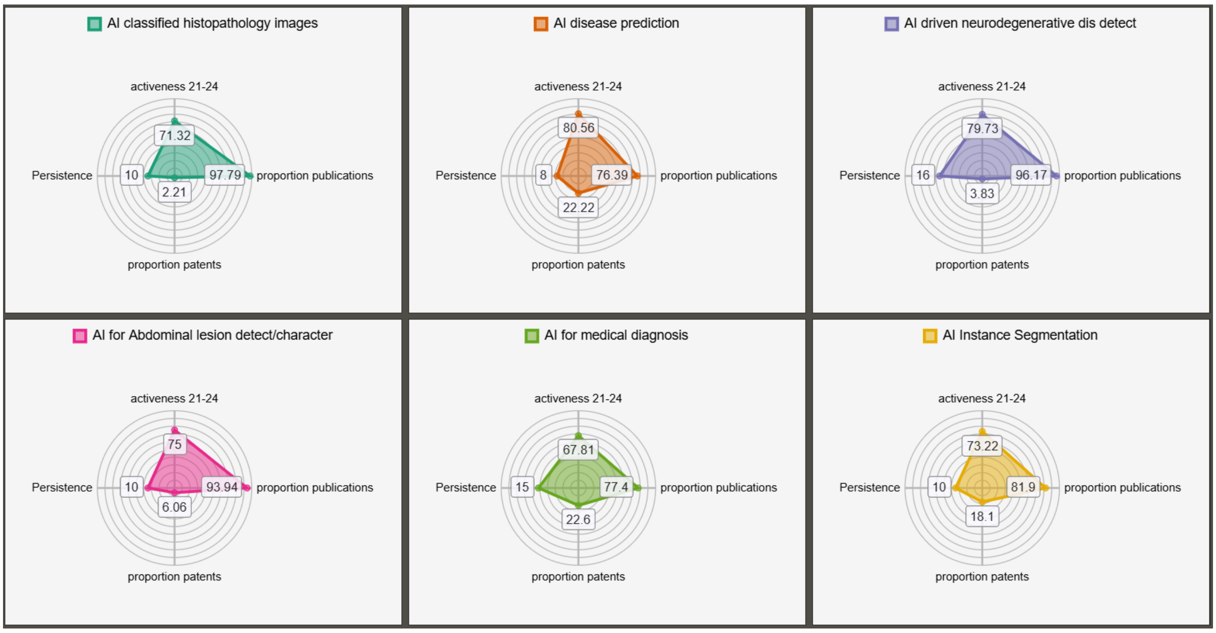
	e-Health	
AI classified histopathology images	AI Instance Segmentation	explainable AI in medical imaging
AI disease prediction	Automated Tumor characterization by AI	explainable anomaly detection
AI driven neurodegenerative dis detect	blockchain 4 electronic health record	Few-shot learning in medical imaging
AI for Abdominal lesion detect/character	bowel pathology analysis with AI	internet of health things
AI for medical diagnosis	digital therapeutics	virtual care

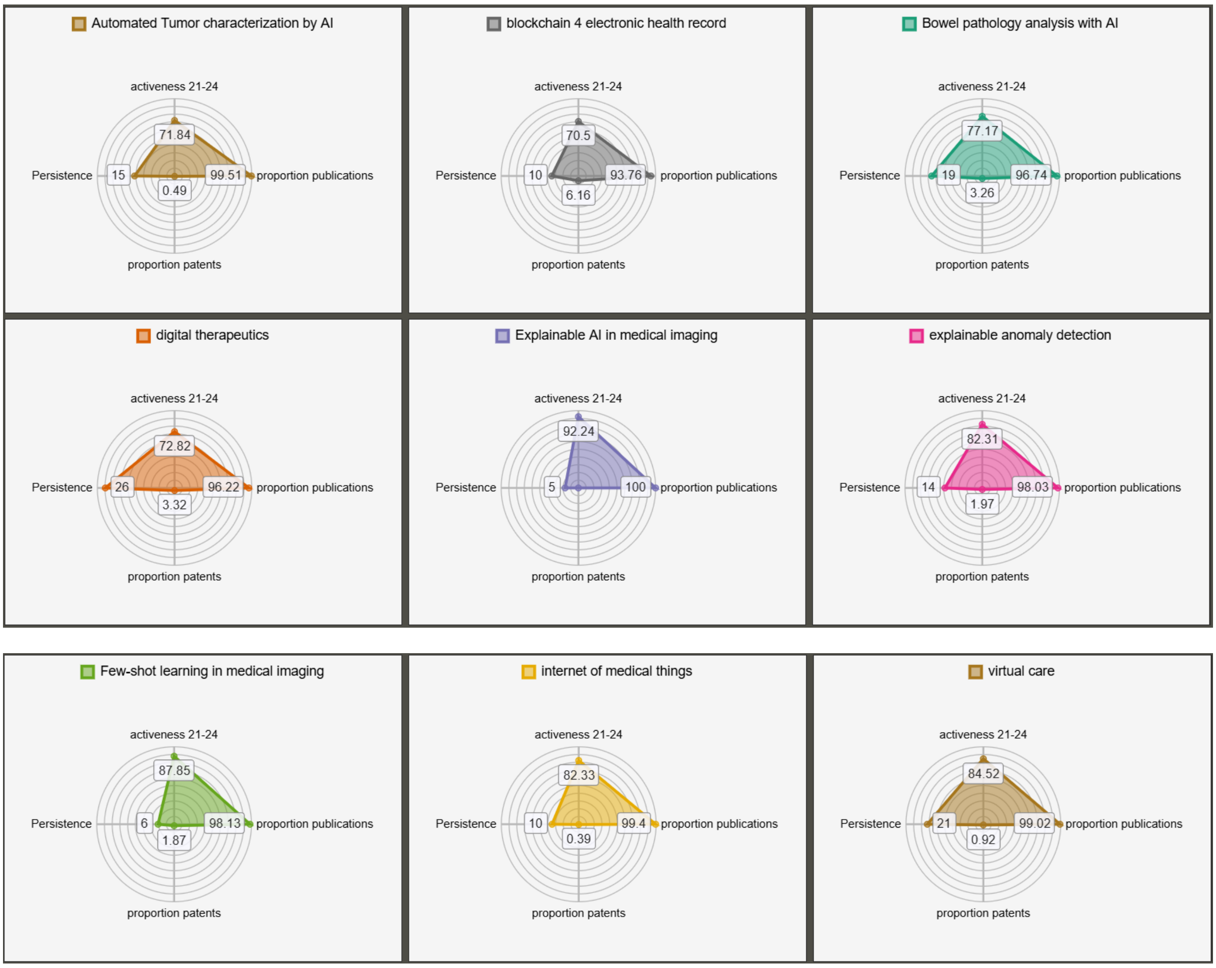
Digital technologies are poised to revolutionize healthcare by improving disease diagnosis and treatment, as well as management of medical data. The impact of AI and machine learning is particularly evident across the technologies included in this dedicated cluster. Technologies such as AI-classified histopathology images, AI-driven neurodegenerative disease detection, and AI for medical diagnosis are at the forefront of automating medical data analysis, aiming to improve disease detection, treatment planning, and prediction of disease progression. These advancements align with the trend towards personalized medicine and precision health, emphasizing the significance of data-driven healthcare and analytics to improve patient care. Moreover, emerging technologies like the Internet of Medical Things and blockchain for electronic health records are driving the shift towards digital health and telemedicine, enabling remote patient care, secure data exchange, and improved healthcare access.

Technology radars

Except for the three emerging technologies “AI for medical diagnosis”, “AI for disease prediction” and “AI instance segmentation”, all emerging technologies in this category have in common a low proportion of patents.

Figure 51. Technology radars for emerging technologies in e-Health.





Source: JRC

Revealed Technology Advantage

India and South Korea exhibit strong specialization in most of the emerging technologies related to e-health, with an average RTA of 3.30 and 1.97, respectively. While China shows some specialization clusters, notably in most of the technologies leveraging AI and machine learning, Europe, the US, and Japan mostly appear under-specialized in this category. India's specialization in e-health research and development is likely driven by efforts to increase accessibility and affordability of healthcare through technology. Initiatives like the Ayushman Bharat Digital Mission (ABDM) and large-scale platforms like “eSanjeevani”, the National Telemedicine Service, have positioned India as a leader in digital healthcare. Notably, “eSanjeevani” stands as one of the largest telemedicine implementations worldwide, highlighting India's commitment to leveraging digital technologies for the advancement of healthcare.

Figure 52. Revealed Technological Advantage for WS in e-Health.

Weak Signals	China	US	Europe	UK	Japan	South Korea	India
AI classified histopathology images	1.16	0.35	0.48	0.55	0.29	0.61	5.04
AI disease prediction	0.67	0.39	0.29	0.80	0.00	4.43	6.50
AI driven neurodegenerative dis detect	0.49	0.40	0.78	0.90	0.45	1.90	7.79
AI for Abdominal lesion detect/character	1.94	1.42	1.34	0.24	1.84	4.26	1.08
AI for medical diagnosis	1.86	0.68	0.74	0.91	0.17	2.52	2.77
AI Instance Segmentation	2.44	0.71	0.83	0.75	0.83	1.54	1.11
Automated Tumor characterization by AI	1.40	1.25	0.82	1.01	0.60	0.79	3.38
blockchain 4 electronic health record	1.09	0.64	0.39	1.06	0.33	1.16	6.70
Bowel pathology analysis with AI	1.76	1.14	1.05	1.32	0.71	2.74	1.42
digital therapeutics	0.40	1.62	1.04	2.26	0.49	1.74	0.54
Explainable AI in medical imaging	0.59	1.26	1.09	1.91	0.33	1.75	3.46
explainable anomaly detection	0.62	0.97	1.46	1.07	1.00	2.14	1.29
Few-shot learning in medical imaging	3.06	1.02	0.57	1.26	0.36	1.93	1.91
internet of medical things	1.07	0.68	0.73	1.46	0.43	1.91	6.19
virtual care	0.07	1.87	0.30	0.90	0.11	0.13	0.35
Average for all weak signals	1.24	0.96	0.79	1.09	0.53	1.97	3.30

Source: JRC

Main actors

There are no European organisations in the lists of top20 organisations. Two European organisations make the top 50: the Technical University of Munich (37th by number of documents published) and the Institute for Telecommunications in Portugal (36th by mean normalized citation). Leading organisations in the emerging technologies related to e-Health are mainly from the US, Canada, and China. Despite the high specialization of India in the technologies in this category, only two actors make it to the top20 lists. Patent owners are mainly organisations based in the US and in China. One organisation from Belgium makes it to the top 10 (Janssen Pharmaceuticals).

Figure 53. Main actors for WS in e-Health.

(Top20 organisations in terms of number of documents + Top20 organisations in terms of mean citation by article, normalized by field and year + Top 10 patenting organisations).

Organisations	Country	#Documents
University of Toronto	Canada	367
University of California	United States of America	240
Harvard University	United States of America	200
Chinese Academy Of Sciences	China	151
University of British Columbia	Canada	121
University of Ottawa	Canada	114
University Health Network	Canada	107
University College London	United Kingdom	97
McMaster University	Canada	96
University of Michigan	United States of America	91
King Saud University	Saudi Arabia	91
University of Sydney	Australia	89
University of Calgary	Canada	88
College of Engineering	India	84
China University of Mining and Technology	China	84
University of Oxford	United Kingdom	83
University of Washington	United States of America	82
University of Electronic Science and Technology of China	China	79
Stanford University	United States of America	76
University of New South Wales	Australia	72

Organisations	Country	Mean normalized citation per article
Dalian University of Technology	China	21.53
Prince Sattam Bin Abdulaziz University	Saudi Arabia	18.48
Prince Sultan University	Saudi Arabia	18.37
University of Sfax	Tunisia	17.42
Tianjin University	China	16.96
Peking University	China	16.17
Taif University	Saudi Arabia	15.69
University of Cambridge	United Kingdom	15.51
Chinese University of Hong Kong	Hong Kong	14.43
Nanjing University of Information Science and Technology (NUST)	China	12.47
Princess Nourah Bint Abdulrahman University	Saudi Arabia	12.36
City University of Hong Kong	Hong Kong	12.01
Sejong University	South Korea	11.89
King Saud University	Saudi Arabia	11.58
Massachusetts Institute of Technology	United States of America	11.26
Case Western Reserve University	United States of America	11.20
King Abdulaziz University	Saudi Arabia	10.55
Menoufia University	Egypt	10.47
Lovely Professional University	India	10.45
University of Texas at San Antonio	United States of America	10.25

Organisations	#Patents	Country
China University of Mining and Technology	77	China
Mahana therapeutics	10	United States of America
CSIC HAIZHUANG WINDPOWER EQUIPMENT CO., LTD.	9	China
TENCENT TECHNOLOGY CO., LTD.	8	China
NVIDIA CORP	6	United States of America
Tsinghua University	5	China
IBM Corp	5	United States of America
click therapeutics	4	United States of America
University of Electronic Science and Technology of China	4	China
JANSSEN PHARMACEUTICA NV	4	Belgium

Source: JRC

International collaborations

The United Kingdom leads with 71% of its research outputs involving international partners, followed by Japan at 56% and Europe at 52%. The United States and South Korea exhibit similar levels of collaboration, at 43% and 42%, respectively. India and China demonstrate lower international collaboration rates, at 39% and 35%. Regarding specific collaborations between the EU, the US, and China, 32% of the EU's collaborations involve US-based organizations, while only 14% include Chinese partners. Similarly, 29% of the US's collaborations are with European organizations, while 19% involve Chinese entities. For China, 21% of its collaborations are with European organizations, and 30% involve the US. These figures underscore stronger collaboration ties between the EU and the US and between the US and China, while EU-China collaborations are relatively limited.

Figure 54. International collaborations between countries and macro-regions in e-Health .

Share of international collaboration		Share of collaboration between EU, US, CN			
United Kingdom	71%				
Japan	56%		EU	US	CN
Europe	52%	EU with	/	32%	14%
United States	43%	US with	29%	/	19%
South Korea	42%	CN with	21%	30%	/
India	39%				
China	35%				

Source: JRC

In this cluster of emerging technologies, Europe and the US, and the UK to a lesser extent, are central in the dissemination of scientific knowledge.

Figure 55. Collaborative networks between countries for the cluster e-Health.

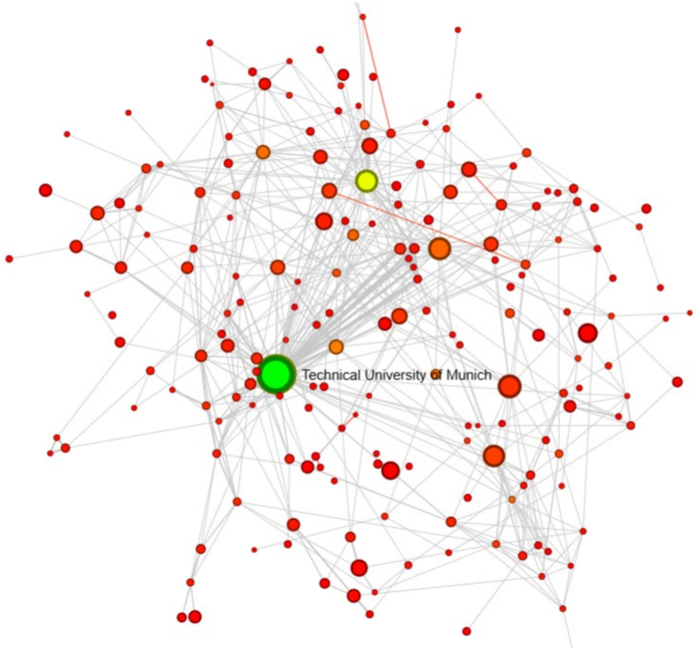
The size of the nodes = number of documents and edges = number of joint publications/patents. Colour coding according to betweenness centrality (from red (low) to green (high)).

Source: JRC

In Europe, the Technical University of Munich has a key role in disseminating knowledge related to these emerging technologies.

Figure 56. Collaborative networks for top200 European organisations in e-Health.

The size of the nodes = number of documents and edges = number of joint publications/patents. Colour coding according to betweenness centrality (from red (low) to green (high)).



Source: JRC

3.10 Environment and Agriculture

Dashboard: Environment and Agriculture

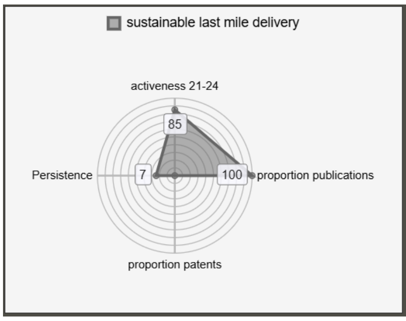
	Environment and agriculture	
agrophotovoltaic	decarbonized chemicals	microplastic biodegradation
atmospheric water harvesting	direct seawater electrolysis	PFAs removal
building decarbonization	edge computing in agriculture	regenerative agriculture
circular construction	e-dna metabarcoding	sustainable last mile delivery
circular food system	food upcycling	urea electrolysis
cultivated meat	hemispherical solar distiller	

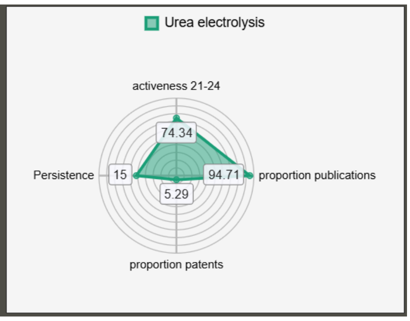
Many of the emerging technologies in this cluster rely on the development of new advanced materials and manufacturing processes aimed to improve performance and efficiency, such as PFAs removal, urea electrolysis, and hemispherical solar distiller. In some other technologies, like regenerative agriculture, circular food systems, or building decarbonization, the need to achieve sustainability goals by considering the complex interactions and interdependencies within and between different systems is prominent. The use of digital technologies, such as artificial intelligence, blockchain, and the Internet of Things, is also a common feature of many of these technologies, like in the case of edge computing in agriculture, e-DNA metabarcoding, or food upcycling. The use of digital twins and simulation is also becoming increasingly prominent, as seen in technologies such as edge computing in agriculture and food upcycling, to enable more accurate predictions and optimizations, leading to improved decision-making and performance. Public acceptance and education are also important factors for some of the technologies that may be perceived as novel or unfamiliar, such as cultivated meat and e-DNA metabarcoding. The integration of multiple disciplines, including biology, chemistry, physics, and social sciences, is also a key feature of many of these technologies. Finally, circular economy approaches also underline some of the technologies, including circular food systems, building decarbonization, and food upcycling, aiming at reducing waste and promote resource efficiency.

Technology radars

This category gathers emerging technologies related to diverse fields such as advanced materials, digital, energy or biotechnologies. It is therefore not a surprise to observe diversity in the various technology radars and no correlation between the four dimensions. Nevertheless, one can see that the proportion of patents is rather low for most of the technologies (the highest proportion is 15% of patents for the emerging technology “cultivated meat”). But that is the only common trait that stands out clearly from the Technology radars.

Figure 57. Technology radars for emerging technologies in Environment and Agriculture.





Source: JRC

Revealed Technology Advantage

With RTA values around 1,5, China, South Korea, and India show some specialisation in this cluster of emerging technologies. Europe has an RTA at 1.09, which corresponds to a very (very) slight specialisation. That being said, no real leader appears overall, as each country/region is leading in 3 or 4 of the technologies (except for Japan, leading in none of the technologies).

China, South Korea, and India are actively engaged in research related to environment and agriculture due to various policy initiatives and priorities. In China, the "Made in China 2025" and "Green Development Plan" initiatives are driving investment in research and development in these areas. In South Korea, it is the "Green Growth Plan" and "Smart Farming Plan" initiatives that promote the development of sustainable agriculture and environmental technologies. In India, the "National Mission on Sustainable Agriculture" and "National Environment Policy" have prioritized sustainable agriculture and environmental protection. The "Make in India Initiative" has also promoted investment and innovation in these areas. Overall, these policy initiatives have created a supportive environment for research and development in environment and agriculture, driving investment and innovation in these fields, which might explain the specialization observed or this cluster.

Figure 58. Revealed Technological Advantage for WS in Environment and Agriculture.

Weak Signals	China	US	Europe	UK	Japan	South Korea	India
agrophotovoltaic	0.59	1.09	1.39	0.36	1.34	2.24	1.49
atmospheric water harvesting	3.02	1.15	0.40	0.54	0.52	1.11	1.02
building decarbonization	1.28	1.58	1.05	1.11	0.18	0.77	0.00
circular construction	0.19	0.30	2.30	2.06	0.00	0.00	0.22
circular food system	0.24	0.76	2.37	1.84	0.38	0.53	0.88
cultivated meat	0.91	0.79	1.08	1.48	1.00	3.28	0.71
decarbonized chemicals	0.98	1.95	1.26	0.67	0.00	0.92	0.00
Direct seawater electrolysis	3.70	0.91	0.74	0.74	0.48	2.54	0.84
edge computing in agriculture	1.61	0.56	0.69	0.96	0.00	0.88	5.83
e-dna metabarcoding	1.04	0.94	1.54	1.95	1.97	1.08	0.12
food upcycling	1.15	0.90	0.74	2.40	0.44	5.67	2.08
hemispherical solar distiller	3.86	0.07	0.19	1.15	0.30	0.00	5.58
microplastic biodegradation	1.62	0.60	0.69	0.26	0.33	2.85	3.13
PFAs removal	1.00	2.09	0.84	0.41	0.45	0.64	0.71
regenerative agriculture	0.22	1.41	1.07	2.00	0.14	0.10	1.07
sustainable last mile delivery	0.62	0.54	1.98	0.37	0.48	0.00	0.56
Urea electrolysis	4.69	0.35	0.20	0.21	0.21	2.84	0.69
Average for all weak signals	1.57	0.94	1.09	1.09	0.48	1.50	1.47

Source: JRC

Main actors

Although the Chinese Academy of Sciences is the most active organisation in terms of number of documents, the geographical distribution of active organisations is more diverse than for some of the other categories of technologies. One can find organisations from various countries including from US, China, South Korea, Japan, France, Australia, Denmark, Italy, etc. Some organisations from Europe are among the leaders: CNRS (France), Wageningen University (Netherlands), Aarhus University (Denmark), University of Belgrade (Serbia), Fraunhofer (Germany). Very few patents were retrieved for this cluster of technologies and the pioneer organisations with some patent filed belong are spread geographically.

Figure 59. Main actors for WS in Environment and Agriculture.

(Top20 organisations in terms of number of documents + Top20 organisations in terms of mean citation by article, normalized by field and year + Top 10 patenting organisations).

Organisations	Country	#Documents
Chinese Academy Of Sciences	China	110
University of California	United States of America	107
CNRS	France	65
Shanghai Jiao Tong University	China	62
Wageningen University and Research	Netherlands	55
Cornell University	United States of America	52
Curtin University	Australia	45
Kyoto University	Japan	44
Aarhus University	Denmark	44
Tanta University	Egypt	44
University of Tokyo	Japan	41
University of El Oued	Algeria	41
Swedish University of Agricultural Sciences	Sweden	37
Nanjing Agricultural University	China	37
Zhejiang University	China	33
Yonsei University	South Korea	33
National University of Singapore	Singapore	33
Massachusetts Institute of Technology	United States of America	32
University of Copenhagen	Denmark	31
Seoul National University	South Korea	31

Organisations	Country	Mean normalized citation per article
Tianjin University	China	16.88
Kafrelsheikh University	Egypt	15.70
Nankai University	China	13.44
University of Belgrade	Serbia	11.61
Huazhong University of Science and Technology	China	11.52
Fraunhofer Institute for Solar Energy Systems ISE	Germany	11.38
University of Salento	Italy	10.49
Sichuan University	China	9.99
South China University of Technology	China	9.94
Ocean University of China	China	9.78
East China University of Science and Technology	China	9.75
University of Toronto	Canada	9.73
Chongqing University	China	9.69
University of Adelaide	Australia	9.68
Lawrence Berkeley National Laboratory	United States of America	9.47
North University of China	China	8.97
Massachusetts Institute of Technology	United States of America	8.34
Central South University of Forestry and Technology	China	8.06
Hong Kong Polytechnic University	Hong Kong	7.79
Hong Kong University of Science and Technology	Hong Kong	7.78

Organisation	#Patents	Country
DAJIU MANUFACTURING CO., LTD.	5	China
EVOQUA WATER TECH LLC	4	United States of America
HUANENG GROUP TECH INNOVATION CENTER CO LTD	4	China
Yonsei University	4	South Korea
NITTO DENKO CORP	4	Japan
University of California	3	United States of America
Seoul National University	3	South Korea
Massachusetts Institute of Technology	2	United States of America
Politecnico di Torino	2	Italy
RESEARCH&BUSINESS FOUND SUNGKYUNKWAN UNIV	2	South Korea
ELECT DE FR	2	France
KR ELECT POWER CORP	2	South Korea
Board of Regents, The University of Texas System	2	United States of America

Source: JRC

International collaborations

The United Kingdom shows the highest level of international collaboration, with 75% of its research outputs involving international partners, followed by India at 58%. Europe collaborates internationally in 49% of its outputs, while the United States, Japan, and China exhibit slightly lower rates, at 45%, 42%, and 38%, respectively. South Korea demonstrates the lowest level of international collaboration, at 26%.

In terms of collaborations between the EU, the US, and China, 28% of the EU's collaborations include US-based organizations, while only 12% involve Chinese partners. The US collaborates with European organizations in 36% of its outputs and with Chinese organizations in 21%. For China, 19% of its collaborations involve European partners, while 26% include the US. These figures reflect relatively stronger collaboration ties between the EU and the US, as well as between the US and China, while EU-China collaborations remain comparatively less frequent.

Figure 60. International collaborations between countries and macro-regions in Environment and Agriculture.

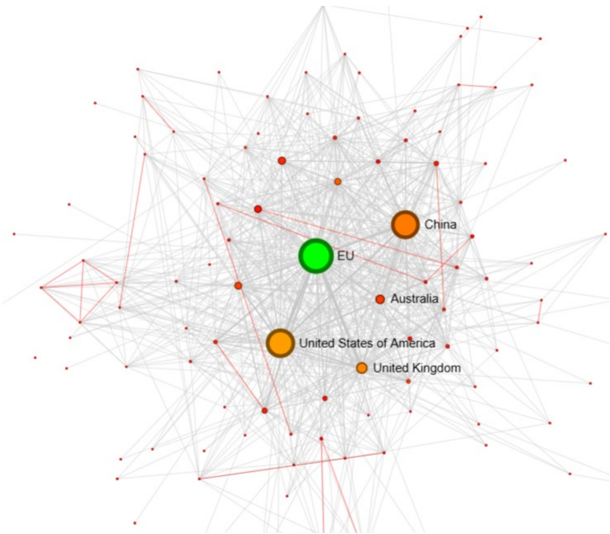
Share of international collaboration		Share of collaboration between EU, US, CN			
United Kingdom	75%				
India	58%		EU	US	CN
Europe	49%	EU with	/	28%	12%
United States	45%	US with	36%	/	21%
Japan	42%	CN with	19%	26%	/
China	38%				
South Korea	26%				

Source: JRC

In this cluster, Europe is pivotal in the dissemination of scientific knowledge. CNRS is the organisations in Europe that facilitate the most the flows of knowledge (Figure 62). The Polish Academy of Science and the Swedish University of Agricultural Sciences are also connecting EU organisations, but to a lesser extent.

Figure 61. Collaborative networks between countries for the cluster Environment and Agriculture.

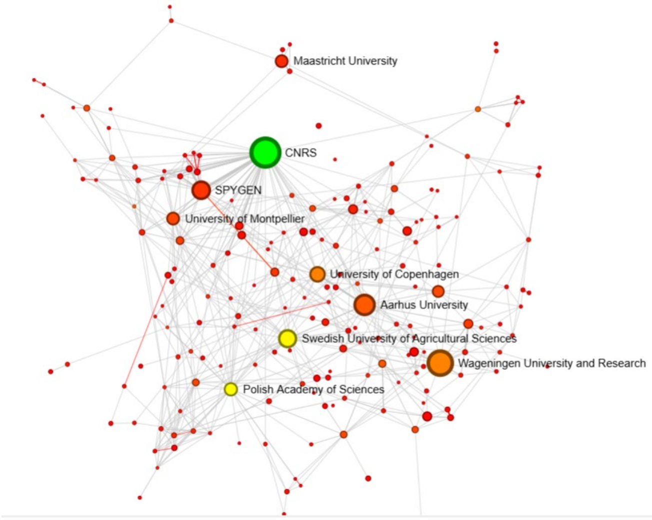
The size of the nodes = number of documents and edges = number of joint publications/patents. Colour coding according to betweenness centrality (from red (low) to green (high)).



Source: JRC

Figure 62. Collaborative networks for top200 European organisations in Environment and Agriculture.

The size of the nodes = number of documents and edges = number of joint publications/patents. Colour coding according to betweenness centrality (from red (low) to green (high)).



Source: JRC

3.11 Energy

Dashboard: Energy

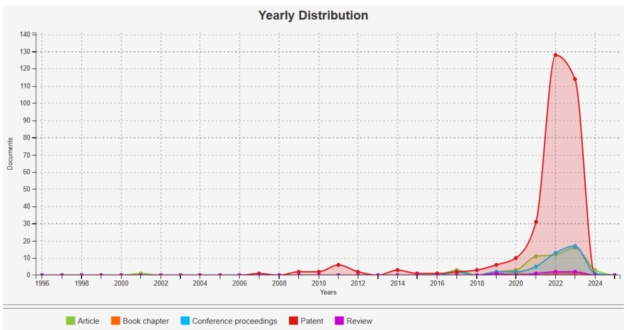
Energy		
5th generation district heating	green hydrogen	positive energy district
blue hydrogen	grey hydrogen	smart local energy systems
direct recycling of batteries	hydrogen geological storage	sustainable ammonia
electrochromic energy storage	levelized cost of hydrogen	sustainable aviation fuel
gravity energy storage	osmotic energy harvesting	turquoise hydrogen
green ammonia	personal thermal management	zinc hybrid supercapacitor

Sustainability is a transversal concern to all the technologies in this cluster, whether through reducing greenhouse gas emissions, increasing energy efficiency, or promoting renewable energy sources. Many of the technologies, such as hydrogen production, battery recycling, and supercapacitors, are related to energy storage and conversion, highlighting the importance of this area in the transition to a low-carbon economy. Several technologies rely on the development of advanced materials and manufacturing techniques to improve performance and efficiency e.g. electrochromic energy storage, osmotic energy harvesting, or zinc-ion hybrid supercapacitors. Finally, some of the technologies in this cluster relate to the importance of integration and systems thinking in achieving sustainability goals he technologies e.g. positive energy districts, smart local energy systems or fifth-generation district heating. The integration of renewable energy sources, such as solar and wind power, also appears a key aspect, highlighting the importance of renewable energy in the transition to a low-carbon economy. In terms of novelty, the development of the technologies in the cluster follows some of the main lines of R&D in energy technologies: advanced electrolysis techniques; new materials and technologies for the storage of energy; integration of multiple energy vectors; focus on local and decentralized energy solutions.

Technology radars

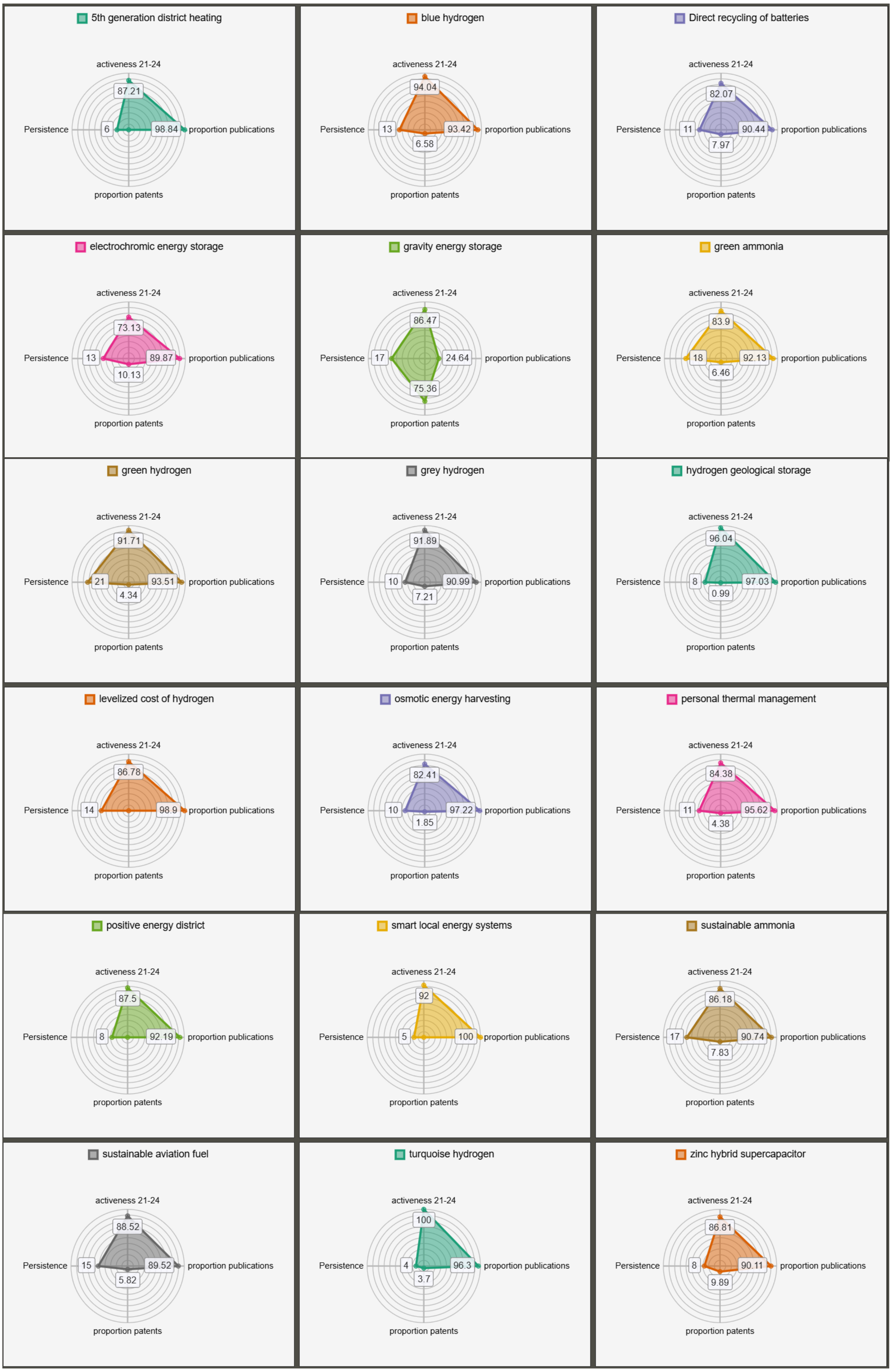
All technologies in this cluster, except for one and subject to some variations, show a similar radar signature: high activeness, low to very low percentage of patents, and persistence between 5 and 15 years (see figure 64). One technology, “gravity energy storage”, stands out with patents representing 75% of the documents retrieved, mostly owned by Chinese organisations, who massively filed patents over the last two years, as shown in figure 63 below.

Figure 63. Technology radars for emerging technologies in Environment and Agriculture.



Source: JRC

Figure 64. Technology radars for emerging technologies in Environment and Agriculture.



Revealed Technology Advantage

China and South Korea have a higher average specialisation than the other territories, including Europe, which has an RTA value of 1 for the technologies in this category (i.e. no specialisation). China has the highest RTA for 8 of the technologies, while South Korea is the more specialized for 6 of them. The U.S. and the EU have the highest RTA for 1 and 3 technologies, respectively.

South Korea and China have become strong players in emerging technologies related to environment and agriculture due to several converging factors. Both Countries have launched recently ambitious policies targeting green and sustainable technologies e.g. the “Made in China 2025 plan” which include specific support to green technologies and green energy, or South Korea’s “Green New Deal” which prioritizes carbon neutrality and green technologies like hydrogen energy, sustainable agriculture, and circular economy initiatives. These plans are supported by the network of state-owned enterprises in China and by industrial conglomerates like Hyundai, SK, and LG in South Korea. These organisations play a significant role in adopting and scaling new technologies in this field. Coupled to less strict regulatory contexts and a higher fragmentation of the actors in the US and Europe, this might explain why, despite the excellence of US and EU organisations in foundational R&D, a strong US private sector, or the leading role of Europe as a leader in eco-innovation policies and climate initiatives, South Korea and China have a higher RTA than the other territories considered.

Figure 65. Revealed Technological Advantage for WS in Environment and Agriculture.

Weak Signals	China	US	Europe	UK	Japan	South Korea	India
5th generation district heating	0.65	0.35	2.51	1.73	0.00	1.43	0.00
blue hydrogen	0.62	0.84	1.09	2.13	0.26	1.91	0.37
Direct recycling of batteries	2.12	1.36	0.84	0.84	0.25	1.07	0.79
electrochromic energy storage	3.99	0.34	0.21	0.72	0.09	5.58	0.99
gravity energy storage	2.00	0.66	0.25	1.01	0.00	0.40	1.97
green ammonia	3.02	0.63	0.75	1.49	1.04	2.02	0.83
green hydrogen	1.49	0.46	1.29	1.00	0.62	2.55	1.47
grey hydrogen	0.92	0.47	1.45	1.17	0.75	1.21	0.88
hydrogen geological storage	0.38	1.01	0.61	1.65	0.00	0.00	1.37
levelized cost of hydrogen	1.12	0.50	1.39	0.94	0.53	3.51	0.62
osmotic energy harvesting	4.52	0.57	0.38	0.00	0.18	0.39	0.21
personal thermal management	4.84	0.58	0.17	0.55	0.33	1.63	0.19
positive energy district	0.07	0.05	3.13	1.00	0.21	0.00	0.00
smart local energy systems	0.00	0.17	0.63	14.15	0.00	1.63	1.34
sustainable ammonia	2.54	0.69	0.84	1.64	1.02	2.10	0.95
sustainable aviation fuel	0.46	1.51	1.23	1.21	0.46	0.38	0.62
turquoise hydrogen	0.36	0.25	1.37	1.42	0.00	6.25	0.86
zinc hybrid supercapacitor	5.02	0.17	0.29	0.24	0.77	1.65	0.91
Average for all weak signals	1.89	0.59	1.02	1.83	0.36	1.87	0.80

Source: JRC

Main actors

Chinese organisations clearly lead in this cluster of emerging technologies, as shown in the top20 of organisations by number of scientific outputs, which include 12th organisations from China. Two organisations from Europe made this top20: Politecnico di Milano (Italy) and RWTH Aachen University (Germany). The top20 by normalized citation shows more diversity: aside 7 Chinese organisations, organisations from various countries are listed, including 2 European organisations. When it comes to patenting, Chinese organisations file most of the patents and no university or company from Europe finds its place in the top 10 patenting organisations. The first European company is Haldor Topsøe A/S (Denmark), with 2 patents; no other organisation from Europe has more than 1 patent.

Figure 66. Main actors for WS in Environment and Agriculture.

(Top20 organisations in terms of number of documents + Top20 organisations in terms of mean citation by article, normalized by field and year + Top 10 patenting organisations).

Organisations	Country	#Documents
Chinese Academy Of Sciences	China	262
Tsinghua University	China	129
Politecnico di Milano	Italy	69
University of California	United States of America	67
Zhejiang University	China	65
University of Electronic Science and Technology of China	China	64
Nanyang Technological University	Singapore	63
Shanghai Jiao Tong University	China	59
Huazhong University of Science and Technology	China	58
Sichuan University	China	58
Technical University of Denmark	Denmark	57
XI'AN JIAOTONG UNIVERSITY	China	55
RWTH Aachen University	Germany	50
Beijing University of Chemical Technology	China	50
Southeast University	China	49
Tianjin University	China	49
National University of Singapore	Singapore	48
Zhengzhou University	China	48
University of Oxford	United Kingdom	46

Organisations	Country	Mean normalized citation per article
GLA University	India	24.95
University College	United Kingdom	22.50
Prince Sattam Bin Abdulaziz University	Saudi Arabia	22.11
Lanzhou Jiaotong University	China	22.06
AGH University of Science and Technology	Poland	20.33
Shandong Normal University	China	20.02
Universiti Teknologi Malaysia	Malaysia	18.94
Korea Advanced Institute of Science and Technology	South Korea	18.77
Cranfield University	United Kingdom	17.25
University of Technology	Australia	15.74
Chengdu University	China	15.47
Politecnico di Milano	Italy	15.31
King Saud University	Saudi Arabia	14.50
Islamic Azad University	Iran	14.48
South China University of Technology	China	13.91
Wuhan University of Technology	China	13.36
Henan University	China	12.96
Stanford University	United States of America	12.82
China University of Mining and Technology	China	12.72
King Khalid University	Saudi Arabia	12.52

Organisation	#Patents	Country
STATE GRID CORPORATION OF CHINA	51	China
STATE GRID HEILONGJIANG ELECTRIC POWER COMPANY LIMITED	29	China
China University of Mining and Technology	24	China
DAJIU MANUFACTURING CO., LTD.	13	China
CHINA ACADEMY OF SPACE TECHNOLOGY	11	China
HUANENG GROUP TECH INNOVATION CENTER CO LTD	10	Singapore
Rolls-Royce plc	10	United Kingdom
CSIC HAIZHUANG WINDPOWER EQUIPMENT CO., LTD.	7	China
Tsinghua University	6	China
Beihang University	5	China

Source: JRC

International collaborations

The United Kingdom exhibits the highest overall international collaboration rate at 63%, followed by Japan at 56%. The United States (49%), India (48%), and South Korea (44%) show moderate levels of international collaboration. Europe and China have lower levels of international collaboration, at 37% and 33%, respectively.

In terms of collaboration between regions, 21% of US research collaborations involve the EU, while 20% involve China. The EU collaborates with US-based organizations in 34% of its outputs, and 35% of Chinese collaborations involve at least one partner from the US. China collaborates with the EU in 20% of its research outputs and with the US in 22%. This demonstrates a relatively balanced distribution of partnerships between the EU, US, and China.

Figure 67. International collaborations between countries and macro-regions for the cluster Energy.

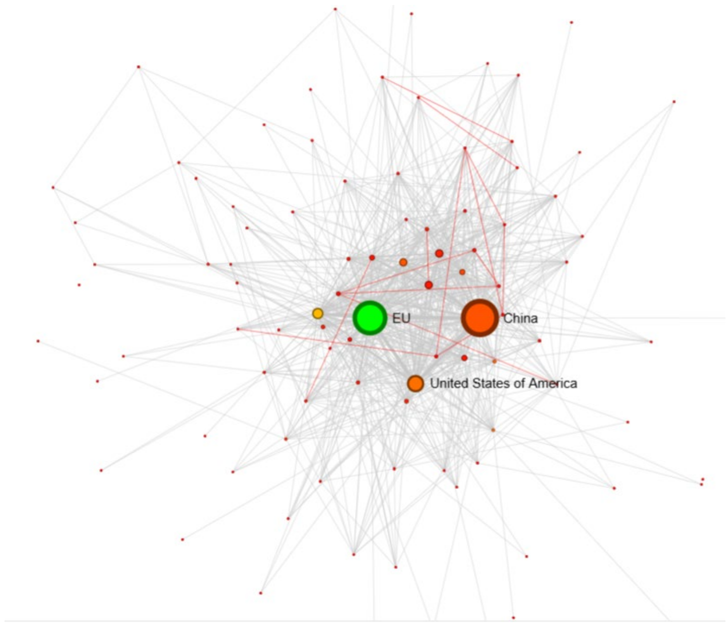
Share of international collaboration		Share of collaboration between EU, US, CN			
United Kingdom	63%				
Japan	56%		EU	US	CN
United States	49%	EU with	/	21%	20%
India	48%	US with	34%	/	35%
South Korea	44%	CN with	20%	22%	/
Europe	37%				
China	33%				

Source: JRC

European organisations are the most connected and play a central role in this cluster in bridging knowledge from various organisations all around the world.

Figure 68. Collaborative networks between countries for the cluster Energy.

The size of the nodes = number of documents and edges = number of joint publications/patents. Colour coding according to betweenness centrality (from red (low) to green (high)).

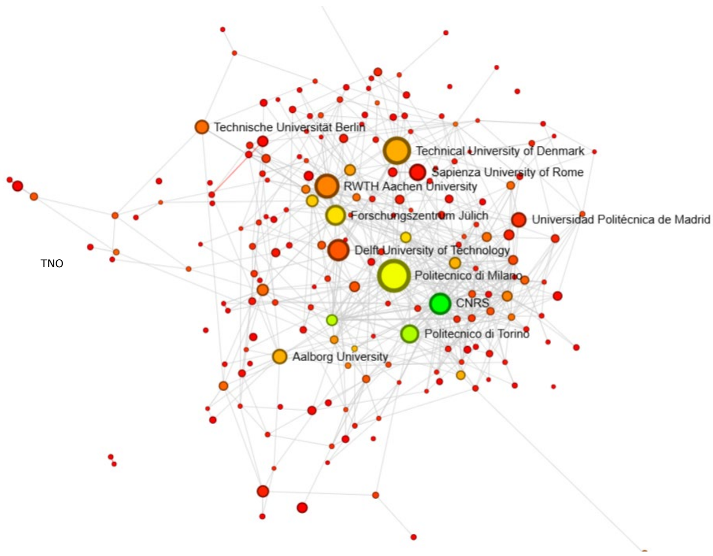


Source: JRC

Looking at the organisations central to the flow of scientific knowledge in Europe, CNRS, Politecnico di Torino and TNO appear to be the organisations connecting others to facilitate scientific exchanges.

Figure 69. Collaborative networks for top200 European organisations in Energy.

The size of the nodes = number of documents and edges = number of joint publications/patents. Colour coding according to betweenness centrality (from red (low) to green (high)).



Source: JRC

3.12 Quantum and Cryptography

Dashboard: [Quantum and Cryptography]

Quantum & Cryptography		
Classic McEliece encryption	quantum blockchain	quantum reservoir computing
gate based quantum computing	quantum classifier	quantum resistant algorithm
HHL algorithm	quantum cloud computing	quantum sdk
kyber digital signature algorithm	quantum compiler	quantum support vector
lattice-based quantum cryptography	quantum drug discovery	quantum transduction
NISQ devices	quantum generative adversarial network	Quantum Variational Algorithms
Parameterized quantum circuits	Quantum microscopy	shallow quantum circuits
quantum autoencoders	Quantum neural networks	superconducting quantum processors
quantum battery	quantum phase estimation algorithms	variational quantum circuits
	quantum reinforcement learning	

The emerging technologies within the quantum category span a broad spectrum of advancements in quantum research, encompassing quantum computing and simulation, quantum-resistant cryptography, quantum machine learning and optimization, quantum communication, quantum hardware and materials, and quantum algorithms and software. These technologies share several innovative aspects that are driving progress in the field:

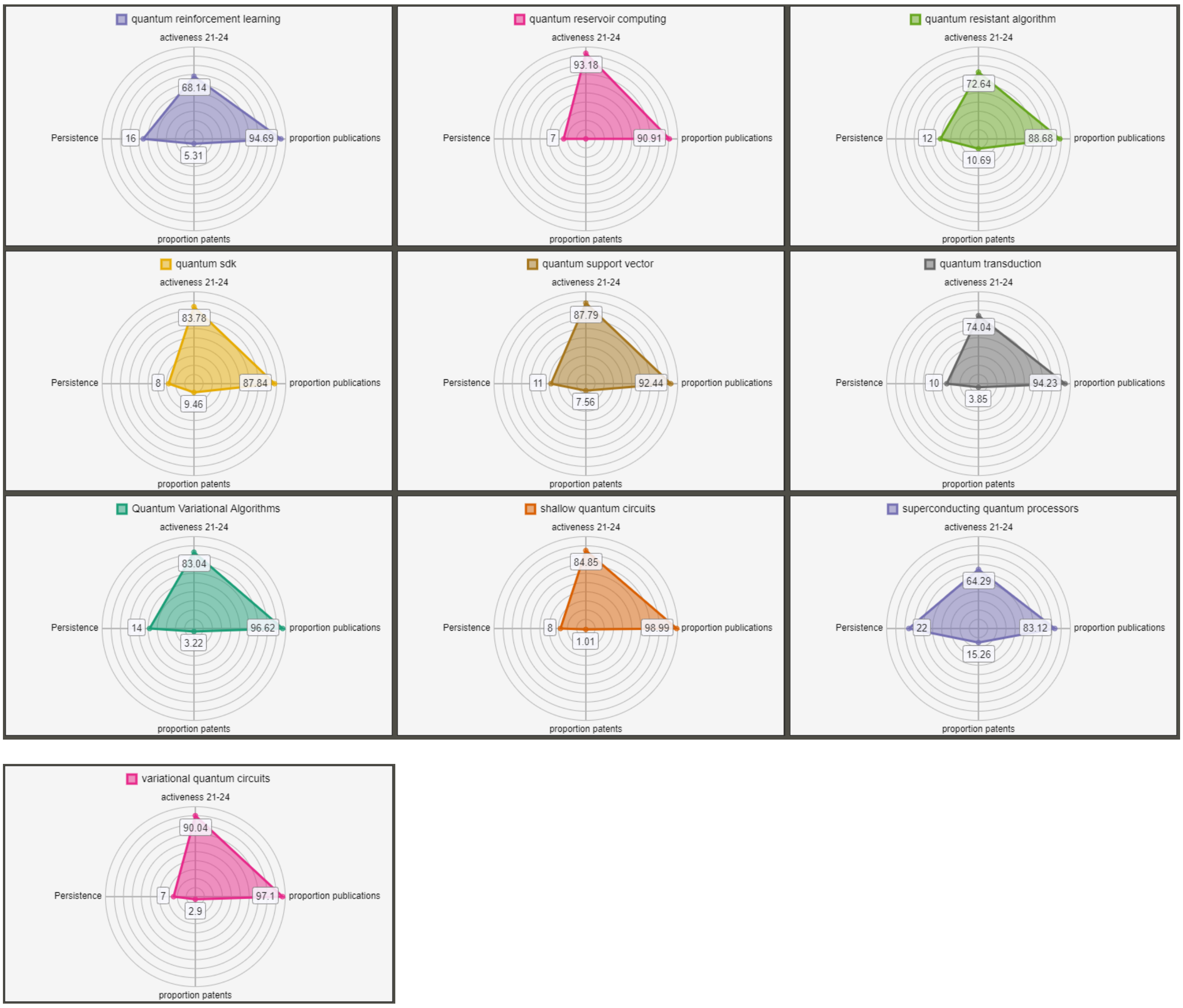
- Leveraging Quantum Principles: A central goal across these technologies is to harness the unique properties of quantum mechanics—such as superposition, entanglement, and interference—to outperform classical computing systems and provide substantial computational benefits.
- Overcoming Quantum Challenges: Addressing the intrinsic challenges of quantum computing, such as quantum noise and the need for effective error correction, is a significant focus. Technologies dedicated to quantum error correction, noise reduction, and the pursuit of fault-tolerant quantum computing are essential for the practical realization of quantum systems.
- Quantum Materials and Hardware: quantum materials and quantum hardware are critical for building scalable and robust quantum systems. Innovations in superconducting qubits, topological quantum computing, and other quantum hardware developments are paving the way for future quantum technologies.
- Hybrid and Quantum-Inspired Approaches: A common thread among these technologies is the exploration of hybrid models that integrate classical and quantum computing, as well as the creation of quantum-inspired algorithms. These approaches seek to capitalize on the strengths of both classical and quantum paradigms, expanding the potential applications of quantum computing.

In summary, the emerging technologies in the quantum category reflect a concerted effort to translate the theoretical promise of quantum science into tangible advances across multiple domains. From computational enhancements to tackling quantum noise and developing new hardware, these innovations are at the forefront of pushing the boundaries of what is possible with quantum technology.

Technology radars

The variety of shapes that can be observed from the visualisations below is, similarly to what has been observed for other categories above, quite broad. Some of the emerging technologies have a high proportion of patents but very different persistence, some have very high activeness but are not similar when it comes to the other dimensions; no correlations can be found between the various dimensions used in the radar visualisations.

Figure 70. Technology radars for emerging technologies in Quantum and Cryptography.



Source: JRC

Revealed Technology Advantage

Looking at the RTAs for the emerging technologies in quantum and cryptography, we can see that Europe is slightly less specialized in the emerging technologies related to quantum than China or the US. Although India is a late entrant in the race for quantum technologies, it appears to have the highest average RTA for this category. This is likely to be linked to recent government initiatives and investments that aim to position the country as a competitive player in this field. In 2020, the Indian government launched the National Mission on Quantum Technologies and Applications (NMQTA) to enhance R&D across key areas, including quantum computing/communication/materials/sensing. This initiative seems to be bearing its fruit.

The United States is considered a leader in quantum technologies, particularly in quantum computing and quantum cryptography, with programs like the National Quantum Initiative (NQI) and major U.S. tech companies like IBM, Google, and Microsoft pushing forward quantum computing hardware and software development, placing the U.S. at the forefront of private-sector quantum innovation. China is also a strong competitor in quantum research, with the Chinese government heavily funding quantum programs, with ambitious plans in quantum key distribution, quantum cryptography, and satellites for secure communications. Europe has a collaborative approach, which aims at bringing together EU member states under the Quantum Flagship program, with an envelope of €1 billion allocated over ten years. The program supports research across various quantum fields, such as quantum computing, quantum communication, and quantum simulation.

Europe's strength lies in its collaborative research networks, linking public and private sectors to spur innovation. Key institutions like CERN and various national initiatives enhance Europe's position, though it remains slightly behind the U.S. and China in quantum computing capabilities, and for the emerging technologies in quantum reported here.

Figure 71. Revealed Technological Advantage for WS in Quantum and Cryptography.

Weak Signals	China	US	Europe	UK	Japan	South Korea	India
Classic McEliece encryption	0.92	0.58	2.03	0.58	1.29	2.20	0.60
gate based quantum computing	0.49	1.29	1.50	1.29	1.14	0.81	1.34
HHL algorithm	2.93	1.45	0.54	1.45	1.19	2.03	1.40
kyber digital signature algorithm	2.74	0.48	0.97	0.48	0.85	0.00	0.50
lattice-based quantum cryptography	2.24	0.99	0.70	0.99	0.84	2.23	1.72
NISQ devices	1.25	1.92	1.00	1.92	1.38	1.36	0.89
Parameterized quantum circuits	1.82	1.80	0.78	1.80	1.53	1.45	1.40
quantum autoencoders	1.61	1.40	1.38	1.40	1.24	0.88	0.49
quantum battery	1.66	0.67	1.77	0.67	0.51	2.18	2.28
quantum blockchain	1.91	0.38	0.74	0.38	0.34	2.16	6.52
quantum classifier	1.35	0.81	1.15	0.81	0.77	0.62	3.29
quantum cloud computing	2.36	0.86	0.86	0.86	0.35	0.74	2.03
quantum compiler	0.79	2.28	1.05	2.28	1.01	0.92	0.68
quantum drug discovery	0.43	1.30	1.01	1.30	0.00	0.94	4.67
quantum generative adversarial network	1.93	1.92	1.00	1.92	0.57	0.00	0.33
Quantum microscopy	0.95	1.21	1.42	1.21	0.49	2.08	0.00
Quantum neural networks	1.78	0.98	0.64	0.98	1.21	0.79	2.63
quantum phase estimation algorithms	1.04	1.95	0.77	1.95	3.21	2.11	1.16
quantum reinforcement learning	1.90	0.68	1.55	0.68	0.18	2.28	1.67
quantum reservoir computing	0.31	0.86	2.47	0.86	3.33	1.02	0.00
quantum resistant algorithm	1.23	1.03	1.00	1.03	0.40	0.43	1.82
quantum sdk	0.57	1.06	1.04	1.06	0.00	0.63	5.15
quantum support vector	0.93	0.70	0.75	0.70	0.36	1.02	6.88
quantum transduction	0.50	3.20	0.89	3.20	0.19	0.41	0.68
Quantum Variational Algorithms	1.14	1.87	1.03	1.87	1.44	0.98	0.95
shallow quantum circuits	1.64	2.10	1.05	2.10	2.72	0.00	0.46
superconducting quantum processors	1.37	2.56	1.22	2.56	1.41	0.32	0.26
variational quantum circuits	0.92	1.49	0.86	1.49	1.14	1.22	1.91
Average for all weak signals	1.38	1.35	1.11	1.35	1.04	1.14	1.85

Source: JRC

Main actors

Organisations from US are clearly dominating the scene when it comes to scientific production or patenting in the quantum related emerging technologies reported here. Europe places two organisations in the top20 organisations ranked by normalized citations number: Barcelona Institute of Science and Technology, and RWTH Aachen University. No organisation from Europe can be found in the top 10 patent owners for these emerging technologies. We also do not observe organisations from India in any of the lists below, which could be an indication of high fragmentation of the quantum research ecosystem in India, with many small actors that lack the critical mass of US or Chinese organisations. This observation could be made for Europe as well, but to a lesser extent.

Figure 72. Main actors for WS in Quantum and Cryptography.

(Top20 organisations in terms of number of documents + Top20 organisations in terms of mean citation by article, normalized by field and year + Top 10 patenting organisations).

Organisations	Country	#Documents
QUANTUM CORP	United States of America	389
IBM Corp	United States of America	187
Tsinghua University	China	121
University of California	United States of America	114
Chinese Academy Of Sciences	China	101
University of Science and Technology of China	China	92
University of Chicago	United States of America	82
Massachusetts Institute of Technology	United States of America	81
University of Oxford	United Kingdom	61
China University of Mining and Technology	China	60
National University of Singapore	Singapore	59
University of Waterloo	Canada	58
University of Maryland	United States of America	57
Harvard University	United States of America	55
Los Alamos National Laboratory	United States of America	53
University of Science and Technology	China	52
Zhejiang University	China	48
Argonne National Laboratory	United States of America	46
Lawrence Berkeley National Laboratory	United States of America	45
University of Tokyo	Japan	44

Organisations	Country	Mean normalized citation per article
Center for Nonlinear Studies	United States of America	27.19
Barcelona Institute of Science and Technology	Spain	24.91
University of Massachusetts	United States of America	24.10
Columbia University	United States of America	23.55
GOOGLE INC	United States of America	23.11
Google Research	United States of America	20.12
RWTH Aachen University	Germany	20.00
University of Texas at Austin	United States of America	19.98
Georgia Institute of Technology	United States of America	19.40
Louisiana State University	United States of America	18.78
Harvard University	United States of America	18.27
CERN	Switzerland	17.88
California Institute of Technology	United States of America	17.46
Los Alamos National Laboratory	United States of America	16.47
Johannes Kepler University Linz	Austria	15.87
University of Sydney	Australia	15.74
University of Toronto	Canada	15.66
Nanjing University of Information Science and Tec	China	14.80
Massachusetts Institute of Technology	United States of America	14.74
Imperial College London	United Kingdom	13.79

Organisation	#Patents	Country
China University of Mining and Technology	58	China
QUANTUM CORP	40	United States of America
IBM Corp	18	United States of America
Tsinghua University	9	China
TENCENT TECHNOLOGY CO., LTD.	8	China
BEIJING BAIDU NETCOM SCIENCE AND TECHNOLOGY CO., LTD.	7	China
University of Electronic Science and Technology of China	5	China
GOOGLE INC	5	United States of America
D WAVE SYSTEMS INC	4	Canada
Samsung Corp	3	South Korea
KR ADVANCED INSTITUTE OF SCIENCE&TECH	3	South Korea

Source: JRC

International collaborations

The United Kingdom leads with the highest rate of international collaboration at 73%, followed by Europe at 51%. Japan and the United States share a collaboration rate of 46%, while India (43%) and South Korea (42%) exhibit slightly lower rates. China has the lowest international collaboration rate, at 35%.

Regarding collaborations between the EU, US, and China, 45% of EU partnerships involve U.S.-based organizations, but only 13% include China. Similarly, China demonstrates strong collaboration with the U.S., with 57% of its partnerships including U.S.-based organizations, but only 19% involve the EU. This indicates that the U.S. plays a central role in international collaborations, particularly.

Figure 73. International collaborations between countries and macro-regions in Quantum and Cryptography.

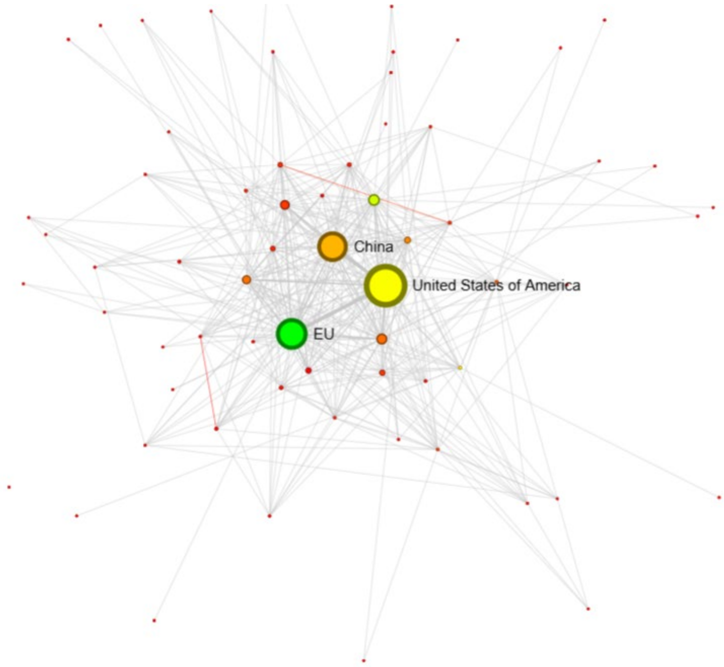
Share of international collaboration		Share of collaboration between EU, US, CN			
United Kingdom	73%				
Europe	51%		EU	US	CN
Japan	46%	EU with	/	45%	13%
United States	46%	US with	36%	/	30%
India	43%	CN with	19%	57%	/
South Korea	42%				
China	35%				

Source: JRC

European organisations contribute most to the flow of knowledges in this cluster dedicated to quantum emerging technologies, despite the fragmentation of the EU landscape. The US contributes to the exchange of scientific knowledge but to a lesser extent.

Figure 74. Collaborative networks between countries for the cluster Quantum and Cryptography.

The size of the nodes = number of documents and edges = number of joint publications/patents. Colour coding according to betweenness centrality (from red (low) to green (high)).

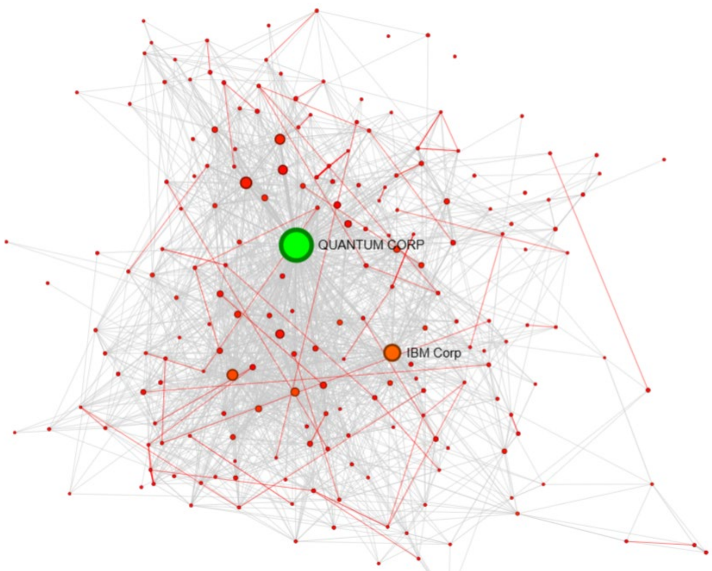


Source: JRC

As seen in figure 75 below, one organisation is mostly responsible for the influence of the US in this cluster: Quantum Corp. It is by far the largest contributor to the field and the most connected to other organisations.

Figure 75. Network graphic of top organisations in Quantum and Cryptography.

Size of the nodes = number of documents and edges = number of joint publications/patents. Colour coding according to betweenness centrality (from red (low) to green (high)).

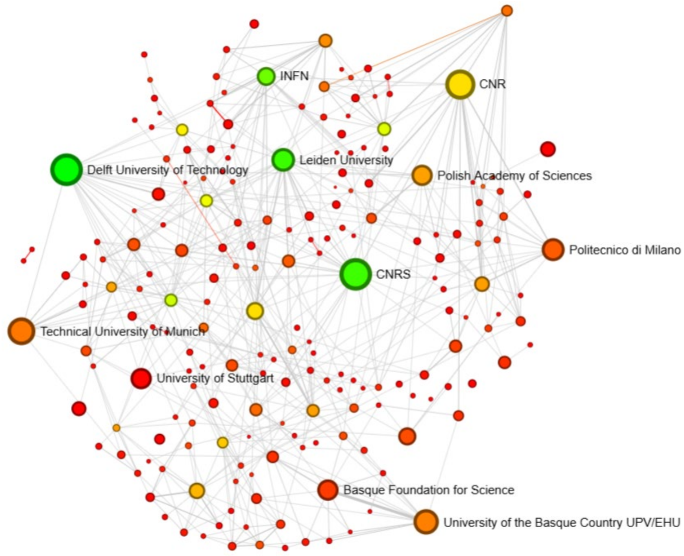


Source: JRC

Quite a few organisations contribute to the flow of knowledge related to emerging technologies in Quantum and Cryptography, with INFN, Delft University of Technology, Leiden University, CNRS being the most connecting organisations. A significant number of organisations contribute to the flows, showing a very well-connected EU research ecosystem in this area.

Figure 76. Collaborative networks for top200 European organisations in Quantum.

The size of the nodes = number of documents and edges = number of joint publications/patents. Colour coding according to betweenness centrality (from red (low) to green (high)).



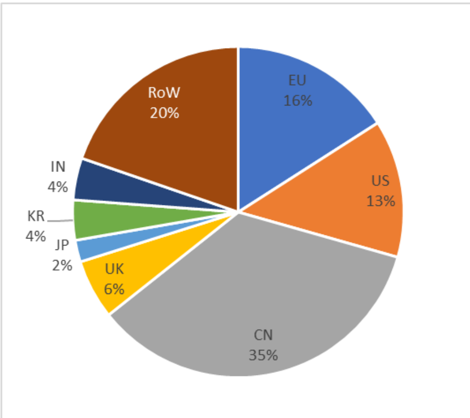
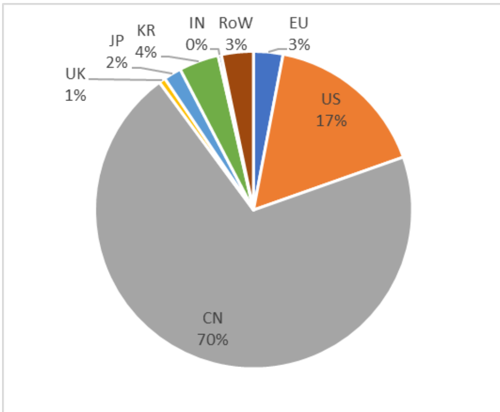
Source: JRC

4 Discussion and meta-analysis

Production of scientific knowledge

European organisations contribute significantly to the production of scientific knowledge across most of the emerging technologies highlighted in this report. This is evident in clusters such as Digital Twin, Artificial Intelligence and Machine Learning, Therapeutics and Biotechnologies, Energy, and Environment and Agriculture (see Figure 77). Overall, Europe stands equal to China and the U.S. in terms of scientific publications. However, the picture changes considerably when it comes to patenting, where the US, South Korea and China hold leading positions. Chinese organisations dominate patent filings in nearly all clusters, except for ICT, where South Korea takes the lead, demonstrating a particularly strong focus in this area.

Figure 77. Participation (in %) of organisations from countries and macro-regions in scientific publications and patents.

<table>
<tr><th></th><th>Scientific Publications</th><th>Patents</th></tr>
<tr><td>Advanced Materials & advanced manufacturing</td><td>
</td><td>
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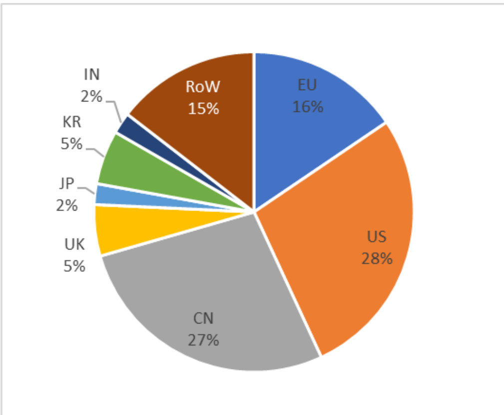
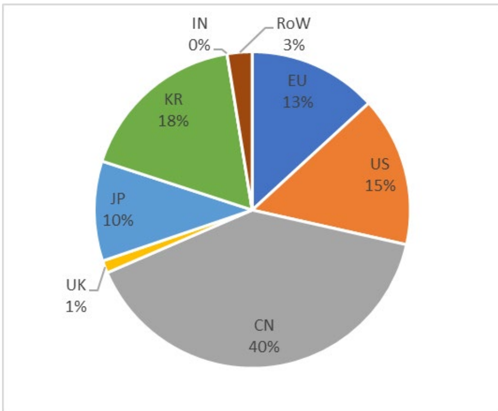
<tr><td>Aerospace</td><td>
</td><td>
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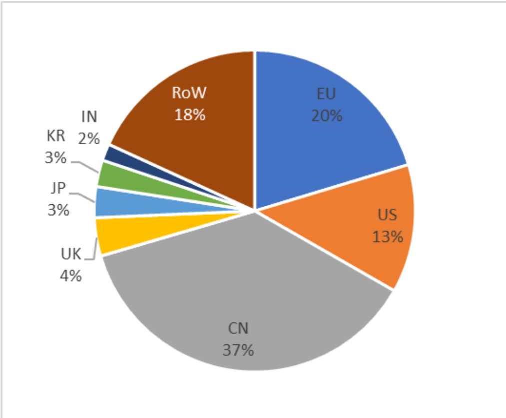
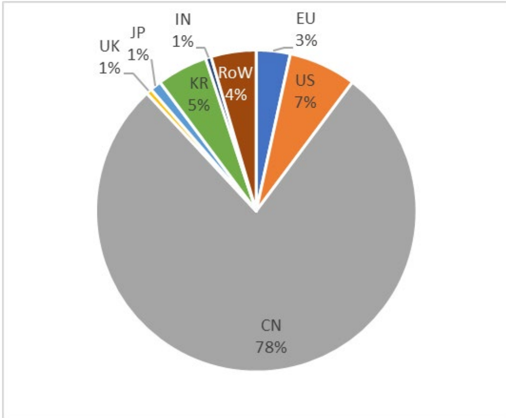
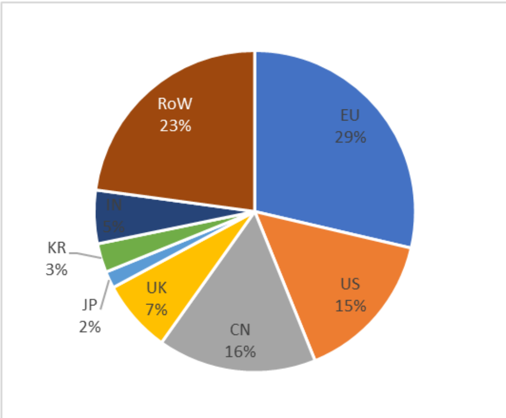
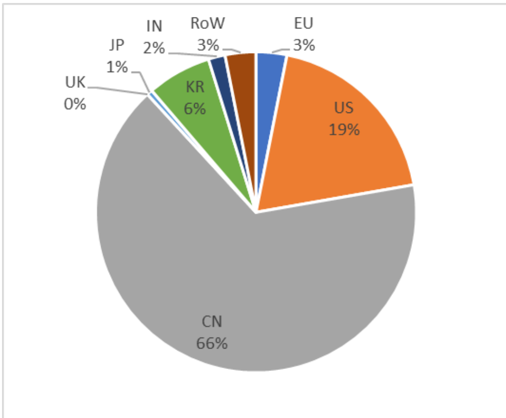
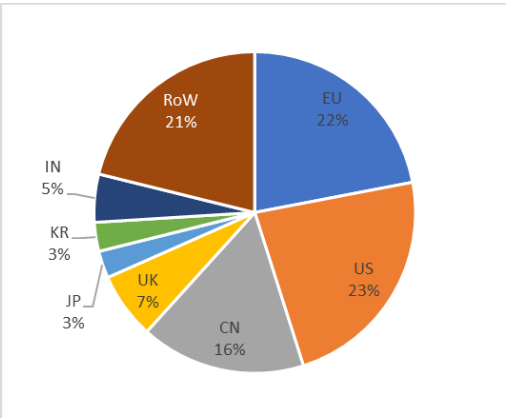
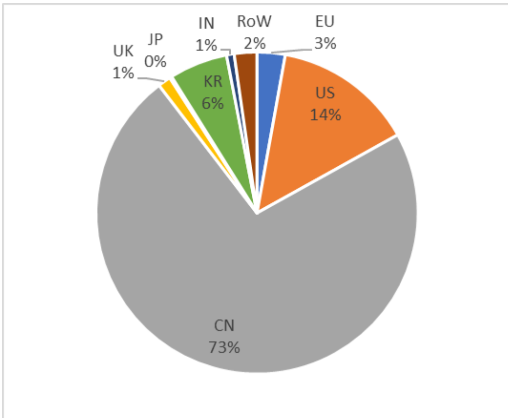
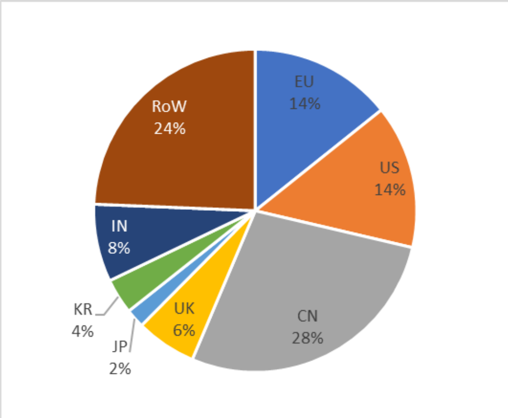
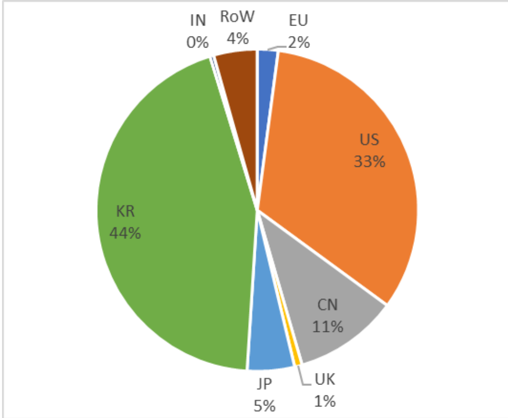
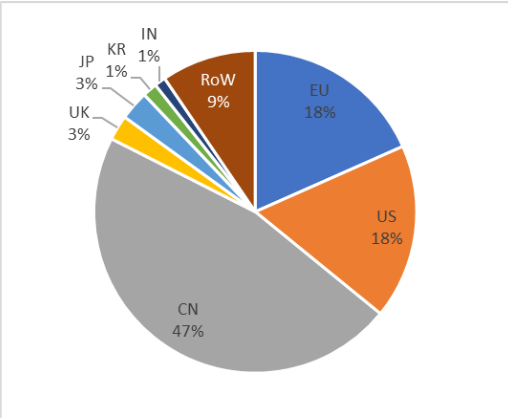
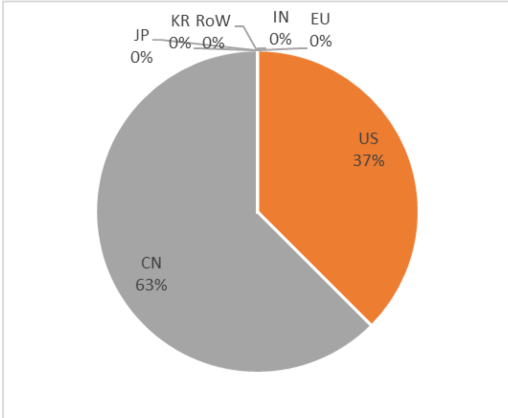
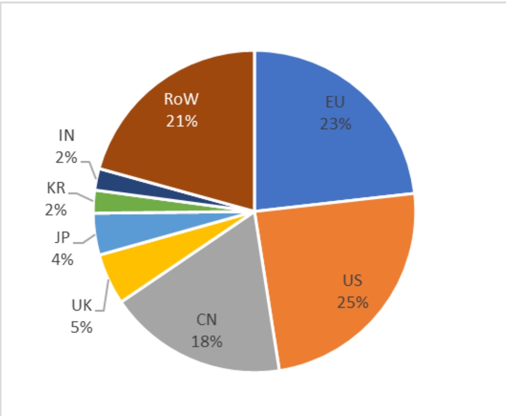
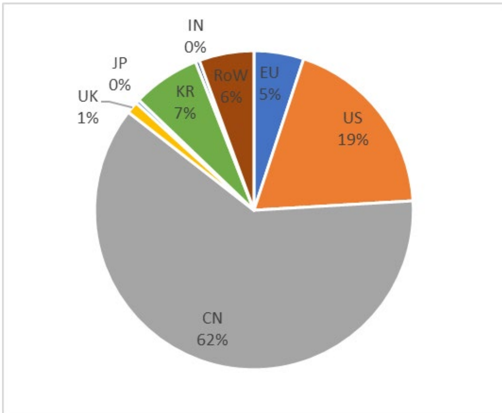
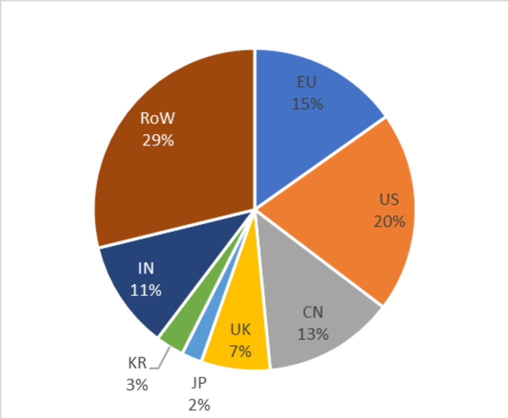
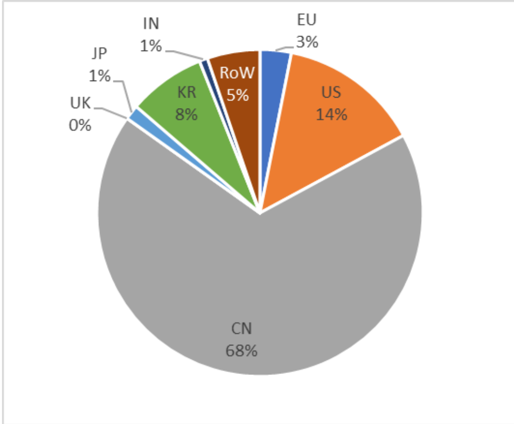
Mobility and Transport		
Digital twin		
Artificial intelligence and Machine learning		

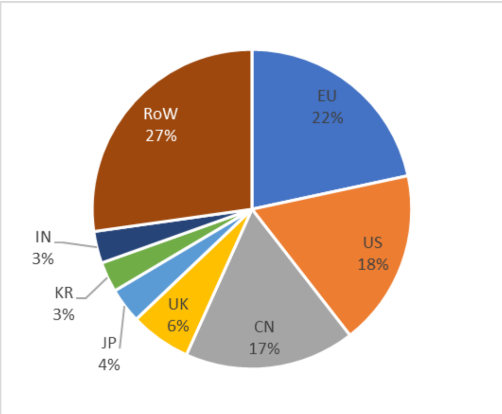
Information & Communication Technologies		
Medical imaging		
Therapeutics and Biotechs		

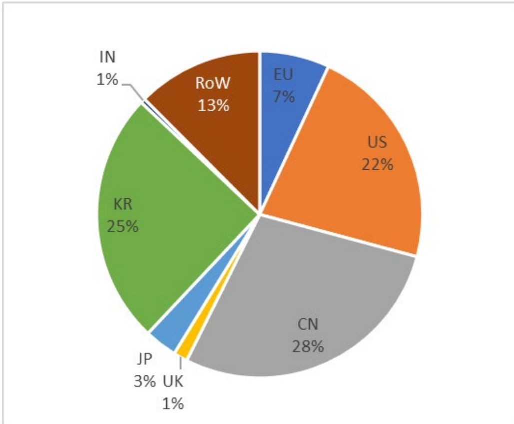
e-Health



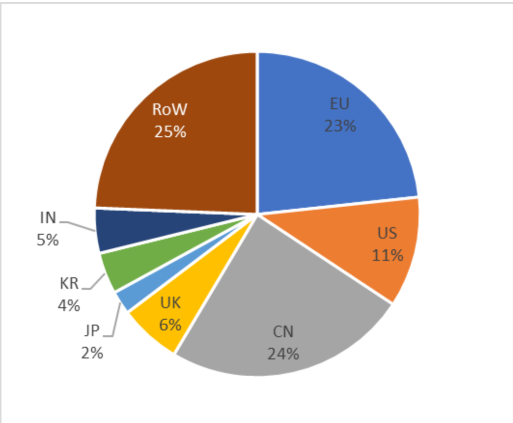


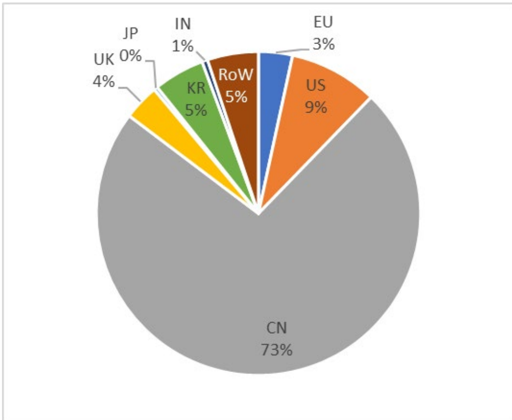
Environment and Agriculture





Energy





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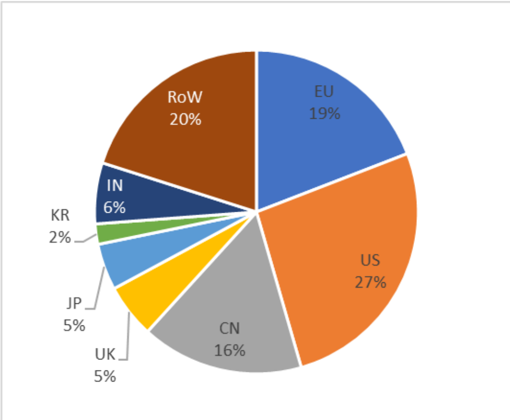
<td>
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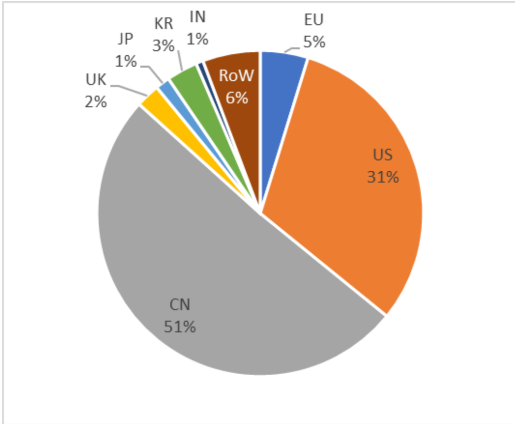
<td>
</td>
</tr>
</table>

Source: JRC

Share of countries in scientific articles in top1% peer-reviewed scientific journals

Figure 78 displays the share of articles published in the top 1% of peer-reviewed journals for each cluster and country. These journals are recognized as publishing the most influential and high-quality research, which ensures rigorous standards and significant global impact. By focusing on publications in top1% journals, this approach identifies research leadership and avoids the inclusion of lower impact studies

The US and China alternate in the top ranking in terms of participation in top 1% scientific journals for 8 of the clusters of emerging technologies:

- The US lead in AI&ML, e-Health, Therapeutics and Biotechnologies, and Quantum and Cryptography.
- China leads in Advanced Manufacturing and Advanced Materials, Aerospace, ICT, Environment and Agriculture, Mobility and Transport, Medical Imaging, Energy, Digital Twin.
- While not leading in any of the clusters, Europe contributes significantly to each of them:
    - It is the second largest contributor in Digital Twin, Energy, Quantum and Cryptography, and Mobility and Transport;
    - It ranks third in Advanced Manufacturing and Advanced Materials, AI & Machine Learning, e-Health, ICT, Environment and Agriculture, Therapeutics and Biotechnologies, Medical Imaging;
    - It is the fourth largest contributor in Aerospace, following China, the US, and South Korea.

Figure 78. Share (in %) in scientific publications in top1% scientific journals (in terms of journal impact factor) for countries and macro-regions.

Advanced Materials and advanced manufacturing		Artificial intelligence and Machine learning		e-Health	
CN	64%	US	36%	US	37%
US	23%	CN	30%	CN	34%
EU	**17%**	**EU**	**27%**	**EU**	**22%**
UK	7%	UK	16%	UK	19%
KR	7%	KR	8%	IN	7%
JP	3%	JP	5%	KR	6%
IN	2%	IN	4%	JP	4%
Aerospace		**ICT**		**Environment and Agriculture**	
CN	49%	CN	43%	CN	40%
US	29%	US	29%	US	28%
KR	12%	**EU**	**19%**	**EU**	**26%**
EU	**11%**	UK	15%	UK	7%
UK	10%	IN	8%	KR	5%
JP	4%	KR	6%	IN	4%
IN	1%	JP	2%	JP	2%
Mobility and Transport		**Medical imaging**		**Energy**	
CN	54%	CN	50%	CN	51%
EU	**25%**	US	31%	**EU**	**24%**
US	22%	UK	25%	US	16%
UK	8%	**EU**	**25%**	KR	9%
KR	4%	JP	13%	UK	9%
JP	3%	KR	6%	JP	3%
IN	1%			IN	2%
Digital Twin		**Therapeutics and Biotechnologies**		**Quantum and Cryptography**	
CN	40%	US	47%	US	68%
EU	**23%**	CN	35%	**EU**	**29%**
US	22%	**EU**	**30%**	CN	26%
UK	18%	UK	10%	UK	18%
IN	7%	JP	4%	JP	6%
KR	6%	KR	3%	IN	3%
JP	3%	IN	2%	KR	2%

Source: JRC

Revealed Technological Advantage

Despite leading or competing with other territories in terms of scientific publications, and despite a leading role for some of the emerging technologies (e.g. circular construction, boron proton capture therapy, Line-field confocal optical coherence tomography, trustworthy AI, multimodal hate speech detection, urban micromobility, or digital twin in real estate), Europe only shows specialization (RTA > 1.5) in one category: Artificial Intelligence and Machine learning (Figure 79 below).

This means that European organisations are slightly more focusing their research efforts on technologies related to AI&ML than on average for other fields, but so do other territories for that specific category. Europe is slightly specialized in Mobility and Transport, Digital Twin, Medical Imaging, Therapeutics and biotechnologies, Environment and Agriculture, Quantum and Cryptography. Europe is under specialized in the emerging technologies related to Advanced Materials and Manufacturing, Aerospace, and to a lesser extent in ICT and e-Health.

Other territories show more specialization than Europe for the various clusters:

- China and South Korea for advanced manufacturing and materials, Aerospace, Environment and Agriculture, Energy and Mobility and Transport;
- China and Japan in ICT and Medical Imaging;
- China (and Europe) in AI and ML;
- US in Therapeutics and Biotechnologies;
- India and South Korea in e-Health;
- India, China and the US for Quantum and Cryptography related emerging technologies.

For a country or a macro-region, specialisation in an area does not mean that these territories are necessarily leading in these categories. Rather, it means their R&D efforts are more intense in these fields than in other fields where they are active. For example, India is not a leader in Quantum technologies, but recent policies have shifted the Indian research ecosystem towards doing more research on quantum science (e.g. the National Quantum Mission launched in 2023 which allocates ~730 million USD to boost quantum research and its applications over the next eight years). Although we are only considering emerging technologies in this report, one could have expected a higher specialization in Environment and Agriculture for Europe, given the emphasis on the green transition in the past five years. That being said, sustainability and environmental concerns appear to be cross-cutting to most of the clusters.

Figure 79. Revealed Technological Advantages, Actors and Patents: Europe's positioning.

Colour coding 1) RTA : red for RTA EU < 0.70; yellow for 0.70<EU RTA<1.30; green for EU RTA>1.30; 2) Actors in top 20 publishing organizations worldwide: red for 0 or 1 EU actor; yellow for 2 to 5 EU actors; green for more than 5 actors; 3) Patents in top 10 by EU: red for 0 patents; yellow for 1 to 3 patents; green above 4 patents.

	RTA	Actors	Patents
Advanced Materials and advanced manufacturing	EU under specialized (0.59) China, South Korea highly specialized India slightly specialized.	5 EU actors in top20 China leading	No EU actor in top 10 China and US leading
Aerospace	EU under specialized (0.70) China and South Korea specialized	3 EU actors (but no actors in most cited top20) US (NASA), UK, China leading	No EU actor in top 10 Patents by JP, CN, SK, US
Mobility and Transport	EU slightly specialized (1.13) China specialized	4 EU actors China leading	1 EU actor in top 10 China leading
Digital twin	EU slightly specialized (1.30) Same for CN, SK, India	EU leading with 9 actors in top20	No EU actor in top 10 China and US leading
Artificial intelligence and Machine learning	EU specialized (1.50) China and South Korea specialized	5 EU actors in top20 US leading	No EU actor in top 10 China and US leading
ICT	EU under specialized (0.74) India, China, SK specialized	1 EU actors in top20 US and China leading	No EU actor in top 10 South Korea, China and US leading
Medical imaging	EU slightly specialized (1.27) JP, US, China specialized	7 EU actors in top20 China leading	No EU actor in top 10 China and US leading
Therapeutics and Biotechnologies	EU slightly specialized (1.21) US specialized	1 EU actor in top20 US leading	1 EU actor in top 10 China, US, South Korea leading

e-Health	EU slightly under specialized (0.79) India, China, SK specialized	No EU actors in top20 US and China leading	1 EU actor in top 10 China and US leading
Environment and Agriculture	EU slightly specialized (1.12) South Korea, India and China specialized	8 EU actors in top20 No country leading	2 EU actor in top 10 No country leading
Energy	EU slightly specialized (1.02). South Korea and China specialized	4 EU actors in top20 China leading	No EU actor in top 10 China leading
Quantum and Cryptography	EU slightly specialized (1.11) US, China, India specialized	3 EU actors in top20 US leading	No EU actor in top 10 China and US leading

Source: JRC

In terms of top actors active in scientific publications, European organisations lead in emerging technologies related to Digital Twin and competes with other territories in Medical Imaging. However, this does not translate into a strong positioning in patenting for neither of these two categories (see below). We observe less actors from Europe for the other technology clusters, all led by organisations from the US or China. Although Europe matches China and the U.S. in terms of scientific publication volume, the absence of European organisations in the top 20 publishing rankings might suggest a fragmented research ecosystem. While Europe is a significant contributor to global research output, the lack of large, prominent European actors, as seen in China and the U.S., indicates that European research efforts may be dispersed among smaller entities.

International collaborations

The tables showing collaboration rates clearly indicate that China and the United States are key partners in scientific publications across most of the 12 clusters of emerging technologies. This highlights that the R&D landscape for the 221 emerging technologies is primarily dominated by these two actors.

Figure 80 highlights the role of various regions and organizations in the global dissemination of knowledge within specific technology clusters, measured by betweenness centrality. In terms of bridging territories, the European Union consistently appears as a significant hub for knowledge transfer across all clusters, with additional contributions from the United States (US) and China in areas like Air and Space, Digital Twin, Artificial Intelligence, Medical Imaging, and e-Health. European organisations are well connected and involved in the ongoing research and development for most of the technology clusters.

The French National Centre for Scientific research (CNRS) plays a central role in facilitating knowledge flows within Europe and is prominently present across multiple clusters, including Advanced Materials, Artificial Intelligence, Therapeutics, and Energy. For Aerospace, notable contributors include Airbus, the Technical University Munich, and the German Aerospace Centre. In the cluster of ICT, several European organizations such as the University of Paris-Saclay (France), University of Oulu (Finland), University of Torino (Italy), and Universidad Politécnica de Madrid (Spain) emerge as key players. Other noteworthy organizations include the Technical University Munich in e-Health, Politecnico di Torino (Italy), and the Netherlands Organisation for Applied Scientific Research (TNO) in Energy, and institutions like the Italian National Institute for Nuclear Physics (INFN) and the Delft University of Technology (Netherlands) in Quantum and Cryptography. No organisations stand out for the clusters Mobility and Transport and Medical Imaging.

Overall, the table illustrates a strong presence of Europe in knowledge dissemination with strategic contributions from specific institutions in Europe, like CNRS in France.

Figure 80. Bridging territories for world knowledge flows and bridging organisations for knowledge flows in Europe.

Clusters	Bridging territories	Bridging organisations in EU
Advanced Materials and advanced manufacturing	EU	CNRS (France)
Air and Space	EU, US, China	Airbus Technical University Munich (Germany) German Aerospace Centre
Mobility and Transport	EU	-
Digital twin	EU, US	CNRS (France) Universidad Politecnica Madrid (Spain)
Artificial intelligence and Machine learning	EU, US	CNRS (France)
ICT	EU	University of Paris-Saclay (France) University of Oulu (Finland) University of Torino (Italy) Universidad Politecnica de Madrid (Spain) to a lesser extent: University of Munich (Germany), Politecnico di Milano (Italy), and CNRS (France)
Medical imaging	EU, US	-
Therapeutics and Biotechnologies	EU, US	CNRS (France)
e-Health	EU, US, UK	Technical University Munich (Germany)
Environment and Agriculture	EU	CNRS (France)
Energy	EU	CNRS (France) Politechnicao di Torino (Italy) TNO (Netherlands)
Quantum and Cryptography	EU	INFN (Italy) Delft University of Technology (Netherlands) Leiden University (Netherlands) CNRS (France)

Source: JRC

Patenting

While European organisations publish on average as many scientific articles as Chinese and US organisations, EU organisations file less patents to protect their research results. Figure 81 below shows the translation ratio of scientific publications into patents across technology clusters. Excluding Medical Imaging, where patent data is limited, China's translation ratios range from 2,30% to 36,51%, while they range from 2,67% to 13,84% for the US. In contrast, Europe's translation ratios are significantly lower, ranging from 0,31% to 2,05%, far from the ranges that are achieved by US and China. South Korean organisations, with translation rates between 4,23% and 67,7%, are also more prone to patent than their EU counterparts. Japan exhibits similarly low translation ratios as Europe in most categories but shows significant patenting activity in ICT and Aerospace. This may be attributed to the presence of major Japanese industrial players such as SONY, DENSO, and NTN Corporation in these fields. Japan exhibits similarly low translation ratios as Europe in most categories but shows significant patenting activity in ICT and Aerospace. This might be attributed to the presence of major Japanese industrial actors such as SONY, DENSO and NTN Corporation in these fields.

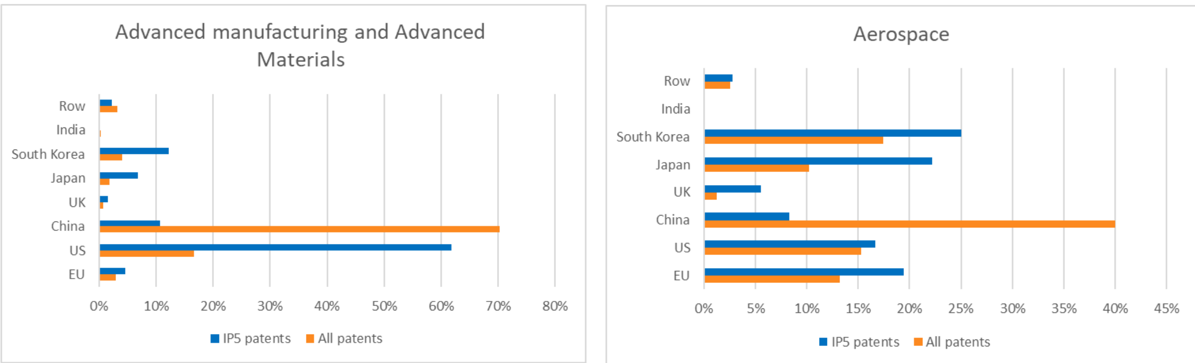
Figure 81. Translation ratio [Patents/scientific publications] for each category for EU, US, China, Japan, and South Korea.

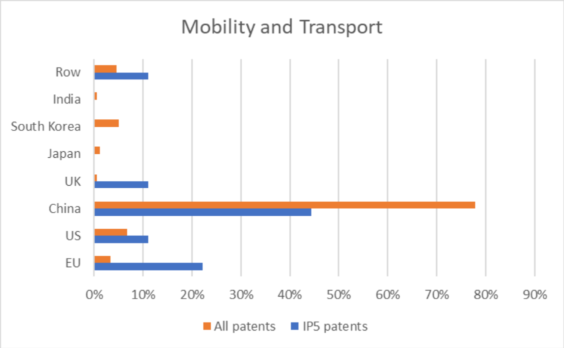
	EU	US	China	UK	Japan	South Korea	India	Row
Advanced Materials and advanced manufacturing	0.96%	6.31%	10.30%	0.58%	4.31%	5.29%	0.41%	0.84%
Air and Space	4.94%	3.23%	8.46%	1.43%	28.24%	18.55%	0.00%	1.02%
Mobility and Transport	0.81%	2.54%	10.05%	0.71%	1.75%	9.18%	1.61%	1.20%
Digital twin	1.08%	12.62%	41.34%	0.00%	3.33%	22.33%	3.16%	1.36%
Artificial intelligence and Machine learning	0.51%	2.43%	17.42%	0.78%	0.32%	8.00%	0.63%	0.43%
ICT	1.11%	17.30%	2.85%	0.95%	18.84%	94.33%	0.37%	1.36%
Medical imaging	0.00%	0.60%	0.37%	0.00%	0.00%	0.00%	0.00%	0.00%
Therapeutics and Biotechnologies	1.11%	3.96%	17.36%	1.20%	0.49%	15.18%	0.95%	1.36%
e-Health	0.78%	2.65%	19.61%	0.00%	2.73%	10.22%	0.28%	0.69%
Environment and Agriculture	1.14%	4.44%	5.83%	0.80%	3.24%	29.03%	0.51%	1.64%
Energy	0.77%	4.27%	16.00%	3.08%	0.85%	6.55%	0.67%	1.11%
Quantum and Cryptography	1.54%	7.32%	19.45%	2.74%	1.90%	9.42%	0.73%	1.76%

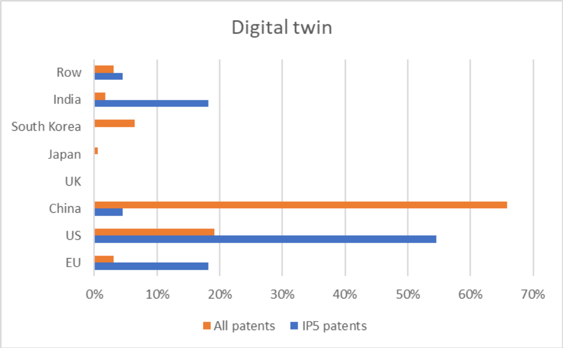
Source: JRC

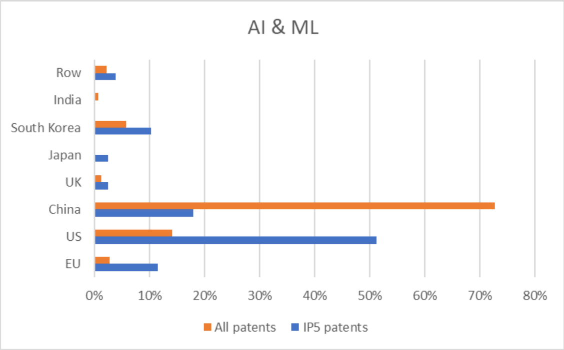
This observation regarding patenting in Europe has to be nuanced when considering IP5 patent families, which are defined as sets of patent applications protecting the same invention filed in at least two intellectual property (IP) offices with at least one application filed in one of the world's top 5 patent offices (IP5): the European Patent Office (EPO), the Japan Patent Office (JPO), the Korean Intellectual Property Office (KIPO), the State Intellectual Property Office of the People's Republic of China (CNIPA) and the United States Patent and Trademark Office (USPTO). This metric is commonly used to account for the heterogeneity in patent quality and to track inventions with significant global importance, as they reflect applications seeking protection across multiple major markets. These patent families are often linked to innovative technologies with substantial commercial or strategic potential. Figure 82 shows the percentage of IP5 patent families compared to all patent families for each territory.

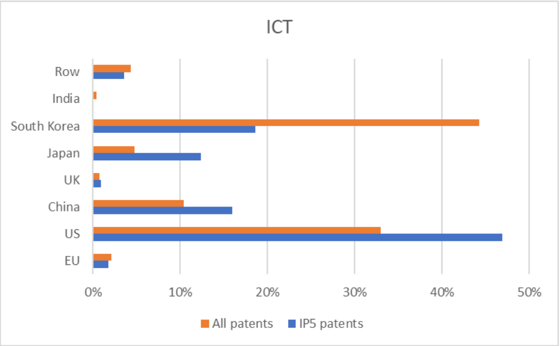
Figure 82. percentage of patents and IP5 patents for each territory and for each cluster of emerging technologies.

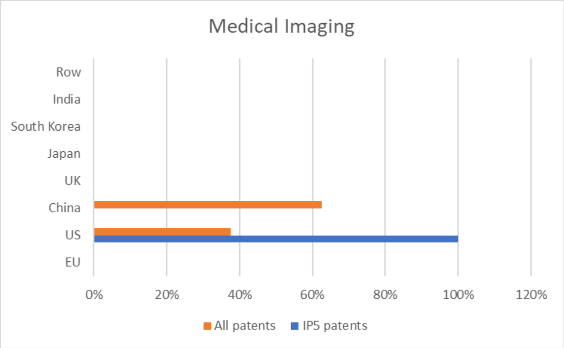


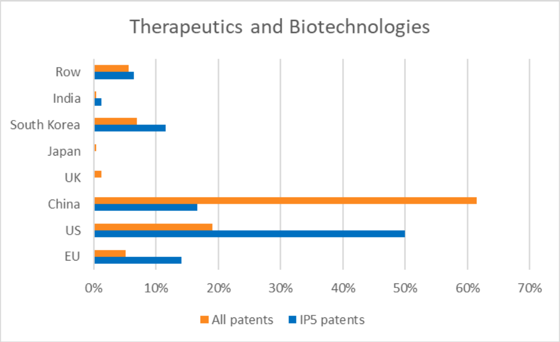

Mobility and Transport
Row
India
South Korea
Japan
UK
China
US
EU
0% 10% 20% 30% 40% 50% 60% 70% 80% 90%
All patents
IP5 patents

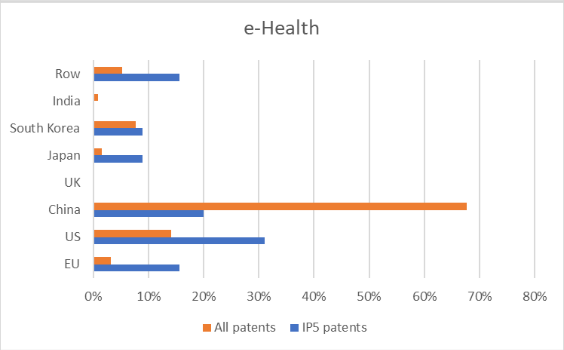

Digital twin
Row
India
South Korea
Japan
UK
China
US
EU
0% 10% 20% 30% 40% 50% 60% 70%
All patents
IP5 patents

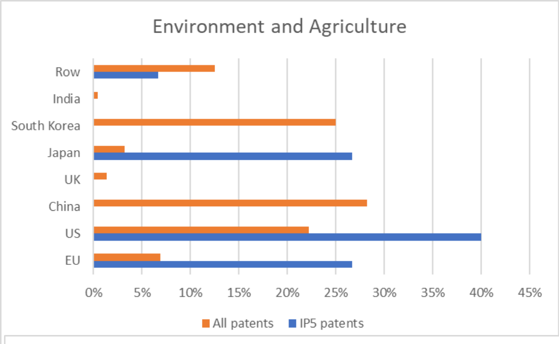

AI & ML
Row
India
South Korea
Japan
UK
China
US
EU
0% 10% 20% 30% 40% 50% 60% 70% 80%
All patents
IP5 patents

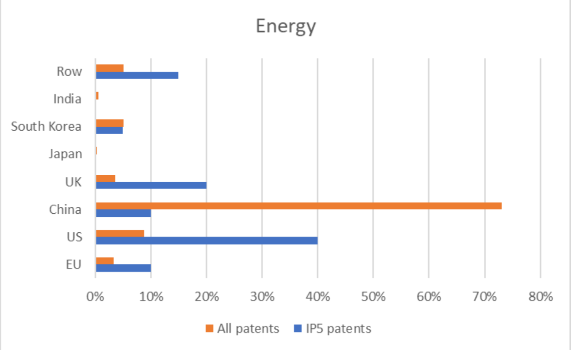

ICT
Row
India
South Korea
Japan
UK
China
US
EU
0% 10% 20% 30% 40% 50%
All patents
IP5 patents

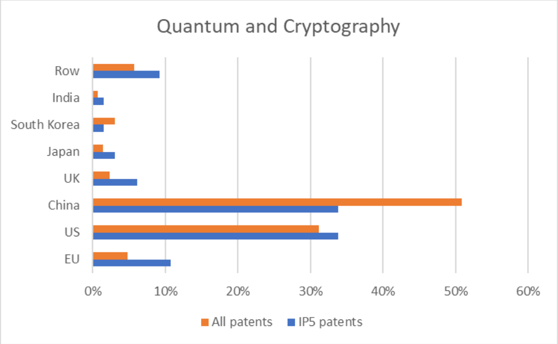

Medical Imaging
Row
India
South Korea
Japan
UK
China
US
EU
0% 20% 40% 60% 80% 100% 120%
All patents
IP5 patents


Therapeutics and Biotechnologies
Row
India
South Korea
Japan
UK
China
US
EU
0% 10% 20% 30% 40% 50% 60% 70%
All patents
IP5 patents


e-Health
Row
India
South Korea
Japan
UK
China
US
EU
0% 10% 20% 30% 40% 50% 60% 70% 80%
All patents
IP5 patents


Environment and Agriculture
Row
India
South Korea
Japan
UK
China
US
EU
0% 5% 10% 15% 20% 25% 30% 35% 40% 45%
All patents
IP5 patents


Energy
Row
India
South Korea
Japan
UK
China
US
EU
0% 10% 20% 30% 40% 50% 60% 70% 80%
All patents
IP5 patents


Quantum and Cryptography
Row
India
South Korea
Japan
UK
China
US
EU
0% 10% 20% 30% 40% 50% 60%
All patents
IP5 patents

Source: JRC

While China leads in patent numbers across most technology clusters, the landscape shifts radically when considering IP5 patents. The US securely holds a dominant position in most areas, including Advanced Manufacturing and Materials, Digital Twin, AI&ML, ICT, Medical Imaging, Therapeutics and Biotechnologies, Environment & Agriculture, e-Health, and Energy. China maintains a leading position in Mobility and Transport only, while South Korea, Japan, the EU, and the US each account for approximately 20% of the IP5 patents in Aerospace. In Quantum and Cryptography, both China and the US lead with 30% of the IP5 patents each. Focusing on Europe, the EU consistently ranks second or third in terms of IP5 patent applications. It holds between 10% and 20% of IP5 patents in Aerospace, Mobility and Transport, Digital Twin, AI&ML, Therapeutics and Biotechnologies, e-Health, Energy, and Quantum and Cryptography, and, notably, for more than 25% of IP5 patents in Environment and Agriculture. However, Europe lags in Advanced Manufacturing and Advanced Materials, and ICT, with less than 5% of IP5 patents.

5 Conclusions

5.1 Converging Paths: High-Level Trends Shaping the Future of Technological Innovation

Emerging technologies across various fields are converging on several key thematic trends that reflect the broader direction of global innovation and development.

One such trend is the **emphasis on sustainability and environmental impact**, a priority that spans from advanced manufacturing techniques, such as Volumetric Additive Manufacturing that minimizes waste, to the development of green ammonia production in the agriculture sector. The adoption of circularity principles is another manifestation of this trend, with technologies like circular food systems and direct recycling of batteries aiming to create closed-loop processes that promote resource efficiency and waste reduction.

Interdisciplinary integration is another significant trend, where different areas of expertise merge to propel technological advancement. For instance, aerospace technologies that combine materials science, computer science, and engineering principles are driving the evolution of air and space mobility. Similarly, the integration of biotechnologies with environmental science is leading to innovative solutions for challenges like microplastic biodegradation.

The **incorporation of AI and machine learning** into various technology fields is transforming traditional processes and enabling new capabilities. From AI-driven analytics in medical imaging to edge computing in agriculture, these tools are optimizing performance, enhancing precision, and unlocking new insights across multiple domains.

Advancements in personalization and precision are becoming increasingly prevalent, particularly in healthcare, where personalized therapies like mRNA vaccines and CAR macrophage therapy are tailored to individual patient needs. In the field of agriculture, precision farming technologies are utilizing data analytics to tailor agricultural practices to the specific conditions of each plot of land, optimizing resource use and crop yields.

Non-invasive and minimally invasive approaches are being prioritized to improve user experience and safety. In medical imaging, for example, techniques like Line-Field Confocal Optical Coherence Tomography are providing high-resolution insights without invasive procedures. In agriculture, non-invasive sensors and monitoring systems are enabling more precise and sustainable farming practices.

The **digitalization of systems and data-driven decision-making** is a cross-cutting trend that is enhancing efficiency and intelligence in fields ranging from environment and agriculture to quantum computing. The rise of digital twins in various sectors illustrates how virtual modelling can optimize the performance of physical systems, while quantum machine learning is set to revolutionize data analysis with unprecedented computational power.

Finally, another pervasive trend across technology fields is the **heightened focus on security and data privacy**, reflecting the critical importance of protecting information in an increasingly digital world. In the realm of ICT, technologies such as Zero Trust architecture and confidential computing are being developed to fortify cybersecurity measures and safeguard sensitive data. Similarly, in AI and ML, advancements like federated learning and privacy-preserving machine learning algorithms ensure that data privacy is maintained during the model training process. Blockchain technologies are contributing to this trend by offering secure and transparent transactional frameworks, thereby enhancing trust in digital interactions. The integration of advanced cryptographic methods, secure multi-party computation, and the emphasis on ethical AI highlight the industry's collective effort to address the growing concerns around data sovereignty and cybersecurity.

These common trends indicate a shift towards technologies that are environmentally friendlier, highly integrated, increasingly personalized, and deeply rooted in data analytics and digitalization. These shared directions not only highlight the interconnectedness of modern technological development but also underscore the collective drive towards a more sustainable, efficient, and responsive future.

5.2 The geography of the 221 Emerging Technologies

Overall, the geographical trends for the emerging technologies in this report reveal a dynamic global landscape where multiple players are competing to influence the direction of technological innovation.

The **United States** confirm their leading position in the global innovation landscape across most of the emerging technologies reported, as underscored by the volume and impact of its R&D output across various technology clusters. American actors are significantly represented in the rankings of top publishing (both in terms of volume and impact) and patenting organizations (both in number of patents and for IP5 patents), reflecting the country's comprehensive technological capabilities and strong private-sector engagement. However, this leadership does not translate into a high Revealed Technology Advantage for most clusters. In areas where the US display specialization, such as Medical Imaging, and Therapeutics and Biotechnologies, this specialization is moderate. This indicates that the US' Science and Technology ecosystem invests in emerging technologies at a level consistent with its efforts in other fields. The secure leadership of US organizations across most emerging technologies despite the lack of pronounced specialization highlights the breadth and strength of the U.S. innovation ecosystem, which thrives on its ability to maintain a diverse and balanced approach across a wide array of technology sectors.

China has closed the gap in terms of research volume and patenting, challenging the long-standing dominance of the US in the global innovation landscape. This shift is illustrated by China's significant contribution to scientific articles in top journals, underscoring the success of its efforts to foster a robust research ecosystem. China's strategic move to bolster its innovation capabilities is further confirmed by strong collaborative ties with leading innovators like the US, and its notable contribution to IP5 patents. Chinese organisations consistently appear in the top rankings in terms of both scientific publications and patenting and the country shows specialization in scientific production for 11 out of 12 clusters of emerging technologies. These metrics collectively underscore Chinas' robust commitment to establishing itself as a high-tech powerhouse by developing its own technology capabilities and directing R&D towards cutting-edge technologies. This is part of a broader ambition to transition from a manufacturing-based economy to one driven by innovation and high-value industries.

South Korea maintains a notable presence in the international technology landscape, showcasing its capacity to compete effectively with larger economies. The country is pursuing a broad technology leadership strategy as suggested by strong specialization across a spectrum of high-tech sectors, including Advanced Materials and Manufacturing, Aerospace, Mobility and Transport, ICT, and Digital Health technologies. This strategic push is underpinned by South Korea's robust industrial base and the influence of its conglomerates, such as Samsung, LG, Hyundai, and Kia, which play a crucial role in supporting and driving innovation across these key sectors.

Japan, although showing under specialization in most emerging technologies, maintains a strategic focus on some technology area, for example in ICT or in Quantum and Cryptography, leveraging its historical strengths in electronics and telecommunications. The overall trend, however, might suggest a potential decline or a need to refocus its R&D strategies to maintain competitiveness.

India, while still modest in terms of R&D output volume, is emerging as a player to watch in the technology arena, leveraging its robust IT sector and demonstrating strategic interest in expanding its high-tech capabilities. Its significant specialization in e-health and quantum technologies, but in general in all emerging technologies with an ICT component, indicate an ambition to rapidly catch up and carve out a space as an innovation hub in specific high-tech domains.

The United Kingdom plays a significant role in scientific research across the 12 clusters, contributing 4% to 7% of the global scientific publications. It demonstrates specialization in technologies within the Energy cluster and, to a lesser extent, in Aerospace, Digital Twin, AI & ML, and Quantum and Cryptography. A distinctive feature of UK research is the high level of international collaborations: 63% to 90% of scientific publications involving UK organizations also include at least one international partner (UK is leading on this aspect for every cluster), making the UK a leader in global research connectivity. In terms of patenting, the UK focuses on emerging technologies related to Energy, Quantum and Cryptography, Aerospace, and Mobility and Transport, aligning with its research specializations. However, despite some specialization in Digital Twin technologies, the UK holds no patents in this area.

Amidst this highly competitive global innovation landscape, the **European Union** remains a prolific and influential producer of scientific knowledge. It leads in the production of scientific publications across emerging technologies such as Digital Twin, AI & Machine Learning (AI & ML), Therapeutics and Biotechnologies, Energy, and Environment and Agriculture, while also contributing a significant share of scientific output in other clusters. This is however tone down by the more modest, but still significant, contribution of European organisations to publications in the top 1% scientific journals. In addition, Europe does not exhibit high levels of specialization in most clusters (even showing under-specialization in Advanced Manufacturing and Materials as well as Aerospace), except in AI & ML, where the EU demonstrates some degree of specialization. This suggests that Europe has a slight focus and is a bit more effective in generating scientific knowledge in AI & ML compared to other scientific fields.

The lack of prominent European entities among the world's top 20 organizations, which are dominated by U.S. and Chinese actors, might suggest the fragmentation of the EU's R&D ecosystems in emerging technologies. While Europe produces a comparable volume of scientific publications than the U.S. and China, the absence of large European actors, as opposed to the concentrated efforts in China and the US, may indicate a fragmented research landscape across many small European entities.

Europe's scientific excellence and its pivotal role as knowledge broker, however, do not consistently translate into patenting and commercialization as effectively as in other regions, thus confirming the existing gap in the rates of return to R&D compared to similar economies like the US[18]. Despite prolific scientific output, Europe's markedly lower ratios of patents to scientific publications compared to China and the US points to systemic weaknesses in translating research into patented inventions. Outside of Medical Imaging, where limited patent data was retrieved, China's translation

[18] Cincera, M., & Veugelers, R. (2014). Differences in the rates of return to R&D for European and US young leading R&D firms. *Research policy*, *43*(8), 1413-1421.

ratios range from 2.30% to 36.51%, and the US from 2.67% to 13.84%. Translation ratios for EU range from 0.31% to 2.05%, much lower than those observed for China and the US. South Korean organizations also demonstrate a higher propensity for patenting, with translation rates between 4.23% and 67.7%. Japan's translation ratios are similar to the ones for Europe for most categories, yet the nation patents significantly in ICT and Air & Space, potentially due to major Japanese industrial players in these sectors, such as SONY, DENSO, and NTN.

As the challenge of patenting in Europe persists, the thematic specialization on broader societal concepts, such as for example micromobility, 15-minute city, sustainable fuels, or ethical AI, suggests a society prone to advance ethical, environmental, and welfare considerations rather than focusing solely on technological commercial applications. There is an observable pivot towards themes associated with well-being and quality of life in European innovation, suggesting that innovation is increasingly viewed through the lens of its societal impact and contribution to sustainability.

The trends described above reveal a **dynamic global landscape** where technological leadership is influenced by a multitude of factors, including government policy, investment priorities, and the agility of research and industry sectors to adapt to the evolving demands of the global economy. The global technological landscape is characterized by intense competition among regions to develop capabilities in key strategic technologies with disruptive potential. In this context, the clusters Quantum and Cryptography or AI & ML stand as prime examples of fields where this dynamic is particularly evident. All major economies demonstrate some relative specialization in various emerging technologies related to these areas, which evidences their understanding of the potential of these emerging technologies to create new opportunities and disrupt existing markets. As emerging technologies appear and new R&D players emerge or grow on the international scene, global technological progress will be shaped by multiple knowledge hubs, adding to the complexity and fierce competition of the worldwide innovation ecosystem.

6 Methodology

6.1 Data

In this report, surges in scientific publications (articles, conference proceedings, review papers) are considered as a proxy for a signal of new technological development. The assumption is that a weak signal of technological development in a certain domain will see a sudden increase in the number of scientific publications (see figure 83).

The Scopus database of scientific publications from Elsevier (covering 01/1996 to 12/2023) and the Patstat database (Winter edition 2023) were used for the detection of weak signals. Scopus is Elsevier's abstract and citation database and covers nearly 37 thousand scientific journals of which around 34,500 are peer-reviewed journals in top-level subject fields such as life sciences, social sciences, physical sciences, and health sciences. PATSTAT (Patent Statistical Database) is a global patent data resource developed by the European Patent Office. It aggregates data from over 100 patent offices worldwide, making it a comprehensive source for patent statistics and analytics.

6.2 Detection of raw weak signals

The approach is to automatically build sets of documents that represent as many concepts included in the data as possible. Indicators are then calculated on those sets to filter for the most emerging ones.

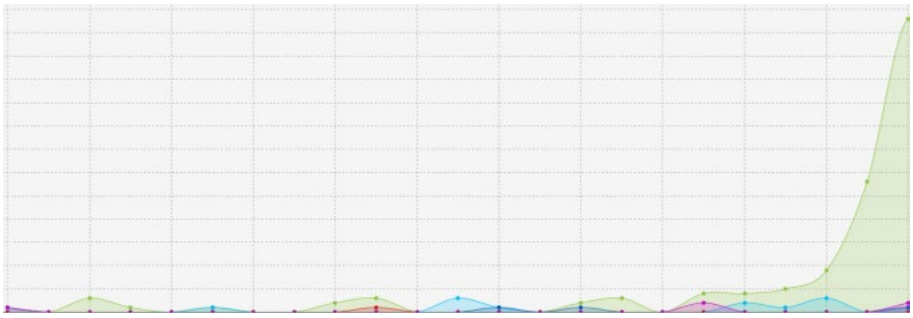
Building the sets of documents

The sets are built by automatically querying the Scopus database for concepts from a text-mining generated dictionary. The creation of the dictionary is a crucial step in this process. The dictionary of multi-words concepts is generated from a corpus of documents using text mining techniques. Single and compound words as well as acronyms are extracted from titles, abstracts, and keyword fields in the reference corpus. To capture the recent vocabulary used in scientific publications, documents from the last seven years (2015-2021) of the Scopus database are used as corpus (~11 million scientific publications). The extracted words are then processed to group instances of the same concept, remove inconsistencies in e.g. spelling or word choice, rank the concepts by relevance and store them in a dictionary. Each concept so obtained is then subsequently used in an automated query process that builds an equivalent number of sets containing scientific publications ranging from 1996 to 2023.

Detection of raw weak signals

After the creation of the sets of documents – each of them representing a "concept" – a custom-built indicator called "activeness" is used to sort these sets. This indicator is defined as the ratio between the number of documents retrieved for a certain period and the total number of documents retrieved for the period 1996-2023. For example, activeness[2021-2023] corresponds to the ratio [#documents published during the period 2021-2023] / [#documents published during the period 1996-2023]. A high activeness score means that a high percentage of documents has been published during the selected period. The sets containing scientific articles with a high activeness are considered as raw weak signals i.e. they might be related to emerging topics in science or emerging technologies.

Figure 83. Typical shape of a weak signal on a graph #documents (Y-axis) Vs years (X-axis).



Source: JRC

6.3 Selection of relevant weak signals

Filtering before reconstruction

Various filters are used to refine the list of raw weak signals, which inevitably also contains false positives. These filters are based on size of the sets of documents, human assessment, or semantic proximity. Manual filtering is used to reject sets resulting from errors in the original corpus (e.g. spelling mistakes). A more elaborated filtering relying on "semantic compactness" is used to reject weak signals containing documents that are not similar from a semantic perspective. Weak signals pertaining to different conceptual areas but with one or two semantic concepts in common are not considered (e.g. documents related to a conference where the only common term between the documents is the name of said conference).

Reconstruction in TIM Technology

To finalise the selection, new sets of articles are re-created for the promising raw weak signals in the TIM Technology system, which, in addition to scientific publications, also contains patents and EU R&D grants.

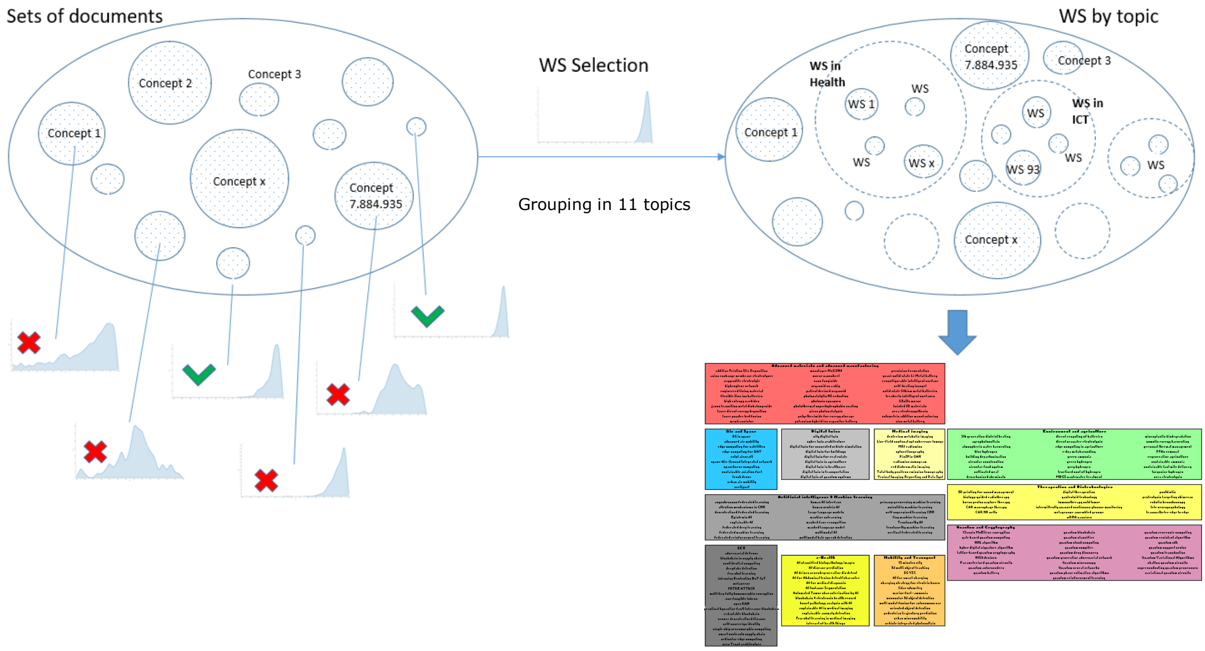
This "reconstruction" consists in optimising the search queries to increase the recall of documents and to further validate the list of signals. Because of the semantic nature of the process, it may be that what was considered as a weak signal appears to be a strong signal i.e. a trend or an issue known for long. A typical example is a technology for which a new word, or new semantic concept appears after a few years: although the technology is not new, the concept is, and it might be detected in the weak signal process. Other examples of such false positive include typos or specific conference names. This reconstruction in TIM Technology may appear as a tedious process, but it is the unfortunate price to pay for a sensitive process. Various features support the optimisation of the search queries: relevant keywords, clustering of articles, documents gram, compactness, document list and online access.

The search queries used for the reconstruction for the raw weak signals in TIM Technology can be found in the thematic dashboards, for each signal.

Thematic grouping

After a pre-clustering based on based on the Leuven community algorithm, the matching between each signal and the thematic cluster is verified manually.

Figure 84. Selection of the weak signals



Source: JRC

Semantic distance in TIM

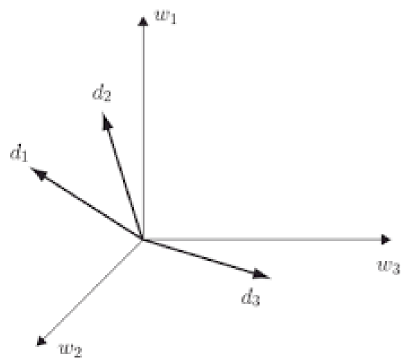
Several features in TIM are using the semantic similarity between documents e.g. clustering, document gram or compactness. This similarity that is measured is similarity in the meaning (semantic, beyond lexicographical): similarity is defined over a set of documents and the distance between documents is based on the likeness of their meaning or semantic content. Computationally speaking, semantic similarity can be estimated using statistical means such as a vector space model to correlate words and concepts. For each document, a vector in a semantic space is computed. Vector operations can then be used to compare the vector- documents with one another. Cosine similarity measures the similarity between two vectors of an inner product space. It is measured by the cosine of the angle between two vectors and determines whether two vectors are pointing in roughly the same direction. It is often used to measure document similarity in text analysis and is expressed as follow:

$$similarity = \cos(\theta) = \frac{A \cdot B}{\|A\| \|B\|} = \frac{\sum_{i=1}^{n} A_i B_i}{\sqrt{\sum_{i=1}^{n} A_i^2} \sqrt{\sum_{i=1}^{n} B_i^2}}$$

with A and B two vectors of terms and cos(θ) the similarity between them. A cosine value of zero means that the two document vectors are orthogonal (90 degrees) and have no similarity at all. A cosine value of 1 would mean that the angle between the two vectors is 0 degrees and the document vectors are identical. The similarity metric between two documents calculated in TIM is therefore a value between 0 and 1.

Figure 85. Vectorial representation of a cosine distance measurement.

cosΘ(d1-d2)= semantic distance between d1 and d2



Source: JRC

Impact factor

The impact factor (IF) or journal impact factor (JIF) of an academic journal is a scientometric index that reflects the yearly mean number of citations of articles published in the last two years in a given journal. As a journal-level metric, it is frequently used as a proxy for the relative importance of a journal within its field; journals with higher impact factor values are given the status of being more important, or carry more prestige in their respective fields, than those with lower values.

In TIM, we compute the Impact Factor (as well as the CiteScore) using the raw data from Scopus. The impact factors are computed per each year, starting from 1998 (since Scopus data date back from 1996, and 2 previous years for citations are needed for the computation). This index was computed for the years 1998 - 2023.

Formula for Computing:

Impact Factor for Year Y = Number of Citations all articles published in this journal in year Y / (Number of Citations all articles appearing in this journal in Year (Y-1) have received + Number of Citations all articles appearing in this journal in Year (Y-2) have received)

List of figures

Annexes

Advanced Manufacturing and advanced materials

Weak signal	What it is? Why is it new?	Main actors
anion exchange membrane electrolyzer	a) Anion exchange membrane (AEM) electrolyzers utilize advanced catalysts and membrane materials to facilitate the electrolysis of water, producing hydrogen. Innovations include bimetallic/multimetallic catalysts, high-entropy spinel oxides, and corrosion-resistant electrocatalysts enhancing activity and stability. They offer potential applications in green energy conversion, direct seawater splitting for hydrogen production, and urea-assisted water electrolysis. b) The novelty of the AEM electrolyzer technology lies in its use of newly designed electrocatalysts and AEMs that achieve high performance and durability. These include catalysts with unique nanostructures, doping strategies, and heterostructures that optimize reaction pathways, and advanced AEMs with high ionic conductivity and stability, pushing the limits of current density and efficiency beyond traditional technologies.	China University of Petroleum, Chinese Academy Of Sciences, Hanyang University, University of Surrey, Materials Science and Engineering
argyrodite electrolyte	a) Argyrodite electrolyte is a sulfide-based solid-state electrolyte with high ionic conductivity, enabling stable and safer all-solid-state lithium batteries (ASSLBs). It facilitates the use of lithium metal anodes, thereby increasing energy densities. Modifications like halide substitution and aliovalent doping improve its air stability, compatibility with Li metal, and interfacial stability, essential for large-scale battery applications. b) The novelty of argyrodite electrolyte technology lies in its enhanced ionic conductivity, air stability, and electrochemical performance through chemical modifications. These advancements address previous limitations of sulfide-based electrolytes, such as moisture sensitivity and poor Li metal compatibility, paving the way for practical and scalable energy storage solutions.	Delft University of Technology, Shanghai Jiao Tong University, Zhejiang University, University of Western Ontario, Fujian Normal University
flexible Zinc ion battery	a) Flexible Zinc ion batteries (ZIBs) are emerging energy storage devices featuring hydrogel electrolytes, which combine high ionic conductivity with solid-like mechanical properties. They are designed for wearable electronics, offering capabilities such as high energy density, long cycle life, and stability under physical deformations, including bending and folding. Their biocompatibility and anti-freezing properties also enable operation in extreme conditions and biological integration. b) The novelty lies in the hydrogel electrolytes' multifunctionality, enabling ZIBs to maintain performance in harsh conditions. Innovations include 3D-printed anodes for dendrite-free cycling, single-ion conduction for improved battery life, and hydrogel customization to prevent zinc corrosion and enhance low-temperature performance. These advancements distinguish them from traditional batteries by their flexibility, safety, and adaptability to wearable and biomedical applications.	Northwestern Polytechnical University, Southeast University, Donghua University, University of Alberta, Nankai University
Potassium hybrid ion capacitor battery	a) The Potassium hybrid ion capacitor battery is an energy storage device that leverages a battery-type anode with high heteroatom doping and a capacitor-type cathode to offer a blend of high energy density, rapid charge-discharge rates, and cycling stability. This technology takes advantage of advanced materials like nitrogen/sulfur-doped carbons, metal phosphides, and molybdenum diselenide to improve ion kinetics and accommodate the large potassium ions effectively, aiming for applications in large-scale energy storage. b) The novelty lies in the creation of electrode materials with ultra-high heteroatom doping and unique morphologies that enhance electrochemical performance for potassium ion storage. These advancements, including "ball-in-tyre" structures and nitrogen-doped porous carbon frameworks, represent a significant progression from traditional lithium-ion systems, with a focus on utilizing abundant potassium resources for improved capacity, rate capability, and structural stability in energy storage applications.	Chinese Academy Of Sciences, Hunan University, King Abdullah University of Science and Technology, Guizhou Education University, University of Kansas

quasi-solid-state Li-Metal battery	a) The quasi-solid-state Li-Metal battery technology incorporates non-flammable solid polycarbonate matrices or polymer electrolytes, encapsulating liquid components to enhance safety and performance. With high ionic conductivity and robust interphases, it suppresses dendrite growth, supporting stable cycling with high-voltage cathodes. Applications include energy storage systems and electric vehicles, providing improved safety and energy density. b) This technology is novel in its approach to combining solid and liquid electrolyte components to form a stable, quasi-solid electrolyte. Innovations include the formation of LiF-rich interphases, non-flammable SLHEs, and in-situ polymerized matrices, addressing safety risks and performance issues prevalent in traditional liquid or solid-state batteries. It represents a significant advancement in electrolyte design for lithium-metal batteries.	Chinese Academy Of Sciences, Nankai University, Zhejiang University of Technology, Fujian Science & Technology Innovation Laboratory for Energy Devices of China (21C-LAB), Harbin University of Science and Technology
Zinc metal battery	a) Zinc metal battery technology utilizes an aqueous electrolyte and zinc anode modifications to enhance stability and suppress dendrite formation, thus improving cycle life and Coulombic efficiency. Advancements include cosolvents to control solvation structure, interfacial coatings for uniform deposition, solid-electrolyte interphases, and pH-buffering strategies. The technology is aimed at large-scale energy storage with potential applications in smart grids and stationary storage. b) The novelty lies in the multifaceted approach to address zinc anode challenges such as dendrite growth, hydrogen evolution, and corrosion, which are major obstacles for traditional zinc batteries. Innovations such as monolithic SEI formation, dynamic pH-buffering, and deep eutectic solvents represent significant advancements over existing zinc battery technologies, offering enhanced safety, energy density, and operational stability.	Huazhong University of Science and Technology, Wuhan University of Technology, Chinese Academy Of Sciences, City University of Hong Kong, Science and Technology Corporation
engineered living material	a) Engineered living materials (ELMs) are advanced composites that integrate living cells or organisms with synthetic matrices, allowing for growth, self-organization, and self-healing. These materials can autonomously perform biological functions, responding to environmental stimuli. Applications range from green energy, bioremediation, and disease treatment to advanced smart materials with potential uses in biosensing, biocatalysis, art restoration, artificial corals, and tissue engineering. b) The novelty of ELMs lies in their dynamic, regenerative, and responsive nature, surpassing traditional materials by combining living organism functionalities with material properties. This integration facilitates the creation of materials with self-healing, growth, and environmental adaptability capabilities, representing a significant innovation in material science and manufacturing.	Massachusetts Institute of Technology, University of Pennsylvania, Chinese Academy of Sciences, Harvard University, Yale University
High entropy carbides	a) High entropy carbides (HECs) are advanced ceramics composed of multiple metal carbides that form a single-phase structure with superior properties, such as high hardness, thermal stability, and oxidation resistance. These materials are produced using techniques like spark plasma sintering and exhibit enhanced mechanical properties even at elevated temperatures, making them suitable for extreme environments. b) The novelty of HECs lies in their unique multi-element composition that significantly improves material performance compared to traditional carbides. With the ability to maintain structural stability and resist irradiation and oxidation at high temperatures, HECs represent a breakthrough in materials for harsh conditions, offering a new paradigm in alloy and ceramic design.	Duke University, Missouri University of Science and Technology, Uppsala University, University of California, North Carolina State University
industry 5.0	a) Industry 5.0 is an advanced technology in the ICT field that leverages bioengineering and artificial intelligence to enhance industrial processes and healthcare, while promoting sustainability and efficiency. It also includes empathy-controlled robots that adapt to the operator's emotional state, facilitating industry 5.0 with a human-robot synergistic approach. b) The novelty lies in its unique integration of bioengineering and AI, enabling unprecedented applications like synthetic metabolisms and artificial DNA. It also pioneers in implementing empathetic interactions in robotics, bringing a human touch to Industry 5.0, unlike traditional ICT technologies.	Lovely Professional University, Chinese Academy Of Sciences, Hong Kong Polytechnic University, Technological University, Politecnico di Torino
Additive Friction Stir Deposition	a) Additive Friction Stir Deposition (AFSD) is a solid-state additive manufacturing technique that utilizes severe plastic deformation at elevated temperatures to create fully-dense metal structures with refined, equiaxed microstructures. This process has wide applications in industries requiring high load-bearing parts, such as aerospace, where it offers improved toughness and potential for novel metal composites. b) AFSD stands out for its ability to produce parts with minimal defects and post-processing needs, compared to traditional fusion-based additive manufacturing methods. Its unique advantage lies in producing fine-grained microstructures and wrought mechanical properties directly in the as-printed state, which is novel in the field of metal additive manufacturing.	University of North Texas, University of Alabama, Oak Ridge National Laboratory, University of Michigan, Central South University

biphenylene network	a) The biphenylene network (BPN) is a novel two-dimensional carbon allotrope distinguished by its unique arrangement of four-, six-, and eight-membered carbon rings, exhibiting metallic, anisotropic electronic transport properties, and directional insulating behavior. BPN's promising applications include advanced nanoelectronics, thermoelectric materials, hydrogen storage, catalysis, and thermal management in electronic devices due to its tailored electronic, mechanical, and thermal properties. b) The biphenylene network represents a significant advancement over traditional sp2-hybridized carbon materials such as graphene, due to its unconventional ring structure and anisotropic properties. Its unique electronic band structure, tunable through doping, and its potential for high hydrogen storage capacities are innovative features not found in established carbon allotropes, marking BPN as a groundbreaking material in carbon-based technology.	Kanazawa University, Nanjing Forestry University, University of Chinese Medicine, Normal University, Jiangsu University of Science and Technology
Janus Transition Metal Dichalcogenide	a) Janus Transition Metal Dichalcogenides (TMDs) are novel two-dimensional materials with asymmetrical, sandwich-like layers of transition metals and chalcogen atoms. They exhibit unique electronic, optical, and catalytic properties due to their inherent asymmetry and internal electric fields. Potential applications include highly efficient photocatalysts, water splitting, spintronics, and nanoelectronics, leveraging their enhanced carrier mobility, dipole moments, and strain-tunable characteristics. b) The novelty of Janus TMDs lies in their broken out-of-plane mirror symmetry, enabling distinctive behaviors not found in conventional TMDs. They offer enhanced hydrogen evolution reaction activity without the need for strain or defects, rapid exciton formation, and extended exciton lifetimes. Their asymmetric structure also leads to new possibilities in ferromagnetism, piezoelectricity, and valleytronics, significantly diversifying their application potential compared to symmetric TMDs.	Southeast University, University of Pennsylvania, Rice University, Hazara University, Science and Technology Corporation
laser direct energy deposition	a) Laser direct energy deposition (LDED) is an additive manufacturing process that leverages focused laser energy to fuse material as it is deposited. This technology enables the fabrication of complex components, repair of existing parts, and creation of multi-material structures with tailored properties. It has applications across aerospace, energy, and medical sectors for producing high-purity ceramics, high-strength metals, and high-entropy alloys with enhanced mechanical properties and thermal stability. b) The novelty in LDED lies in its advanced process control, which includes manipulating spatial laser intensity profiles and multi-eutectoid elements alloying to refine microstructures and improve material performance. Innovations also encompass the integration of multisensor fusion for in-situ quality monitoring, enabling self-adaptive manufacturing. These advancements surpass traditional manufacturing in precision, material properties, and the capability to repair and enhance complex, high-value components.	Singapore Institute of Manufacturing Technology, Dalian University of Technology, Guangdong Key Laboratory of Modern Control Technology, Shenzhen Xinjinquan Precision Technology Co.,Ltd., Hunan University
laser powder bed fusion	a) Laser powder bed fusion (LPBF) is an additive manufacturing process where a high-power laser selectively melts and fuses metal powder layers to build complex parts. It allows for intricate designs with potential applications in aerospace, medical implants, and the automotive industry, benefitting from its ability to create strong, corrosion-resistant materials like stainless steel, nickel-copper alloys, and titanium. b) Compared to traditional manufacturing, LPBF presents a novel approach by enabling multi-material printing and in-situ process monitoring, which can predict and mitigate defects like porosity. Its advancements lie in the understanding of keyhole-mode melting, melt pool dynamics, and real-time control mechanisms, providing higher precision and repeatability in part production.	Lawrence Livermore National Laboratory, National Institute of Standards and Technology, Centro Atómico Bariloche, Carnegie Mellon University, University of Virginia
memtransistor	a) The memtransistor combines the memory function of a memristor and the gating capability of a transistor into a multi-terminal device, enabling neuromorphic computing with high plasticity and low energy consumption. This advanced material, typically using two-dimensional semiconductors like MoS2, offers tunability over resistance states and potential applications in in-memory computing, AI hardware accelerators, and secure IoT encryption. b) Memtransistors are novel in their integration of memory and gating functions within the same multi-terminal structure, allowing for complex synaptic emulation not possible with two-terminal memristors. They introduce new resistive switching mechanisms and improved synaptic plasticity tuning, which can significantly enhance the efficiency and density of neuromorphic networks.	Penn State University, Northwestern University, National University of Singapore, Massachusetts Institute of Technology, University of California

monolayer MoSi2N4	a) Monolayer MoSi2N4 is a two-dimensional layered material with semiconducting properties, high strength, and excellent ambient stability. Fabricated by chemical vapor deposition, it presents a tunable bandgap influenced by strain, making it suitable for electronic and optoelectronic applications, including valleytronics, spintronics, and photocatalytic water splitting. Its high lattice thermal conductivity and notable piezoelectric coefficients also position it for use in thermal management systems and energy storage/conversion. b) The novelty of monolayer MoSi2N4 lies in its unique septuple-atomic-layer structure, yielding exceptional mechanical, electronic, and thermal properties that surpass traditional 2D materials like graphene and transition metal dichalcogenides. Its strain-tunable bandgap and superior piezoelectric performance, coupled with the ability to maintain stability in ambient conditions, present new opportunities in advanced material applications not achievable with established technologies.	Chinese Academy Of Sciences, Hunan Normal University, Persian Gulf University, Xi'An University of Technology, University of Science and Technology of China
mxene nanosheet	a) MXene nanosheets, advanced two-dimensional materials with excellent conductivity and mechanical properties, are being used to enhance energy storage (supercapacitors, batteries), improve durability in polymer coatings, boost electrocatalytic activity in sensors, and enable flexible electronic devices. Their versatile integration with other materials like graphene and polymers leads to composites with increased interlayer spacing, facilitating ion diffusion and access to electroactive sites, which is crucial for high-performance supercapacitors and batteries. b) The novelty of MXene nanosheet technology lies in its unique combination of high electrical conductivity, flexibility, and mechanical strength. Compared to traditional materials, MXenes offer improved energy storage capacities, enhanced durability against environmental factors, and superior electrochemical performance. Their ability to form heterostructures with other nanomaterials creates new opportunities for applications in wearable electronics, electromagnetic wave absorption, and advanced sensor technologies.	Beni-Suef University, Qingdao University, Northwestern Polytechnical University, Hubei University of Technology, Harbin Engineering University
nano fungicide	a) Nano fungicides employ nanoparticles (NPs) to inhibit fungal growth in crops by disrupting pathogen morphology and gene expression, as seen with silver nanoparticles (AgNPs) against rice pathogens. Green synthesis methods utilizing plant extracts create eco-friendly zinc oxide (ZnO NPs) or iron oxide (Fe3O4 NPs) with antifungal properties, offering controlled release and enhanced efficiency compared to traditional methods. Potential applications include disease control in agriculture, post-harvest preservation, and nutrient delivery enhancement. b) The novelty of nano fungicides lies in their multifunctional capabilities, such as targeted delivery, controlled release, and reduced environmental impact through green synthesis. Unlike conventional fungicides, nano fungicides offer potential enhancements in crop yield and protection while mitigating resistance development due to their unique modes of action and physicochemical properties.	Qatar University, Government College University, Ain-Shams University, Nanjing Agricultural University, Habitat Centre
organoid on a chip	a) Organoid on a chip technology integrates self-organizing 3D organ-like structures with microfluidic systems to closely mimic human organ functionalities. It provides controlled environments for organ development, mechanical and electrical stimuli, real-time monitoring of biochemical parameters, and vascularization, enabling advanced studies in disease modeling, drug testing, and organ interactions. b) The novelty of organoid on a chip lies in its ability to emulate human organ physiology more accurately than traditional 2D cultures or animal models. Innovations include on-chip vascularization, multi-organ interactions, and dynamic microenvironments that offer ethical advantages and enhanced fidelity in human tissue and disease simulation for biomedical research and pharmaceutical development.	Chinese Academy Of Sciences, University of Pennsylvania, Zhejiang University, Weizmann Institute of Science, Royal Netherlands Academy of Arts and Sciences
patient derived organoid	a) Patient-derived organoids (PDOs) are 3D cell cultures created from a patient's own tumor cells, mirroring the complex biological architecture and diverse cell populations of original tissues. They serve as dynamic models for studying disease mechanisms, testing drug responses, and tailoring personalized therapies in cancer treatment, offering a promising tool for precision medicine. b) The novelty of PDO technology lies in its ability to closely replicate the patient's tumor environment, reflecting the heterogeneity and specific molecular characteristics of individual cancers. This provides a more accurate platform for drug testing and understanding resistance mechanisms compared to traditional 2D cultures or animal models, thereby potentially enhancing the predictive power for clinical outcomes.	Harvard University, National University of Singapore, Delft University of Technology, Oncode Institute, Military Medical University

photocatalytic N2 reduction	a) Photocatalytic N2 reduction is a process that converts nitrogen (N2) into ammonia (NH3) using light energy in the presence of a photocatalyst. Innovations in this technology involve defect engineering, such as oxygen and metal vacancies, and the introduction of single atoms or heterojunctions to enhance electron transfer and N2 activation, enabling more efficient and sustainable ammonia production under mild conditions compared to traditional high-energy industrial methods. b) The novelty of photocatalytic N2 reduction lies in its use of advanced catalyst designs that introduce defects, piezoelectric effects, and electronic metal-support interactions to improve ammonia synthesis rates. These approaches offer lower energy barriers, increased adsorption sites, and enhanced charge separation, representing significant advancements over conventional ammonia synthesis, which requires high temperatures and pressures.	Ocean University of China, University of Ottawa, China University of Geosciences, Zhejiang University of Technology, Nanyang Technological University
photonic synapses	a) Photonic synapses are advanced materials that emulate biological neural functions, integrating mechanical and optical plasticity for memory and information processing. These devices, often based on hybrid structures like graphene/MoS2 or perovskite quantum dots, show potential in neuromorphic computing, artificial vision, and smart sensory applications by modulating charge transfer in response to mechanical and light stimuli. b) The novelty of photonic synapses lies in their multifunctional capabilities, which combine mechanical and optical inputs to modulate synaptic behaviors. This dual-modality, along with their potential for high image recognition accuracy and low-energy consumption, distinguishes them from traditional electronic-only or optical-only memory devices, offering a promising approach for interactive artificial intelligence and advanced computing architectures.	Chinese Academy Of Sciences, School of Materials Science and Engineering, Nankai University, Sichuan Normal University, Purdue University
Phototherm-al superhydrop-hobic coating	a) Photothermal superhydrophobic coatings combine light-to-heat conversion with water repellence, enabling surfaces to resist wetting and icing. They are crafted via simple methods such as spraying, providing resilience to abrasion and environmental factors. Key applications include anti-icing for wind turbines, biofilm prevention, and industrial anti-icing/deicing. b) The novelty lies in the multifunctionality of these coatings, integrating self-healing, anti-corrosive, and photothermal properties. Unlike traditional materials, these coatings offer rapid deicing under low sunlight, self-repair capabilities, and are made using eco-friendly processes, representing a significant advancement in smart surface technologies.	Chinese Academy Of Sciences, Northeast Agricultural University, Hubei University, China Academy of Engineering Physics, Sinopec Research Institute of Safety Engineering
piezo photocatalys-is	a) Piezo photocatalysis is a technology that synergistically harnesses mechanical and solar energies to accelerate chemical reactions, particularly for environmental remediation and energy conversion. It involves piezoelectric materials that generate an electric field upon mechanical stress, enhancing the separation of charge carriers in photocatalysts, thereby increasing reaction rates for processes like CO2 reduction, N2 fixation, and pollutant degradation. b) The novelty of piezo photocatalysis lies in its dual-action mechanism, combining piezoelectric and photocatalytic effects to overcome rapid charge recombination, a common limitation in traditional photocatalysis. Recent advancements include the introduction of defects, tailored nanostructures, and heterojunctions to optimize the piezoelectric properties and the catalytic interface, significantly boosting performance beyond conventional photocatalytic systems.	King Abdullah University of Science and Technology, Hunan Agricultural University, Central South University, Graduate School, China University of Geosciences
Polyetherimi-de for energy storage	a) Polyetherimide (PEI) for energy storage utilizes PEI nanocomposites with inorganic nanoparticles or nanofibers to enhance dielectric properties for high-temperature capacitor applications. These advanced materials achieve high energy storage densities and efficiencies by improving breakdown strength, reducing leakage current, and stabilizing performance across a wide temperature range. b) The novelty lies in the strategic incorporation of nanoscale fillers into PEI matrices, which significantly surpasses traditional polymers in energy density and thermal stability. Innovations include core-shell nanoparticles, high-entropy nanofillers, and molecular semiconductor blending, leading to record energy storage performances at elevated temperatures with promising scalability for high-power applications.	Xi'An Jiaotong University, Tsinghua University, Wuhan University of Technology, Science and Engineering, Hubei University
precision fermentation	a) Precision fermentation is a biotechnological process that utilizes microorganisms, such as filamentous fungi and genetically engineered microbes, to produce specific proteins, enzymes, and other molecules with high precision and efficiency. By manipulating microbial metabolic pathways, this technology enables the sustainable production of advanced materials, such as recombinant proteins for food and material applications, without relying on traditional agricultural or chemical processes. b) The novelty of precision fermentation lies in its ability to create proteins and materials with enhanced functionality and tailored properties, such as modified protein structures for improved solubility and aggregation behavior. It offers a shift from crop-derived feedstocks to more sustainable sources like electro-synthesized acetate, potentially reducing competition with the food supply and environmental impact.	Technische Universität Braunschweig, Université de Lorraine, Wageningen University and Research, Loma Linda University, University of Bonn

reconfigurable intelligent surface	a) Reconfigurable intelligent surfaces (RIS) are advanced materials that dynamically manipulate electromagnetic waves for enhanced wireless communication. By adjusting passive elements, RISs achieve directive beamforming without active RF components, optimizing signal paths and improving energy efficiency. Applications include 6G networks, secure IoT communications, integrated sensing, and intelligent resource allocation in OFDM systems. b) The novelty of RIS technology lies in its passive nature and ability to control wavefront properties (phase, amplitude) without traditional active RF processing. This enables significant gains in wireless system capacity and energy efficiency. RISs also introduce novel capabilities for secure and intelligent communication, surpassing conventional reflectors and relays.	National University of Singapore, Université Paris-Saclay, CNRS, Paris Research Center, National University of Defense Technology
scaffold for cultivated meat	a) In vitro meat, also known as cellular or lab-grown meat, is a food science and biotechnology concept that involves cultivating muscle cells on a scaffold in a bioreactor. The microstructure of the scaffold is crucial for aligning muscle cells to form fibers. The technology offers a sustainable way to meet increasing global meat demand, bypassing the inefficiencies and environmental challenges associated with conventional animal farming. b) The novelty of in vitro meat technology lies in its potential to produce meat without animal slaughter using non-mammalian biopolymers as scaffolds. The key innovation is the development of microstructured edible films, created through micromolding technology, that enable muscle cells to grow and align into muscle fiber structures. This marks a significant shift from traditional meat production methods, offering a more sustainable and potentially animal-free solution.	Zhejiang University, Nanjing Agricultural University, IND ACADEMIC COOP FOUND YONSEI UNIV, University of California, Tufts University
self-healing ionogel	a) Self-healing ionogels are advanced materials that combine ionic liquids with polymeric networks to create gels with remarkable properties such as high mechanical strength, stretchability, and transparency. They can autonomously repair damage at room temperature, making them ideal for use in stretchable electronics, wearable sensors, energy storage devices, and smart windows. Their multifunctionality extends to sensing strain, temperature, human motion, and even underwater operation. b) The novelty of self-healing ionogels lies in their robust mechanical properties coupled with room-temperature self-healing capabilities, a significant advancement over conventional gels. These ionogels exhibit enhanced strength, environmental resistance, and energy harvesting ability, surpassing previous limitations in flexibility, transparency, and multifunctional sensory applications, thus opening new avenues in advanced material design for complex environments.	Jilin University, Donghua University, Sichuan University of Science and Engineering, Tsinghua University, Fudan University
solid-state lithium metal batteries	a) Solid-state lithium metal batteries employ non-flammable solid electrolytes, often incorporating sulfide, polymer, or ceramic materials, to enhance ionic conductivity and suppress lithium dendrite growth. These batteries offer higher energy density, improved safety, and longer lifespans over traditional lithium-ion batteries. Their potential includes powering electric vehicles, portable electronics, and enabling grid storage solutions. b) The novelty lies in the development of innovative materials like Ag-C composites, $BaTiO_3$–$Li_{0.33}La_{0.56}TiO_{3-x}$ nanowires, and chlorine-rich argyrodites, which address previous limitations in ionic conductivity and interfacial stability. Enhanced manufacturing techniques, such as warm isostatic pressing and vacuum infusion, contribute to the superior performance and integration of these advanced materials in practical applications.	Chinese Academy Of Sciences, University of Maryland, Huazhong University of Science and Technology, Shenzhen University, Samsung Corp
ternary hybrid nanofluid	a) Ternary hybrid nanofluids are advanced heat transfer materials composed of three different nanoparticles dispersed in a base fluid. These nanofluids show improved heat transfer properties, with applications in energy transportation and cooling systems in automotive and industrial sectors. Their thermal performance can be optimized by varying the nanoparticle shapes, sizes and concentrations. b) The novelty of ternary hybrid nanofluids lies in their enhanced thermophysical properties. Compared to traditional single and binary hybrid nanofluids, the ternary versions demonstrate higher thermal conductivities and lower viscosities, attributed to the diverse particles they contain. This results in more efficient heat transfer, which is promising for applications where thermal management is critical.	King Khalid University, Future University, Prince Sattam Bin Abdulaziz University, Davangere University, King Mongkut's University of Technology Thonburi

ti3c2tx mxene	a) Ti3C2Tx MXene, a 2D transition metal carbide, displays versatile applications in advanced materials due to its high surface area, tunable surface chemistry, and excellent conductivity. Uses span energy storage, electromagnetic interference shielding, water purification, photocatalytic degradation of pollutants, hydrogen storage, flexible electronics, and antimicrobial wound dressings. b) The novelty of Ti3C2Tx MXene lies in its unique combination of electrical conductivity, mechanical flexibility, and ease of processing, outperforming traditional materials in a variety of applications. Its ability to form single-atom structures and composite materials showcases a significant advancement in multifunctional material design.	Qilu University of Technology, Central South University, Islamic University, Jiangsu Academy of Agricultural Sciences, Beijing Jiaotong University
twisted 2D materials	a) Twisted 2D materials are engineered by adjusting the twist angle between layers of two-dimensional materials, such as graphene, to form Moiré superlattices. This manipulation alters the electronic, optical, and mechanical properties, creating tunable bandgaps and quantum phenomena. Potential applications include nanophotonics, quantum computing, sensing, and energy-efficient electronics. b) The novelty of twisted 2D materials lies in the precise control of interlayer twist angles, enabling the discovery of new quantum states and topological properties not present in untwisted counterparts. This control allows for the exploration of strong correlation physics and the engineering of flat bands at higher twist angles, expanding the scope for innovative device applications.	Zhejiang University, Northeastern University, University of Manchester, Simons Foundation, National University of Singapore
urea electrsynthesis	a) Urea electrosynthesis is a sustainable method that converts nitrate and carbon dioxide into urea using electricity under ambient conditions. It employs advanced catalysts, such as single-atom and diatomic configurations, defect-engineered materials, and frustrated Lewis pairs, to facilitate the C-N coupling reaction. This technology has potential applications in agriculture as a synthetic fertilizer, in environmental management through carbon and nitrogen waste recycling, and in contributing to a circular, net-zero carbon economy. b) The novelty of urea electrosynthesis lies in its departure from the traditional energy-intensive Haber-Bosch process, offering a more environmentally friendly alternative by operating at room temperature and pressure. Recent advancements include the development of high-efficiency catalysts with unique active sites for better activation of reactants, novel strategies for enhancing C-N coupling efficiency, and the successful synthesis of urea using various electrocatalytic systems, some achieving notable Faradaic efficiencies and yield rates.	Chinese Academy Of Sciences, University of Science and Technology of China, Nanjing Normal University, Hunan University, Avenida da Universidade
volumetric additive manufacturing	a) Volumetric additive manufacturing (VAM) is an advanced 3D printing technique that rapidly creates objects by projecting dynamic light patterns into a photosensitive resin from multiple angles, solidifying the entire volume simultaneously. This layerless approach allows for the creation of complex structures, including biomaterials, with smooth surfaces and intricate features, such as internal channels and micro-optics. VAM's applications span biomedical engineering for organoid and tissue scaffolding, microfluidics, and the integration of heterogeneous materials for multi-functional devices. b) The novelty of VAM lies in its departure from traditional layer-by-layer fabrication methods, offering a significant reduction in print time and enhanced geometrical freedom. Recent advancements have improved print resolution and fidelity by addressing challenges related to light scattering and photo-polymerization kinetics. The technology has expanded to include a wider range of materials, such as cell-laden hydrogels and silk-based bioinks, and can now incorporate pre-existing objects within printed structures, pushing the boundaries of additive manufacturing capabilities.	Utrecht University, University of California, Harvard University, University of Colorado at Boulder, Ecole Polytechnique Fédérale de Lausanne
terahertz intelligent surfaces	a) Terahertz intelligent surfaces (TIS) are advanced materials that manipulate terahertz (THz) waves for improved wireless communication, particularly for 6G networks. These surfaces consist of large-scale elements that can be optimized to adjust phase shifts and time delays, effectively managing beam squint problems in both far-field and near-field scenarios. Potential applications of TIS include enhancing data rates and reliability for virtual reality, enabling covert communication with drones in IoT networks, and facilitating secure, efficient data transmission in multi-user MIMO systems. b) The novelty of terahertz intelligent surfaces lies in their ability to overcome the unique beam squint effects associated with the terahertz spectrum, something traditional materials cannot address. TIS technology integrates advancements in metasurfaces, beamforming, and advanced manufacturing to achieve high-resolution channel and location sensing, which is crucial for the emerging 6G infrastructure. This represents a significant leap forward in intelligent reflecting surfaces and their operational efficiency at THz frequencies.	Nanjing University of Aeronautics and Astronautics, Ajou University, University of Surrey, Virginia Tech, SUNY Polytechnic Institute
zinc hybrid supercapacitor	a) Zinc-ion hybrid supercapacitors (ZHSs) are flexible and self-healing energy storage devices that combine the merits of batteries and supercapacitors. They offer high energy density, excellent rate capability, and superb cyclability. They are ideal for wearable electronics and potentially large-scale energy storage.	Chinese Academy Of Sciences, Xinjiang University, Anhui University, Anhui

	b) The novelty of ZHSs lies in their use of zinc, a resource-abundant and safe element, and their unique design that includes a redox iodide ion in the electrolyte for high energy density and a polyvinyl alcohol/nanocellulose hydrogel for mechanical stability and self-healing feature. This makes them safer, more environmentally friendly, and potentially more cost-effective than existing energy storage technologies.	University of Technology, City University of Hong Kong

Aerospace

Weak signal	What it is? Why is it new?	Main actors
6G in space	a) 6G in space technology involves leveraging advanced communication frameworks like Rate-Splitting Multiple Access (RSMA) to manage interference and enhance efficiency in space-air-ground integrated networks. It operates across various spectra, including the THz band, utilizing massive MIMO, AI, and reconfigurable intelligent surfaces to provide ubiquitous connectivity and support for IoT, with applications in healthcare, vehicular systems, UAVs, and more. b) The novelty of 6G in space resides in its integration of non-terrestrial networks with terrestrial systems, offering global coverage and high data rates. It surpasses previous generations by employing THz communications, advanced AI-driven algorithms, and federated learning for improved security, efficiency, and low-latency applications across diverse and challenging environments.	Southeast University, Purple Mountain Laboratories, University of New South Wales, Beijing University of Posts and Telecommunications, Princeton University
advanced air mobility	a) Advanced Air Mobility (AAM) leverages electric or hybrid-electric propulsion, distributed propulsion systems, and autonomy to enable flexible, on-demand aerial services. Potential applications include urban passenger transport, cargo delivery, emergency response, and integrated airspace management for efficient and safe operations across diverse vehicle types. b) The novelty of AAM lies in integrating novel propulsion technologies, machine learning for optimization, digital twins for mixed-reality testing, and 3D GIS for route planning. These advancements foster fuel flexibility, noise reduction, and automation, representing a significant evolution from traditional aviation methods.	University of California, NASA Langley Research Center, Institute of Flight Systems, Aberdeen Proving Ground, Cranfield University
edge computing for satelittes	a) Edge computing for satellites involves integrating computational resources into satellite systems to process data in orbit, reducing latency and bandwidth usage by offloading tasks from terrestrial networks. This technology supports applications in remote sensing, Internet of Things (IoT), and mobile communications, enabling efficient resource allocation, real-time analytics, and enhanced quality of service, even in remote regions. b) The novelty lies in the deployment of machine learning algorithms, such as federated learning and reinforcement learning, to optimize task offloading and resource allocation dynamically, directly within satellite networks. This approach contrasts with traditional ground-based processing, offering significant improvements in latency, energy consumption, and handling of large-scale, distributed satellite data.	Beijing University of Posts and Telecommunications, Chinese Academy Of Sciences, University of Sussex, Zhejiang University of Technology, Beijing Jiaotong University
edge computing for UAV	a) Edge computing for UAV involves integrating Unmanned Aerial Vehicles (UAVs) with Mobile Edge Computing (MEC) to bring computational resources closer to end-users and devices, enabling low-latency, energy-efficient data processing for mobile applications. This technology enhances wireless power transfer, supports large-scale user equipment, optimizes task execution in complex environments, and secures communications, particularly in areas with challenging geographies like maritime domains or during emergency medical situations. b) The novelty of edge computing for UAV lies in its ability to reduce reliance on distant cloud centers and satellites, thereby minimizing propagation delays and energy consumption. Innovations include the use of Intelligent Reflecting Surfaces (IRSs) for signal enhancement, task-driven multimodal communication for robust task execution, and reinforcement learning for secure and efficient computation offloading, representing significant advancements over traditional MEC systems.	University of Macau, Queen Mary University of London, Zhejiang University of Technology, Dalian University of Technology, Central South University
evtol aircraft	a) eVTOL aircraft technology enables vertical takeoff and landing for urban and regional air mobility, utilizing distributed electric propulsion for quieter, cleaner operation. These vehicles offer alternative transportation in congested urban areas, potentially easing traffic and reducing transit times. Applications range from air taxis and emergency services to cargo delivery and personal travel. b) The novelty of eVTOL aircraft lies in their electric propulsion systems, advanced aerodynamics, and integration of technologies like 3D printing for rapid prototyping. They represent a significant shift from traditional aviation, focusing on zero-emission urban transit. Hybrid power systems, incorporating fuel cells and batteries, and innovative health management algorithms for flight control systems underscore their cutting-edge status.	NASA Langley Research Center, Politecnico di Torino, University of Dayton, University of Maryland, Amrita School of Engineering
Space-Air-Ground Integrated	a) The Space-Air-Ground Integrated Network (SAGIN) is a comprehensive communication framework that unifies satellite, aerial, and terrestrial systems to enhance Internet of Vehicles (IoV) performance. Leveraging technologies like software-defined networking (SDN),	Beijing University of Posts and Telecommunications,

network	network function virtualization (NFV), and advanced modulation schemes, SAGIN supports high-mobility connectivity, robust interference management, and efficient resource allocation, enabling reliable, low-latency communication for diverse applications such as autonomous vehicles, IoT, and high-altitude platform relaying. b) The novelty of SAGIN lies in its integrated approach to managing a heterogeneous network environment, utilizing Rate-Splitting Multiple Access (RSMA) for interference management and resource optimization. It surpasses existing technologies by offering a universal framework that is adaptable to various service requirements, user deployments, and traffic conditions, and is resilient against channel uncertainty, positioning it as a critical enabler for 6G and beyond.	Chinese Academy Of Sciences, Sichuan Normal University, University of Applied Sciences, University of Tokyo
Spaceborne computing	a) Spaceborne computing refers to the deployment of edge computing capabilities on satellites within satellite-terrestrial integrated networks (STINs), enabling on-board processing of tasks, low-latency services, and efficient resource use. It supports hyperspectral image processing, machine learning, and real-time data analysis in orbit, optimizing communication with terrestrial networks and enhancing services for remote areas. b) The novelty of spaceborne computing lies in the integration of advanced machine learning techniques, such as federated learning and deep reinforcement learning, with satellite networks to manage resources dynamically, reduce energy consumption, and ensure quality-of-service. It introduces in-orbit processing for tasks like Earth observation while adapting to the energy constraints and changing conditions of Low-Earth-Orbit satellites.	Chinese Academy Of Sciences, Beijing University of Posts and Telecommunications, Southeast University, University of Sussex, Zhejiang University of Technology
sustainable aviation fuel	a) Sustainable aviation fuel (SAF) is a low-carbon alternative to conventional jet fuel, derived from renewable resources like biomass and waste oils. It is designed to be drop-in compatible, meaning it can be used without modifying existing aircraft engines or fuel distribution infrastructure. SAF production pathways include Hydroprocessed Esters and Fatty Acids (HEFA), Fischer-Tropsch synthesis, and Power-to-Liquid processes. These fuels aim to reduce greenhouse gas emissions and dependency on fossil fuels in the aviation sector. b) The novelty of SAF lies in its ability to integrate with current aviation systems while significantly reducing lifecycle carbon emissions. Innovations include the diversification of feedstocks, advancements in biorefinery retrofitting, and the integration of carbon capture and storage. New processes like Power-and-Biomass-to-Liquid (PBtL) and electrofuels offer improved carbon efficiency and are part of a broader strategy to decarbonize aviation, addressing the high energy density requirements and global scale of the industry.	Purdue University, University of California, Hamburg University of Technology, Technion-Israel Institute of Technology, Stanford University
truck drone	a) Truck drone technology integrates autonomous aerial vehicles with traditional truck delivery systems, enhancing efficiency in cargo transport. Drones launched from trucks can serve a wider area, perform multi-visit deliveries, and support pickup services, thereby reducing delivery times and energy consumption while optimizing routing. b) The novelty lies in the truck drone's advanced operational capabilities, such as flexible docking, en route drone dispatch, and multiple back-and-forth trips. The ability to dynamically allocate drones to trucks and consider payload and energy consumption in routing reflects significant innovation beyond traditional delivery methods.	Southwest Jiaotong University, Jilin University, Aston University, Zhejiang University of Finance and Economics, Purdue University
urban air mobility	a) Urban Air Mobility (UAM) refers to the use of advanced aerial vehicles, primarily electric or hybrid, for transportation in urban spaces. UAM leverages technologies like digital twins, edge computing, federated learning, and blockchain for real-time traffic management, vehicle maintenance, and secure, decentralized operations. It aims to offer efficient, on-demand air transportation services with vehicles ranging from single-passenger drones to larger, multi-passenger crafts, potentially transforming urban transit. b) The novelty of UAM lies in its unique integration of emerging technologies for real-time, secure, and autonomous operations at low altitudes in urban areas. Unlike traditional air traffic systems, UAM incorporates advanced computational models, AI, and networked infrastructure to manage a dense ecosystem of manned and unmanned aerial vehicles, with an emphasis on safety, efficiency, and reduced environmental impact.	NASA Ames Research Center, NASA Langley Research Center, Stanford University, Ajou University, Konkuk University
vertiport	a) A vertiport is a hub for vertical take-off and landing (VTOL) aircraft, facilitating Urban Air Mobility (UAM) by managing traffic, ensuring safe aircraft separation, and integrating autonomous flight operations within urban environments. It supports navigation, scheduling, and autonomous operation, promising efficient transport of people and goods in densely populated areas. b) The novelty of vertiport technology lies in its integration of advanced algorithms, such as AutoResolver for traffic management, and vision-aided navigation systems for autonomous landing. It leverages network-based augmentation for improved navigation integrity and employs deep learning for optimal scheduling, representing a significant evolution from traditional air traffic control systems.	Universities Space Research Association, NASA Ames Research Center, Stanford University, Ajou University, Collins Aerospace

Mobility and Transport

Weak signal	What it is? Why is it new?	Main actors
AI for smart charging	a) AI for smart charging utilizes artificial intelligence and machine learning algorithms to optimize electric vehicle (EV) charging patterns, reducing strain on the power grid and minimizing costs. By analyzing various data sources, such as driving habits, energy prices, and environmental factors, AI-powered smart charging systems can predict energy demand and adjust charging schedules accordingly. Potential applications include: * Smart charging of EVs to shave peak loads and reduce grid instability * Optimization of energy consumption and cost savings for EV users * Integration with renewable energy sources to increase sustainability * Improved energy management for EV fleets and public charging stations * Enhanced grid stability and reliability through predictive analytics b) The novelty lies in its ability to integrate machine learning algorithms with real-time data to optimize EV charging patterns. Unlike traditional charging methods, AI-powered smart charging systems can adapt to changing energy demand and user behavior, providing a more efficient and sustainable solution. Recent developments in the field have seen the introduction of deep learning techniques, blockchain technology, and IoT-based smart charging systems, which have improved the accuracy and efficiency of smart charging algorithms. Overall, AI for smart charging represents a significant advancement in the field of mobility and transportation, enabling a more sustainable and efficient energy future.	Economic Research, Stanford University, DONGHUA UNIVERSITY, Monash University, Université Paris-Saclay
15 minutes city	a) The 15-Minute City is a mobility and transport concept that aims to create an urban environment where residents can meet their essential needs within a short walking or cycling distance from their homes. This approach prioritizes people's time, energy, and health by reducing daily commutes and promoting active modes of travel. The concept has been gaining attention globally as a sustainable urban planning strategy, with potential applications in reducing emissions, improving public health, and enhancing social cohesion. The 15-Minute City model can be used to evaluate the performance of cities and neighborhoods, identify areas for improvement, and inform urban planning decisions. Recent developments include the creation of indices and metrics to measure the effectiveness of the 15-Minute City concept, such as the 15-Minute Walking City (15-MWC) index. Additionally, GIS-based models have been developed to assess pedestrian accessibility to neighborhood facilities and evaluate the impact of railway stations on the surrounding territory. b) The novelty of the 15-Minute City concept lies in its focus on accessibility and proximity as key drivers of sustainable urban development. While the idea of compact and walkable cities is not new, the 15-Minute City approach offers a refreshing chrono-centric vision that prioritizes people's time and energy. The concept also builds on recent trends in urban policies that emphasize active mobility and the proximity dimension. The development of new metrics and indices, such as the 15-MWC index, and GIS-based models represent a significant advancement in the field, providing policymakers and urban planners with new tools to evaluate and improve the sustainability of urban environments.	Politecnico di Milano, Systematica, National Technical University of Athens, Goudappel BV, Università Roma Tre
6G V2X	a) High-level explanation of the technology and its potential applications**: 6G V2X (Vehicle-to-Everything) is a next-generation wireless communication technology that enables seamless and intelligent connectivity between vehicles, infrastructure, and other entities in the transportation ecosystem. This technology has the potential to revolutionize intelligent transportation systems by providing ultra-low latency, high-data rate, and high reliability. Potential applications of 6G V2X include autonomous vehicles, smart cities, intelligent traffic management, vehicle tracking and localization, and enhanced road safety. Recent developments in 6G V2X have focused on improving resource allocation, reducing latency, and increasing network throughput. Techniques such as Federated Learning, edge computing, and reconfigurable intelligent surfaces have been explored to optimize 6G V2X performance. b) The novelty of 6G V2X lies in its ability to provide ultra-low latency, high-data rate, and high reliability, which are critical for mission-critical applications such as autonomous vehicles and smart cities. Compared to established technologies, 6G V2X offers significant improvements in terms of network throughput, latency, and reliability. The use of advanced techniques such as Federated Learning, edge computing, and reconfigurable intelligent surfaces enables 6G V2X to provide a more efficient and adaptive communication network. Overall, 6G V2X represents a significant advancement in wireless communication technology, enabling a wide range of innovative applications in the transportation sector.	University of Victoria, Anna University, School of Computer Science and Engineering, University of Johannesburg, University of Surrey
charging strategy for electric buses	a) A charging strategy for electric buses is a technological approach that optimizes the energy consumption and recharging processes of electric buses in public transportation systems. This strategy works by predicting energy consumption patterns, scheduling charging sessions, and allocating charging resources to minimize costs, reduce greenhouse gas emissions, and ensure reliable transit services. The technology integrates various aspects, including energy forecasting models, optimization algorithms, and real-time monitoring systems, to create an efficient and adaptive charging schedule for electric bus fleets. Potential applications of this technology include urban public transportation systems, regional bus networks, and electric bus fleets operated by private companies or government agencies.	Hong Kong Polytechnic University, Beijing Jiaotong University, Tsinghua University, Tongji University, Beijing University of Technology

	b) The novelty of the charging strategy for electric buses lies in its ability to address the limitations of existing electric bus systems, such as limited driving range and long recharging times. Recent developments in this technology have focused on optimizing charging schedules, incorporating real-time data and uncertainty, and integrating multiple charging modes, such as plug-in fast charging and battery-swapping charging. These advancements have improved the efficiency, reliability, and scalability of electric bus systems, making them a more viable alternative to traditional diesel-powered buses. The technology's novelty also stems from its potential to reduce energy consumption, lower operating costs, and promote the widespread adoption of electric buses in public transportation systems.	
	Lidar Odometry a) Lidar odometry is a technology that enables the estimation of a vehicle's or robot's motion and position by analyzing the data from a lidar sensor. It works by combining visual odometry with lidar odometry to improve robustness to aggressive motion and temporary lack of visual features. The technology involves two stages: visual odometry to estimate ego-motion and register point clouds, followed by scan matching-based lidar odometry to refine motion estimation and point cloud registration. Recent developments have focused on improving the accuracy and efficiency of lidar odometry, including the use of neural networks, multi-modal sensor fusion, and non-iterative distortion compensation methods. Potential applications of lidar odometry include autonomous driving, unmanned aerial vehicles, and Simultaneous Localization and Mapping (SLAM) for robotic applications. It can also be used in challenging environments, such as subterranean mines and tunnels, and has shown promise in large-scale environments with incremental lidar data. b) The novelty lies in its ability to provide a robust and accurate estimation of motion and position in a wide range of environments and conditions. Compared to established technologies, lidar odometry offers improved performance in terms of accuracy, efficiency, and robustness to motion and sensor noise. Recent advancements have made lidar odometry more computationally efficient, allowing for real-time processing and application in various fields. The use of machine learning and neural networks has also improved the technology's ability to handle complex environments and sensor data. Overall, lidar odometry represents a significant improvement over traditional odometry methods, offering a more reliable and accurate solution for autonomous systems and robotic applications.	Chinese Academy Of Sciences, Carnegie Mellon University, National University of Defense Technology, Massachusetts Institute of Technology, Stevens Institute of Technology
marine fuel - ammonia	a) Marine fuel ammonia is a promising alternative fuel for the shipping industry, offering a potential solution for reducing greenhouse gas emissions and meeting global climate targets. Ammonia can be produced from renewable energy sources, making it a carbon-neutral fuel option. Its physicochemical properties make it suitable for use in domestic and short-sea shipping, with potential applications in heavy fuel diesel engines and solid oxide fuel cells. Ammonia has been identified as one of the most balanced carbon-free fuels, with a high gravimetric energy density, making it a viable option for powering Europe's shipping fleet. The use of ammonia as a marine fuel can lead to significant reductions in NOx and greenhouse gas emissions, with some studies suggesting a reduction of up to 93.4% and 92% respectively. Additionally, ammonia can be easily stored and transported, making it a more practical option than other alternative fuels like hydrogen. b) The use of ammonia as a marine fuel represents a significant departure from traditional fossil fuels, offering a carbon-neutral alternative that can be produced from renewable energy sources. The novelty of this technology lies in its potential to decarbonize the shipping industry, which is a significant contributor to global greenhouse gas emissions. The development of ammonia as a marine fuel also presents opportunities for the creation of green shipping corridors, where low- and zero-carbon maritime transportation solutions can be provided. Furthermore, the use of ammonia as a marine fuel can be adapted to existing marine engines and infrastructure, making it a more practical and feasible solution than other alternative fuels. Overall, the use of ammonia as a marine fuel represents a significant innovation in the field of sustainable shipping.	Beni-Suef University, Queen's University Belfast, Finnish Meteorological Institute, Aston University, NATIONAL MARITIME RESEARCH INSTITUTE
monocular 3d object detection	a) Monocular 3D object detection is a technology that enables the detection of 3D objects from a single 2D image, without the need for additional sensors or information. This technology has significant potential applications in the field of mobility and transport, particularly in autonomous driving, where it can be used to detect and track objects in real-time, improving safety and navigation. The technology works by leveraging advances in computer vision and machine learning to infer depth information from 2D images, allowing for the estimation of 3D bounding boxes and object poses. Recent developments in this field have focused on improving the accuracy and efficiency of monocular 3D object detection, including the use of novel network architectures, depth estimation techniques, and fusion methods that combine visual and non-visual data. b) The novelty lies in its ability to overcome the limitations of traditional 2D object detection methods, which are unable to provide depth information. Recent advances in this field have introduced new techniques, such as end-to-end depth-aware transformer networks, multivariate probabilistic modeling, and sparse vision transformers, which have significantly improved the accuracy and efficiency of monocular 3D object detection. These developments have also enabled the creation of more robust and generalizable models that can operate in a variety of environments and conditions, making monocular 3D object detection a promising	University of Toronto, Tsinghua University, National Taiwan University, Wuhan University, Imperial College London

	technology for real-world applications.	
multi modal fusion for autonomous car	a) **High-level Explanation and Potential Applications**: Multi modal fusion for autonomous cars is a technology that integrates data from various sensors, such as cameras, LiDAR, radar, and thermal imaging, to enhance the perception and understanding of the environment. This fusion enables autonomous vehicles to better detect and respond to objects, lanes, and other critical elements, even in adverse weather conditions or complex scenarios. The technology has the potential to improve the accuracy, completeness, and robustness of environmental perception, leading to safer and more efficient autonomous driving. Applications include 3D object detection, semantic segmentation, and end-to-end driving tasks, with potential benefits for various industries, such as transportation, logistics, and smart cities. b) The novelty of multi modal fusion for autonomous cars lies in its ability to effectively integrate and leverage the strengths of different sensor modalities, overcoming the limitations of individual sensors. Recent developments have introduced new architectures, such as hierarchical multimodal fusion, multi-interactive feature learning, and attention-based semantic fusion, which have shown significant improvements in performance. Additionally, the exploration of new sensor modalities, such as 4D imaging radar, and the development of novel view transformation strategies, such as 'sampling', have further enhanced the capabilities of multi modal fusion. These advancements have pushed the state-of-the-art in autonomous driving, enabling more accurate and robust perception, and paving the way for the widespread adoption of autonomous vehicles.	Beihang University, Shanghai University, Technical University of Munich, Peng Cheng Laboratory, University Avenue
oriented object detection	a) Oriented object detection is a technology application in the field of mobility and transport that enables the detection of objects in images or videos, regardless of their orientation. This technology works by using deep learning algorithms to learn features from images and classify objects based on their shape, size, and orientation. Recent developments in oriented object detection have focused on improving the accuracy and efficiency of detection methods, including the use of novel bounding box representations, dynamic anchor learning, and shape-adaptive selection strategies. Potential applications of oriented object detection include autonomous vehicles, aerial surveillance, and traffic monitoring, where the ability to detect and classify objects in real-time is critical for safety and efficiency. b) The novelty of oriented object detection lies in its ability to detect objects in images or videos, regardless of their orientation, which is a significant improvement over traditional object detection methods that rely on horizontal bounding boxes. Recent developments in oriented object detection have introduced new techniques such as polar coordinate system-based bounding box representations, dynamic anchor learning, and shape-adaptive selection strategies, which have improved the accuracy and efficiency of detection methods. These advancements have the potential to revolutionize applications such as autonomous vehicles, aerial surveillance, and traffic monitoring, where the ability to detect and classify objects in real-time is critical for safety and efficiency.	Chinese Academy Of Sciences, NORTHWESTERN POLYTECHNICAL UNIVERSITY, Shanghai Jiao Tong University, Wuhan University, School of Automation
pedestrian trajectory prediction	a) Pedestrian trajectory prediction is a technology that forecasts the future movement of pedestrians in various environments, taking into account their individual behaviors, social interactions, and spatial dependencies. This technology has numerous applications in mobility and transport, including autonomous driving, robotics, surveillance systems, and unmanned vehicles. By accurately predicting pedestrian trajectories, these systems can ensure safety, efficiency, and smooth navigation in complex scenarios. Recent developments in this field have focused on addressing the challenges of modeling multi-modal future motion states, capturing complex spatio-temporal correlations, and improving the interpretability of predictions. b)The novelty lies in its ability to model the indeterminacy of human motion and capture the complexities of social interactions and spatial dependencies. Unlike traditional methods that rely on stochastic processes or hand-crafted rules, recent approaches employ advanced techniques such as Markov chains, Transformers, Generative Adversarial Networks (GANs), and Graph Neural Networks (GNNs) to learn and predict pedestrian trajectories. These innovations enable more accurate and diverse predictions, better handling of multi-modal scenarios, and improved interpretability of results. Furthermore, the development of domain-adaptive models and attention-based mechanisms has expanded the applicability of pedestrian trajectory prediction to various environments and scenarios.	XI'AN JIAOTONG UNIVERSITY, Wormpex AI Research, SenseTime Research, Northeastern University, JD Finance America Corporation
urban micromobility	a) Urban micromobility refers to the use of small, lightweight vehicles, such as electric scooters, dockless bikes, and other micro-mobility devices, for short-distance transportation in urban areas. This technology works by providing users with access to a fleet of vehicles through smartphone applications, allowing for per-minute rental fees and flexible parking options within designated service areas. The potential applications of urban micromobility include: (i) first- and last-mile connections to public transportation; (ii) non-commute related travel; (iii) commuting to and from university; (iv) enhancing the connectivity of urban public transport systems; (v) promoting sustainable urban mobility plans; and (vi) supporting the development of 15-minute cities, where daily needs are accessible within a 15-minute walk or bike ride. b) The novelty of urban micromobility lies in its ability to provide a flexible, efficient, and sustainable transportation solution for short-distance trips, filling the gap between traditional	Systematica, Politecnico di Torino, Southeast University, Institute of Transport Economics, Beijing Jiaotong University

	public transportation and walking or cycling. Recent developments in urban micromobility have led to the emergence of new business models, such as shared dockless bikes and e-scooters, which have disrupted traditional transportation systems and created new opportunities for urban planning and policy-making. The integration of urban micromobility with public transportation, as well as the development of new regulatory frameworks and infrastructure designs, are also novel aspects of this technology.	
vehicle integrated photovoltaic	a) Vehicle Integrated Photovoltaic (VIPV) technology involves the integration of photovoltaic systems into vehicles to generate electricity and power the vehicle's propulsion system. This technology has the potential to extend the range of electric vehicles, reduce greenhouse gas emissions, and mitigate the impact of ambient conditions on electric range. VIPV can be applied to various types of vehicles, including passenger cars, buses, and delivery vans. The energy generated by VIPV can be used to power the vehicle's electric motor, reducing the need for external charging and decreasing energy consumption. Additionally, VIPV can be used to power auxiliary systems, such as air conditioning and heating, further improving the overall efficiency of the vehicle. The technology has been shown to be effective in various climates and usage scenarios, with the potential to cover up to 35% of a vehicle's annual driving range. b) The novelty lies in its ability to harness solar energy and convert it into electricity, which can be used to power a vehicle's propulsion system. Compared to traditional photovoltaic systems, VIPV is designed to be integrated into the vehicle's body, providing a unique solution for extending the range of electric vehicles. Recent developments in VIPV technology have focused on improving the efficiency of solar cells, reducing costs, and optimizing energy management systems. The use of high-efficiency solar cell modules, such as III-V compound triple-junction solar cells, has been shown to increase the energy generation capacity of VIPV systems. Additionally, advances in energy management systems and power electronics have improved the overall efficiency and performance of VIPV technology.	Toyota Technological Institute, University of Miyazaki, Sharp Corp, Toyota Motor Corp, NISSAN MOTOR CO LTD
Lidar Slam	a) The combination of LIDAR (Light Detection and Ranging), used for generating environmental point cloud data for robots, with Simultaneous Localization and Mapping (SLAM) algorithms, enables robots to sense their environment, making it essential for mobile robotics, navigation, and environmental mapping in areas where GPS is unavailable or unreliable. b) The novelty of this technology lies in its integration with Inertial Navigation Systems (INS) and SLAM technologies to overcome their respective drawbacks, delivering centimeter-level positioning accuracy even in featureless environments. The use of LIDAR in SLAM-aided 2D and 3D mapping systems for deep space exploration research also signifies a new direction for this technology.	Chinese Academy Of Sciences, Wuhan University, Nanyang Technological University, School of Mechanical Engineering, Shanghai Jiao Tong University
3d multi object tracking	a) High-Level Explanation and Potential Applications: 3D multi-object tracking (MOT) is a crucial technology in the field of mobility and transport, enabling autonomous systems to accurately detect, traLidar Slam "[a) The ${emm_dname} technology, Laser Range Finder (LRF) or Laser Distance Sensor (LDS), also known as LIDAR (Light Detection and Ranging), is used for generating environmental point cloud data for robots. This technology, combined with Simultaneous Localization and Mapping (SLAM) algorithms, enables robots to sense their environment, making it essential for mobile robotics, navigation, and environmental mapping in areas where GPS is unavailable or unreliable. b) The novelty of this technology lies in its integration with Inertial Navigation Systems (INS) and SLAM technologies to overcome their respective drawbacks, delivering centimeter-level positioning accuracy even in featureless environments. The use of LIDAR in SLAM-aided 2D and 3D mapping systems for deep space exploration research also signifies a new direction for this technology.]" [Chinese Academy Of Sciences, Wuhan University, Nanyang Technological University, School of Mechanical Engineering, Shanghai Jiao Tong University]ck, and predict the movements of multiple objects in 3D space and time. This technology has numerous potential applications, including autonomous driving, assistive robotics, and mobile robots in various environments, such as agro-food and dynamic road environments. 3D MOT can be used to improve motion planning and navigation, scene interpretation, and decision-making in these applications. Recent developments in 3D MOT focus on real-time systems, geometric relationships, and deep learning-based approaches, which have shown promising results in achieving state-of-the-art performance on various benchmarks, including KITTI and nuScenes. b) The novelty of 3D MOT technology lies in its ability to accurately and efficiently track multiple objects in 3D space and time, overcoming the limitations of traditional 2D tracking methods. Recent advancements in 3D MOT, such as the use of graph neural networks, joint feature extractors, and end-to-end multi-camera frameworks, have introduced new techniques for data association, feature learning, and motion modeling. These innovations have significantly improved the performance and robustness of 3D MOT systems, making them more suitable for real-world applications. Furthermore, the development of new evaluation tools and metrics has facilitated a more comprehensive assessment of 3D MOT methods, enabling researchers to identify areas for further improvement.	Carnegie Mellon University, Technical University of Munich, Northeastern University, Zenuity, University of Illinois at Urbana-Champaign

Digital Twins

Weak signal	What it is? Why is it new?	Main actors
city digital twin	a) A city digital twin is a virtual representation of urban areas, utilizing Internet of Things (IoT), artificial intelligence, machine learning, and big data to simulate, monitor, and analyze urban environments. It facilitates efficient planning, resource management, and decision-making in areas such as infrastructure, healthcare, retail, and disaster management. b) The novelty of city digital twin technology lies in its integration of diverse data streams and advanced technologies, creating a realistic, real-time digital mirror of a city. It surpasses traditional urban modeling by providing dynamic, predictive insights into urban operations and future scenarios, enabling more sustainable and smart urban governance.	Beijing Bicotest Technology Co.,Ltd., Dimitrie Cantemir Christian University, University of Zilina, Bucharest University of Economic Studies, China Academy of Space Technology
Dig twin for connected vehicle simulation	a) A Digital Twin for Connected Vehicle Simulation is a technology that creates a data-driven artificial intelligence (AI) cloud-based replica of physical entities in the mobility sphere — humans, vehicles, and traffic. It aids in user management, driver type classification, traffic flow monitoring, variable speed limit, and advanced driver-assistance systems. The technology also allows for real-time monitoring, synchronization, and performance enhancement of autonomous vehicles. b) Compared to traditional methods, this technology provides a novel framework for a cooperative merging of vehicle-to-cloud (V2C) communication, enabling real-world activities to be mirrored in virtual space. This new approach significantly reduces the cost and increases the efficiency of testing autonomous driving algorithms and optimizing delivery systems, creating the potential for significant improvements in smart mobility platforms.	Tennessee Tech University, Free University of Bozen-Bolzano, Joint Research Centre, Universidad de Alcalá, University of California
digital twin for buildings	a) A digital twin for buildings is a dynamic digital model that replicates physical buildings using artificial intelligence, machine learning, and data analytics. It integrates data from multiple sources such as building information models, IoT-based sensors, and asset management systems to predict future conditions and performance. Applications range from operation and maintenance optimization, asset tracking, equipment failure prediction to energy efficiency monitoring and occupancy prediction. b) The novelty of this technology lies in its integration of artificial intelligence, machine learning, and data analytics to create a living, learning digital model of a physical building. This is a departure from traditional building modeling approaches, enabling real-time updates and predictive capabilities. Furthermore, the application of computer vision technology using building camera feeds and the simultaneous calibration of physical and virtual sensors in the digital twin model are significant advancements.	University of Cambridge, Bos Winner Company,Ltd., Universidad de Castilla-La Mancha, Southeast University, University of Helsinki
Digital twin for real estate	a) Digital twin for real estate is a technology that employs digital models to replicate physical properties, leveraging Building Information Modelling (BIM) and Internet of Things (IoT). It facilitates efficient property management, monitoring of as-is conditions, anomaly detection, and adaptability in the face of operational uncertainties. This technology is being adopted in various sectors including real estate management, healthcare, and construction. b) The novelty of the digital twin for real estate lies in its ability to extend beyond traditional 3D modeling to a more comprehensive and interactive digital representation of physical properties. It enables the integration of real and virtual realities, thereby enhancing the value of property-related information and processes. The technology also harnesses data-driven insights, AI, and developments like non-fungible tokens (NFTs), offering new ways to navigate and manage real estate assets.	Politecnico di Milano, Carnegie Mellon University, Kazan State University of Architecture and Engineering, KTH Royal Institute of Technology, Beijing University of Posts and Telecommunications
digital twin in agriculture	a) Digital twin in agriculture is a technology that creates virtual equivalents of real-life farming objects, mirroring their behavior and states in a virtual environment. It allows farmers to manage operations remotely, simulate the effects of interventions, and act immediately in case of deviations, based on near-real-time digital information. b) The novelty of this technology lies in its ability to decouple physical flows from their planning and control. Unlike traditional farming methods that rely on direct observation and manual tasks, digital twin in agriculture uses Internet of Things, artificial intelligence, and big data to enable predictive analyses and decision-making support, providing new levels of control, productivity, and sustainability.	Wageningen University and Research, Free University of Bozen-Bolzano, Software Engineering Group, Ferme d'Hiver Technologies, STIFTELSEN SINTEF
digital twin in healthcare	a) The digital twin in healthcare is a technology that replicates a physical system into a virtual model, integrating real-time data and advanced simulation techniques to monitor, analyze, and optimize the system's performance. Potential applications include predictive health management, personalized patient care, and the creation of safer, more reliable healthcare systems. b) As a novelty, digital twin technology goes beyond conventional methods by offering a high-fidelity, dynamic representation of physical systems. It leverages artificial intelligence, machine learning, and data analytics to provide unprecedented levels of safety, reliability, and efficiency in healthcare, which traditional approaches cannot achieve.	NASA Langley Research Center, Ho Chi Minh City University of Technical Education, University of New South Wales, University of Liverpool, National University of Singapore
digital twin in transportation	a) Digital twin technology in transportation involves creating digital replicas of physical entities like vehicles, drivers, and traffic systems. Leveraging data from IoT devices, these	Qingdao University, Wuhan University of

	digital twins can simulate real-world transportation scenarios, optimize traffic operation, and predict potential problems. Applications range from road and maritime transportation to intelligent transportation systems, electromobility, and autonomous vehicles. b) The novelty of digital twin technology in transportation lies in its capacity to provide real-time data integration and continuous synchronization with the physical world. Unlike traditional static simulations, digital twins offer dynamic, continuously calibrated, and highly accurate models, enabling real-time predictive analytics for safety-critical decisions in traffic management. This technology introduces a new level of sophistication in traffic modeling and simulation.	Technology, North China Sea Offshore Engineering Survey Institute, Macau University of Science and Technology, NORTHWESTERN POLYTECHNICAL UNIVERSITY
digital twin of quantum systems	a) The technology of digital twins of quantum systems aims to enhance communication security and improve operations efficiency in domains such as the Industrial Internet of Things (IIoT) and healthcare. This involves the incorporation of quantum communication technologies into digital twin systems, enabling secure data transmission and efficient resource management through mechanisms like quantum key distribution and quantum federated learning. b) The novelty of this technology lies in its fusion of quantum communication and digital twin technologies, transcending the limitations of classical systems. This integration offers a revolutionary approach to secure and efficient data management, promising immediate transaction confirmations and resilience against quantum attacks, which are significant advancements over traditional methods.	The Second Monitoring and Application Center, Queen Mary University of London, NEOMA Business School, Uppsala University, EDHEC Business School

AI and Machine Learning

Weak signal	What it is? Why is it new?	Main actors
artificial intelligence of Things	a) The Artificial Intelligence of Things (AIoT) is a merger of Artificial Intelligence (AI) and the Internet of Things (IoT) technologies. It's used in various domains like healthcare, traffic management, and agricultural engineering to analyze data, improve efficiency, and solve complex issues. In education, it can be integrated into virtual reality courses to enhance learning experiences. b) Compared to traditional technologies, AIoT provides a novel approach in managing and analyzing large amounts of data. By applying AI to IoT, it revolutionizes the way data is processed, providing real-time, intelligent responses. It offers a unified interface layer for various applications, making it a flexible and adaptable solution for diverse fields.	National University of Singapore, National Cheng Kung University, Chinese Academy Of Sciences, Nanyang Technological University, Chitkara University
asynchronous federated learning	a) Asynchronous Federated Learning is a technological application that enhances communication efficiency in cloud-edge-terminal collaboration in Artificial Intelligence of Things (AIoT). It allows for distributed model training without centralizing data, addressing privacy and security concerns. This technology can also tackle issues of differing computational loads, data volume variations, and availability in edge devices, thereby improving the convergence rate and capacity to deal with dynamic systems. b) Compared to established synchronous technologies, Asynchronous Federated Learning introduces novelty by allowing continuous online learning and asynchronous model updates. It addresses the heterogeneity of devices and data, and the varying system configurations and computational times of edge devices. It also incorporates adaptive weight allocation and momentum strategies to improve training efficiency and model convergence. This technology offers a significant improvement in handling dynamic and diverse systems, making it a promising solution for scenarios where synchronicity and data centralization are challenged.	University of Science and Technology of China, Central South University, JIANGSU ACADEMY OF AGRICULTURAL SCIENCES, Nanjing Agricultural University, George Mason University
attention mechanisms in CNN	a) Attention mechanisms in convolutional neural networks (CNN) enhance model performance by focusing on key features in data, much like human visual attention. This allows for more accurate predictions and feature extraction in applications such as urban metro operation management, agricultural product quality inspection, crowd counting, disease identification, code smell detection, and remaining useful life estimation. b) The novelty lies in the combination of global context capturing and local dependencies modeling, imitating human cognitive processes for superior data interpretation. This offers advancements over traditional CNNs, improving the generalization ability, accuracy, and interpretability of models. The attention mechanism, particularly when combined with other network structures like the Transformer and Swin Transformer, delivers higher performance in diverse applications.	National University of Defense Technology, Jilin University, Central South University, Southeast University, Northwest Normal University
decentralized federated learning	a) Decentralized federated learning is a technology that enables distributed data across multiple agents to collaboratively learn a shared model without compromising data privacy. The technology addresses data heterogeneity and system heterogeneity challenges, improving the efficiency and accuracy of machine learning over distributed data. Potential applications span various fields such as fault diagnosis, recommendation systems, traffic management strategies, and cyberattack detection. b) The novelty lies in its ability to learn from highly heterogeneous data distributions without	Nanyang Technological University, XI'AN JIAOTONG UNIVERSITY, Science and Technology Corporation, Southeast University,

	the need for data centralization, addressing privacy concerns and reducing the cost of large-volume data transmission and analysis. This technology also integrates adaptive control of local updating frequency and network topology, enhancing the model's performance in heterogeneous scenarios. Furthermore, it provides robustness against adversarial attacks and ensures data freshness in applications like industrial metaverses.	University of Social Sciences
Epistemic AI	a) Epistemic AI, in the field of digital twins, involves the application of artificial intelligence to model and manage uncertainty in data. This technology enables the prediction of outcomes in areas from risk and reliability assessments to autonomous driving, by leveraging epistemic uncertainty. It also provides explainable AI models for credit risk assessments and supports AI-driven scientific discovery. b) The novelty of Epistemic AI lies in its ability to quantify the uncertainty of AI outputs, thus enabling more accurate and trustworthy predictions. Unlike traditional AI models, Epistemic AI can provide calibration properties that hold irrespective of the data distribution, and it offers a way to handle epistemic uncertainty arising from insufficient training data.	University of Liverpool, University of Michigan, Technion, University of Geneva, University of Pennsylvania
explainable AI	a) Explainable AI (XAI) in digital twins works to increase transparency and trust in AI-based systems by providing clear explanations for machine learning algorithms' decisions and predictions. Potential applications include enhancing human-AI interaction, assessing the quality of learned clusters, improving the interpretability of tree-based machine learning models, and supporting decision-making processes in industries such as healthcare, manufacturing, and cybersecurity. b) The novelty of XAI lies in its ability to offer insights into the black-box nature of AI systems, a capability absent in traditional AI technologies. It introduces a new level of user interaction, enabling a better understanding of AI outputs, and facilitating improved collaboration, skill enhancement, and system feedback. This technology goes beyond explaining AI's outputs to calibrating trust and adjusting user behavior.	University of Washington, Sorbonne Universitè, Parc d'activité de Pissaloup, Aignostics, National Heart Centre Singapore
federated deep learning	a) Federated deep learning is a technology that allows multiple devices or systems to collaboratively learn from a shared model, while keeping their data local, thereby maintaining data privacy. It has potential applications in industrial cyber-physical systems, IoT devices, and intelligent transportation systems where it can aid in intrusion detection, zero-day botnet attack detection, and trust evaluation. b) The novelty of federated deep learning lies in its ability to leverage deep learning techniques across a distributed network while preserving data privacy. Unlike traditional centralized deep learning methods, it enables the training of models on local datasets and sharing of learning outcomes, ensuring high efficiency and security.	TU Darmstadt, Cyraatek Ltd., Torrens University, University of Geneva, Fujian Normal University
federated machine learning	a) Federated machine learning is a decentralized artificial intelligence approach where devices collaboratively train a shared model without sharing raw data. It addresses privacy concerns, particularly in sensitive sectors like healthcare, by allowing data to stay on local devices while still enabling the development of robust predictive models. This technology can be applied to medical imaging fields, recommender systems, and wireless edge computing, among others. b) The novelty lies in combination of machine learning, cryptography, and economic principles to ensure data privacy and security. Unlike traditional machine learning methods, it allows multiple data owners to collaboratively train a shared prediction model while keeping local training data private. This addresses the growing demand for responsible AI development and application, in adherence with stringent data privacy laws such as the GDPR.	Imperial College London, Princeton University, Hong Kong University of Science and Technology, Sejong University, University of Guelph
federated reinforcement learning	a) Federated reinforcement learning (FRL) is a technology that allows multiple agents to collaboratively learn a global model without sharing individual data and policies, thereby preserving privacy and reducing communication costs. This approach has potential applications in diverse areas such as energy management in smart homes, network slicing in open radio access networks, adaptive beam management in ultra-dense networks, and energy and carbon allowance trading in multi-energy systems. b) The novelty of FRL lies in its combination of distributed machine learning, cryptography, and incentive mechanism design. Compared to traditional machine learning, FRL addresses the challenges of data privacy and heterogeneity, offering a new foundation for responsible AI development and application. This technology also provides a linear convergence speedup, improved training speed, and convergence stability, which are new compared to established technologies.	Hong Kong University of Science and Technology, Science and Technology Corporation, Carnegie Mellon University, Peking University, Nanyang Technological University
human centric AI	a) Human-centric AI (HAI) is a technology that integrates artificial intelligence with human intelligence to design systems that prioritize human well-being and learning. Applications of HAI span across medicine, education, manufacturing, and edge computing, enabling intelligent healthcare systems, automated essay assessments, smart manufacturing, and human-centric embedded machine learning applications. b) The novelty of HAI lies in its human-centric approach, which is a departure from traditional AI systems. This approach focuses on empathy, safety, transparency, and trust, embodying the shift towards responsible and ethical AI. It also incorporates stakeholder input and user demographics for more inclusive and fair applications, which are not commonly addressed in established AI technologies.	Nanyang Technological University, University College London, SONY Corp, Dong-A University, Hamad Bin Khalifa University

large language models	a) Large language models (LLMs) are advanced AI models that generate human-like text based on input data. They can be fine-tuned with human feedback for better alignment with user intent, making them applicable in fields like digital twins for task planning, predicting protein structures, generating photorealistic images from text, improving reasoning abilities, answering medical and educational questions, and even writing code for robots based on natural language commands. b) The novelty of LLMs lies in their incredible versatility and adaptability when fine-tuned with human feedback. Unlike traditional models, they can understand and generate high-fidelity, context-specific responses across a broad range of tasks. This ability to generalize knowledge and apply it to diverse scenarios represents a significant advancement over established technologies.	Brain Team, Stanford University, Jordan University Hospital, University of Jordan, University of Tokyo
machine unlearning	a) Machine unlearning is a technology that enables the erasure of specific data from a trained machine learning model. This technology is increasingly applied in federated learning systems or digital twins, where user data privacy is paramount. It operates by reversing or recalibrating the historical parameter updates to remove a user's contribution without requiring complete retraining of the model. b) The novelty of machine unlearning lies in its ability to selectively erase certain data from a trained model, preserving the integrity of the remaining data. This contrasts with traditional methods that require complete model retraining. The technology also offers potential resistance against malicious attacks and compliance with data protection regulations, such as the "right to be forgotten."	University of Toronto, University of Wisconsin-Madison, National University of Singapore, NORDAKADEMIE GAG Hochschule der Wirtschaft, Monash University
masked face recognition	a) Masked face recognition technology uses advanced algorithms, including Principal Component Analysis (PCA) and deep learning techniques, to identify individuals even when their faces are partially obscured by masks. Applications include security systems, surveillance equipment, emotion detection and attendance marking in education during pandemic conditions. b) This technology represents a significant advancement over traditional facial recognition systems that struggle with occlusions. The novelty lies in the ability to identify individuals despite mask-wearing, using features from the unobscured portion of the face, and achieving high accuracy rates. This is a crucial development in the context of widespread mask usage due to COVID-19.	Rajshahi University of Engineering and Technology, Fraunhofer Institute for Computer Graphics Research IGD, TU Darmstadt, National University of Singapore, Badji Mokhtar-Annaba University
masked language model	a) Masked language models (MLMs) are a type of artificial intelligence technology that uses pre-training tasks such as masked language modeling, reconstruction, and prediction to learn and generate high-quality, coherent outputs. MLMs can be applied to a wide range of fields, including audio synthesis, visual-and-language reasoning, image-text embedding, relation extraction, cybersecurity, and document AI. b) The novelty of MLMs lies in their ability to efficiently learn from large amounts of data and generate high-quality outputs in multiple domains. Compared to traditional methods, MLMs can leverage the discrete codes and activations of pre-trained models to achieve higher reconstruction quality, long-term consistency, and fine-grained alignment between different modalities. Moreover, they are capable of handling low-resource languages and cyber threat intelligence, outperforming existing methods in these areas.	GOOGLE INC, Microsoft Corp, Carnegie Mellon University, Stanford University, CIFAR
Multimodal AI	a) Multimodal AI integrates and analyzes data from diverse sources, such as molecular diagnostics, radiological and histological imaging, and clinical data in healthcare, as well as visual and textual data for tasks like bridge inspections. It is also used in creative fields like AI art and news illustration, enhancing operational efficiency in organizations, and in personalized medicine, digital clinical trials, remote monitoring, pandemic surveillance, and digital twin technology. b) Multimodal AI's novelty lies in its ability to synthesize and learn from multiple data types, improving the accuracy and efficiency of tasks. It has demonstrated superior performance in areas like detecting glaucomatous optic neuropathy and visual question answering. It also enables innovations like text-to-image generations, multimodal transformer models for multimodal AI tasks, and efficient knowledge sharing and diagnosis in medical fields.	Columbia University, Chinese Academy Of Sciences, Center for Advanced Intelligence Projects, National University of Singapore, Computer Sci.&Engg
privacy-preserving machine learning	a) Privacy-preserving machine learning employs techniques such as Federated Learning and Two-Party Computation to train predictive models without compromising data privacy. It allows data curators to contribute to a global model, whilst keeping local data private, enabling applications in fields such as agriculture and disease diagnosis. b) The novelty of this technology lies in its ability to combine distributed machine learning, cryptography, security, and incentive mechanism design, providing a more robust solution than traditional machine learning approaches. It offers stronger privacy guarantees and more efficient communication protocols, making it a promising foundation for responsible AI development.	University of Tennessee, Chitkara University, University of Virginia, University of Rochester, University of Maryland
scientific machine learning	a) Scientific machine learning integrates advanced neural network models with physical laws to solve complex problems, incorporating uncertainties and errors in data. This technology is used in the development of digital twins, enabling sophisticated simulations of real-world scenarios, from fluid-structure interactions to chemical reactions. Applications include solving partial differential equations, approximating functions, and predicting outcomes in physics	University of Pennsylvania, Brown University, University of Notre Dame, University of

	and engineering. b) The novelty of scientific machine learning lies in its ability to incorporate physical domain knowledge into machine learning models, leading to more accurate and reliable predictions. Unlike traditional methods, this approach can handle uncertainty, tackle complex problems, and adapt to new information, making it a powerful tool for digital twin technology and beyond.	Colorado at Boulder, International Computer Science Institute
self supervised learning CNN	a) Self-supervised learning convolutional neural networks (CNNs) leverage unlabeled data to enhance performance in various tasks. The technology can be applied in diverse domains such as digital twins, audio and speech classification, 6D object pose estimation, salient object detection, image colorization, galaxy morphology identification, histopathological image analysis, vision-language processing, graph-structured data learning, and pulmonary embolism diagnosis. b) Compared to established methods, self-supervised learning CNNs demonstrate superior performance in learning from unlabeled data, reducing reliance on expensive and time-consuming annotations. They offer robust and transferrable learning capabilities and show potential in improving performance on tasks traditionally reliant on supervised learning or large-scale labeled datasets.	University of California, GOOGLE INC, Arizona State University, Texas A and M University, University of Michigan
tiny machine learning	a) Tiny machine learning (TinyML) integrates machine learning and embedded systems to achieve ultra-low-power, low-cost, efficient, and privacy-preserving machine learning on edge devices such as microcontroller units (MCUs). It is used in applications such as electronic skin systems, unmanned aerial vehicles, and IoT devices, enabling real-time processing, energy efficiency, and autonomous decision-making. b) The novelty of TinyML lies in its ability to provide machine learning capabilities on highly constrained hardware, eliminating the need for high-end systems or cloud-based computing. This shift in computational capacity to edge devices addresses challenges of energy consumption, latency, and data privacy, fundamentally transforming the landscape of machine learning deployment and applications.	MEDIATEK INC., Fraunhofer Institute for Experimental Software Engineering, IMEC, Politecnico di Torino, Stanford University
Trustworthy AI	a) Trustworthy AI integrates deep learning and symbolic knowledge representation within artificial intelligence systems, facilitating robust learning, logical reasoning, and explainability. This neurosymbolic approach enhances the transparency, safety, and interpretability of AI models. Potential applications include digital twin technology, environment and human welfare, financial services, content moderation, and high-risk settings, among others. b) The novelty of Trustworthy AI lies in offering a sound and non-redundant explanation of AI models' decision-making, addressing the 'black-box' issue of conventional AI. It improves user trust in AI technologies, allowing for effective risk management, and compliance with ethical and regulatory standards. This technology also has the potential to provide a rigorous understanding of deep neural networks, making AI interpretable, robust, and ultimately more reliable.	Michigan State University, Sungkyunkwan University, University of Pisa, Basque Research and Technology Alliance (BRTA), University of Padua
trustworthy machine learning	a) Trustworthy machine learning employs reliable and fair algorithms to increase trust and transparency in artificial intelligence systems. The technology uses visualization techniques for model explainability, checks deep learning architectures, and ensures fairness and privacy. Applications range from healthcare (heart disease detection), waste management (classification of waste), recommender systems, fault diagnosis in industrial machinery, to chatbot safety. b) Novel aspects of trustworthy machine learning include the use of unsupervised deep learning for waste classification, application of Distributionally Robust Optimization for fairness-aware recommendation systems, and the Bayesian deep learning framework for fault diagnosis. The technology also reveals a trade-off between classification accuracy and calibration in uncertainty measures, highlighting the need for balance in overparameterized neural networks.	National University of Singapore, Chitkara University, Institute of Technology and Management, Technische Universiteit Eindhoven, University of Maryland
vertical federated learning	a) Vertical Federated Learning (VFL) is a privacy-preserving machine learning technique that enables multiple organizations to jointly train models using different subsets of features about the same set of data samples, without sharing raw data or model parameters. Used in digital twins, it can facilitate data collaboration while maintaining privacy, especially when one organization owns sensitive labels. b) The novelty of VFL lies in its unique ability to handle disjoint features across organizations, unlike traditional federated learning methods that require the same feature space. This makes it particularly useful in scenarios where datasets share the same sample space but differ in feature space, thereby preserving privacy and mitigating data leakage risks more effectively.	Nanyang Technological University, Hong Kong University of Science and Technology, National University of Singapore, University of Surrey, East China University of Science and Technology
multimodal hate speech detection	a) Multimodal hate speech detection is a technology that aims to identify and moderate harmful content in digital platforms. It uses machine learning and deep learning models to analyze both text and visual content, such as text-embedded images, to detect hate speech and its targets. b) The novelty of this technology lies in its multimodal approach, which combines analysis of textual and visual data. This is a significant advancement from traditional methods that	Jamia Millia Islamia, College of Engineering, University of São Paulo, University of Siegen, Instituto Politécnico Nacional

	primarily focus on text analysis. Despite its complexity and challenges, the technology shows promise in enhancing the effectiveness of hate speech detection and moderation.	

ICT

Weak signal	What it is? Why is it new?	Main actors
adversarial defense	a) Adversarial defense technology, in the context of Information and Communication Technologies (ICT), works by enhancing the robustness of machine learning systems against adversarial attacks. These attacks involve intentionally altered data inputs designed to mislead or manipulate the performance of machine learning models. The technology finds applications in various domains, including Android malware detection, air transportation communication jamming recognition, visual detection in autonomous driving, and natural language processing. b) The novelty in adversarial defense technology lies in its approach to enhancing system robustness. This includes the use of self-supervised defense frameworks that can detect, localize, and purify adversarial attacks, and the implementation of game theory-inspired strategies. It also encompasses the development of methods to train larger models that are provably robust against adversarial perturbations, and the use of adversarial samples for retraining models to combat adversarial attacks.	Zhejiang University, Carnegie Mellon University, Teesside University, Prince Mohammad Bin Fahd University, UT Austin
confidential computing	a) Confidential computing is an advanced technology in the field of ICT that secures sensitive data during processing. It creates and enforces a new physical address space known as Realm world, ensuring data confidentiality and integrity even in virtual machines. Applications range from secure authentication in social internet of vehicles to privacy-preserving computation and fair machine learning algorithms. b) The novelty of confidential computing lies in its ability to protect data in-use, which is a significant advancement over traditional methods that only secure data at-rest or in-transit. It also introduces novel verification techniques and enables hardware-based isolation, leading to more secure and efficient computing environments.	University of Science and Technology, Hunan University, Ohio State University, Hong Kong Polytechnic University, ARM LIMITED
deepfake detection	a) Deepfake detection technology utilizes advanced machine learning models, such as convolutional neural networks, to identify artificially created or manipulated media content. This technology can analyze facial similarities, identity representation, forensic noise traces, and text content among others. It holds potential for safeguarding online information integrity and enhancing security measures in various systems. b) Novelty in deepfake detection lies in the development of more efficient deepfake detection models with improved generalization ability. Technologies such as the ID-unaware Deepfake Detection Model and the NoiseDF model are breaking new ground by reducing identity leakage and focusing on forensic noise traces, respectively. Furthermore, these technologies are capable of handling real-time detection and cross-dataset evaluation, significantly outperforming previous methods.	State University of New York, Karabuk University, University of Chicago, Technical University of Munich, University of Virginia
evolutionary Neural Architecture Search	a) Evolutionary Neural Architecture Search (ENAS) uses evolutionary algorithms to automatically design the architecture of deep neural networks. This method can optimize network configurations for various applications, including image classification, wind frequency mapping, and sensor fusion in automotive systems. b) The novelty of ENAS lies in its use of mutation and crossover operators, reinforced mutations, and node inheritance strategies to improve the efficiency and performance of network architecture design. Additionally, some ENAS methods incorporate performance predictors and memetic algorithms, which further enhance the optimization process.	Sichuan University, University of Information Technology, XIDIAN UNIVERSITY, University of Surrey, Northwest Normal University
few shot learning	a) Few-shot learning is a technology in the ICT field that enables machine learning models to make accurate predictions or classifications from limited examples. It involves large language models like GPT-3 and PaLM, and techniques like prompting, domain adaptation, and prototypical networks. Applications range from language translation and question answering to visual language tasks and speech recognition. b) The novelty of few-shot learning lies in its ability to generalize from a small number of examples, a significant step forward from the traditional requirement for large labeled datasets. Recent advancements include the development of diverse verifier approaches, graph prompting frameworks, and techniques to enhance reasoning capabilities, demonstrating substantial improvements over established technologies.	Google Research, Meta Ai Research, Carnegie Mellon University, National University of Singapore, Johns Hopkins University
human cyber physical system	a) Human-Cyber-Physical Systems (HCPS) is a technology that integrates human, robotic and neuromechanical decision-making agents, utilizing internal forward and inverse mathematical models. Potential applications span across sectors like manufacturing, industrial hygiene, and security, involving tasks like teleoperation, tracking, predictive modeling, and automation dynamics inversion. b) The novelty of HCPS lies in its ability to dynamically couple human and cyber-physical	Zhejiang University, University of Michigan, Tongji University, University of Hong Kong, Vanderbilt University

	entities, guaranteeing performance across various applications. Unlike traditional technologies, it fosters a unique interplay between human agents and automation, mediated by predictive models. Its potential to improve task performance, safety, and efficiency, particularly in intelligent manufacturing and Industry 4.0, sets it apart.	
Intrusion Dectection BoT-IoT	a) Intrusion Detection BoT-IoT is a technology that enhances network security in the Internet of Things (IoT) domain. It employs machine learning and deep learning algorithms to identify and mitigate threats such as Denial-of-Service (DoS) and botnet attacks. The technology includes models like Hybrid DoS Attack Intrusion Detection System (HDA-IDS) and CL-GAN, which combine signature-based and anomaly-based detection to identify malicious traffic effectively. b) The novelty of Intrusion Detection BoT-IoT lies in its hybrid approach to intrusion detection, combining signature-based and anomaly-based techniques. It leverages machine and deep learning algorithms to enhance traditional Intrusion Detection Systems (IDS). The use of CL-GAN model for anomaly detection is particularly innovative, providing superior accuracy and efficiency in detecting DoS and botnet attacks. Additionally, the technology's application to IoT-specific networks is a new and significant advancement in network security.	Cadi Ayyad University, Moulay Ismail University, Ibn Tofail University, Singidunum University, Institution of Intelligent System
metaverse	a) The metaverse is a digital virtual world, enabled by technologies like IoT, Blockchain, and Artificial Intelligence. It offers immersive, interactive social and economic activities that go beyond the physical world's limitations. In particular, it has found significant applications in the educational sector, providing an uninterrupted learning environment during the Covid 19 pandemic. b) The novelty of the metaverse lies in its ability to create a fully immersive, hyper spatiotemporal, and self-sustaining virtual shared space. Unlike traditional digital platforms, it provides a realistic, interactive, and comprehensive digital environment that can be adapted to various sectors, from education to healthcare and manufacturing, revolutionizing the way we interact with digital technology.	Inje University, Reich College of Education Appalachian State University, Swinburne University of Technology, University of Padova, Universidade Aberta
MITRE ATT&CK	a) MITRE ATT&CK is a technology that provides a comprehensive repository of adversarial tactics, techniques, and procedures (TTPs) to enhance cybersecurity. It is used in mapping potential cyber attack strategies, predicting unobserved attack techniques, risk assessment, and selecting mitigation mechanisms for security enhancement in various sectors including healthcare, power plants, and industrial control systems. b) The novelty of MITRE ATT&CK lies in its ability to facilitate understanding of cyber adversaries' methods and predicting potential techniques for exploiting network vulnerabilities. Unlike traditional methods, it uses machine learning to generate significant correlations between techniques for attack prediction and automated threat hunting, improving the efficiency and effectiveness of cybersecurity measures.	Carnegie Mellon University, Minnesota State University, Texas A and M University-Kingsville, Queensland University of Technology, University of Greenwich
multi key fully homomorphic encryption	a) Multi-key Fully Homomorphic Encryption (MKFHE) is a privacy-preserving technology that allows computations on data encrypted by different parties. Its application in federated learning and deep learning systems, particularly in medical and emergency response services, ensures secure data transfer and privacy protection while retaining the ability for collaborative training and data analysis. b) The novelty of MKFHE lies in its ability to enable operations on data encrypted by multiple keys, thus facilitating secure multi-party computation. Unlike traditional encryption methods, it supports dynamic joining of parties in the computation process, reducing interactions, and offering enhanced security against data leakage, even when some clients drop out.	Chinese Academy Of Sciences, University of California, Nankai University, British University in Dubai, University of Hong Kong
Non-fungible tokens	a) Non-fungible tokens (NFTs) utilize blockchain technology to create and maintain unique digital entities, each identified by a distinct smart contract and token ID. This technology enables global identification of an NFT's history, including asset ownership, previous owners, and original creator. NFTs find application in managing ownership of both digital and physical assets and cryptocurrencies, enhancing medical visits, and assisting with cardiovascular interventions. They could act as security assets for patient data in telemedicine and play a significant role in metaverse commerce, enterprise management, and fashion branding in video games. b) NFTs represent a novel approach compared to established technologies by offering a unique, transparent, and secure way to manage ownership of assets. Unlike traditional digital assets, each NFT is unique and cannot be replaced, introducing a new level of individuality and ownership in the digital world. The technology also offers a new incentive mechanism for managing enterprises and facilitates the prediction of financial performance in NFT markets, making it a transformative tool in the field of ICT.	Chinese Academy Of Sciences, School of Business, Dublin City University, Macau University of Science and Technology, University of Tennessee
open RAN	a) Open RAN is a revolutionary technology in the ICT field that promotes the creation and optimization of virtualized Radio Access Networks (RANs) through intelligent controllers and open interfaces. It leverages artificial intelligence and machine learning for better network functionality, enabling a multi-vendor, interoperable ecosystem capable of programmatically optimizing operations through a centralized abstraction layer. b) The novelty of Open RAN lies in its disaggregation of components, enabling a more flexible, competitive, and innovative RAN ecosystem. Unlike traditional RAN systems, Open	Northeastern University, Samsung Corp, Politecnico di Torino, San Jose State University, LANCASTER UNIVERSITY

	RAN facilitates the entrance of multiple infrastructure providers, offers improved control mechanisms, enables intelligent radio resource management, and supports on-demand service provision for diverse applications. However, challenges related to interoperability, convergence, and AI/ML management remain to be addressed.	
practical byzantine fault tolerance	a) Practical Byzantine Fault Tolerance (PBFT) is a consensus protocol used in blockchain technology to ensure system reliability despite malicious attacks or software bugs. It's particularly applicable to large-scale, mission-critical applications like the Internet of Things (IoT), autonomous driving, and collaborative AI training, where it can handle issues such as latency, security, and privacy. b) The novelty of PBFT lies in its ability to tolerate any number of faults over time, provided that fewer than 1/3 of the replicas become faulty within a short window. With the use of symmetric cryptography for message authentication, PBFT ensures system performance comparable to non-replicated systems, and its application in fields requiring high consensus efficiency offers new potential for the development of trustworthy AI and secure, large-scale data-sharing systems.	Chinese Academy Of Sciences, 545 Technology Square, Beijing Jiaotong University, Concordia University, Graphic Era University
redactable blockchain	a) Redactable blockchain is a novel blockchain technology that introduces controlled mutability to the typically immutable blockchain records. This is achieved through the application of policy-based chameleon hashes (PCH), allowing authorized entities to alter blockchain objects. The technology also incorporates accountability measures to identify and track modifications. b) The novelty lies in its break from the traditional immutability of the blockchain. It introduces a level of controllable mutability that can be monitored and traced, making it an appealing adaptation for applications where blockchain storage abuse and legal obligations may be an issue. This novel approach could revolutionize the way blockchain technology is used and regulated.	Fujian Normal University, Shanghai Jiao Tong University, Aarhus University, Singapore Management University, University of Texas at San Antonio
secure decentralized finance	a) Secure decentralized finance (DeFi) is a blockchain-based financial system that allows peer-to-peer transactions, utilizing smart contracts for integrity and security. It includes applications such as decentralized exchanges, voting rights through governance tokens, and automated market makers. However, vulnerabilities in governance protocols and potential for economic attacks present significant security challenges. b) The novelty of secure DeFi lies in its elimination of traditional banking intermediaries, providing financial services in a decentralized manner. Innovations include the creation of governance tokens for decentralized decision-making, and the use of automated market makers for algorithmic asset pricing. However, new security risks, such as governance attacks and blockchain extractable value (BEV) exploitation, have emerged.	Imperial College London, Hong Kong Polytechnic University, University College London, University of California, Hebrew University of Jerusalem
self sovereign identity	a) Self-sovereign identity (SSI) is a technology that allows individuals to control and manage their own personal data. It utilizes distributed ledger technology, like blockchain, to decentralize identity management, improve security, and enhance user privacy. Applications of SSI include smart cities, web services, vehicular networks, healthcare data sharing, and digital identity in emerging concepts like the metaverse. b) SSI's novelty lies in its user-centric approach, a significant shift from traditional centralized identity management models. It offers greater control and privacy to the user, reduces security breaches, and facilitates easier management and sharing of identity information. The technology can be integrated into various domains, presenting a transformative solution to identity and data management challenges.	Centre Tecnològic de Telecomunicacions de Catalunya, Massachusetts Institute of Technology, United Nations University, Hainan University, Egyptian Russian University
Smart contracts supply chain	a) Smart contracts supply chain technology leverages Internet of Things (IoT), big data, and artificial intelligence (AI) for modernizing agricultural supply chains. It uses blockchain for traceability and transparency, enabling seamless integration of IoT devices for data collection and verification, thereby enhancing food safety, quality, and efficiency in supply chain management. b) This technology introduces a novel approach to supply chain management, shifting from traditional linear models to a decentralized system, thanks to blockchain. It eliminates single points of failure, prevents data tampering and ensures full traceability. The integration of AI and machine learning further boosts its novelty, offering predictive analytics for improved decision-making.	Chitkara University, Ingenium Naturae Private Ltd., AgResearch Grasslands Research Centre, School of Management, Hong Kong Polytechnic University
vehicular edge computing	a) Vehicular Edge Computing (VEC) is a technology that integrates resources from vehicles, roadside units, base stations, and cloud centers to enhance data processing and computing capabilities in vehicular networks. It supports real-time vehicular applications, secure data storage and sharing, and efficient task offloading and scheduling, particularly for data-intensive and delay-sensitive tasks. b) The novelty of VEC lies in its ability to leverage the computational resources of individual vehicles and the deployment of edge servers in proximity to task-generated devices. This comes with the introduction of sophisticated mechanisms such as consortium blockchain, smart contracts, and advanced machine learning algorithms to ensure high-quality data sharing, secure offloading, and efficient resource allocation.	University of Oslo, XIDIAN UNIVERSITY, Chinese Academy Of Sciences, Beijing Key Laboratory of Mobile Computing and Pervasive Device, University of British Columbia
Zero Trust architecture	a) Zero Trust Architecture (ZTA) is a cybersecurity approach that assumes no trust for any entity within a network, requiring continuous verification for all connections. It is increasingly	Kyoto University, Qatar University,

	used in modern ICT systems such as cloud-native computing, industrial cyber-physical systems, and emerging 6G networks to enhance security through continuous authentication, dynamic access control, and trust evaluation. b) The novelty of ZTA lies in its departure from traditional perimeter-based security models, providing a more robust defense against potential attacks. It not only enhances security in conventional ICT systems but also addresses unique challenges in new digital environments like the metaverse, digital twin technologies, and edge computing in 6G networks.	University of Technology Sydney, Datta Meghe Institute of Higher Education & Research, Shanghai Electric Power Company
blockchain in supply chain	a) Blockchain in supply chain is a decentralized technology that enhances transparency and authenticity in the tracking and tracing of goods. It integrates with Internet of Things (IoT) and other digital technologies to provide real-time, trustworthy data, minimizing fraud and errors. This technology is particularly effective in the agri-food industry for ensuring food safety. b) The innovation of blockchain in supply chains lies in its decentralized nature, providing a solution to the vulnerability of centralized systems. It introduces immutability, auditability, and provenance, which are revolutionary compared to traditional systems. However, challenges remain in scalability and integration across various levels of the supply chain.	Vienna University of Economics and Business, Lappeenranta University of Technology, KIIT Deemed to be University, University of North Carolina, University of North Texas
single chip neuromorphic computing	a) Single chip neuromorphic computing is a technology that attempts to mimic the human brain's structure and function, integrating sensors and artificial neurons into a single device. It is used in fields such as virtual/augmented reality systems, bio-inspired machine vision systems, artificial visual systems, non-volatile memory devices, gas sensors, and image recognition systems. b) The novelty of this technology lies in its integration of sensory and neuromorphic computing capabilities into a single chip, providing real-time response, high recognition accuracy, and adaptability to changing conditions. Unlike traditional digital neural networks, these chips utilize low-power, high-efficiency spiking neural networks and demonstrate potential for self-regulation and multi-scene perception in complex environments.	Chinese Academy Of Sciences, Korea University, Korea Institute of Science and Technology, National University of Defense Technology, Beijing Normal University

Medical Imaging

Weak signal	What it is? Why is it new?	Main actors
red dichromatic imaging	a) Red dichromatic imaging (RDI) is an advanced endoscopic technology that enhances the visibility of blood vessels and bleeding points by using specific wavelengths (540, 600, and 630 nm). This technique facilitates the detection and treatment of bleeding during endoscopic submucosal dissection (ESD) and may reduce the time and psychological stress associated with hemostasis. It shows promise in improving the management of gastrointestinal bleeding and the assessment of inflammatory activity in conditions like ulcerative colitis. b) The novelty of RDI lies in its use of dual red wavelengths to achieve a higher contrast between bleeding sites and surrounding tissues compared to traditional white light imaging (WLI). This leads to superior visualization of bleeding points in various endoscopic procedures, potentially improving clinical outcomes with faster, safer interventions. Its recent development and application in endoscopy signify an advance over WLI, particularly in the efficacy and efficiency of endoscopic hemostasis.	Gunma University Graduate School of Medicine, National Hospital Organization, Gunma University, Keio University School of Medicine, National Hospital Organization Tokyo Medical Center
Total body positron emission tomography	a) TB-PET is an advanced medical imaging modality that captures high-sensitivity, dynamic images of the entire body. It leverages positron-emitting radiotracers, like 18F-FDG, and advanced computation to visualize metabolic processes, aiding in the diagnosis of diseases, tracking drug distribution, and evaluating treatment efficacy. b) The novelty of TB-PET lies in its extended field-of-view, enabling simultaneous whole-body imaging. This facilitates reduced scan times, lower radiotracer doses, and improved image quality. Innovations include deep learning for image reconstruction, optimized SiPMs for better timing resolution, and novel radiolabeling techniques for diverse tracer development.	Chinese Academy Of Sciences, Fudan University, Shanghai Institute of Medical Imaging, Cardiff University, Ghent University
Vesical Imaging-Reporting and Data Syst	a) The Vesical Imaging-Reporting and Data System (VI-RADS) is an MRI-based framework for standardized reporting in bladder cancer imaging. It integrates T2-weighted, diffusion-weighted, and dynamic contrast-enhanced MRI techniques to assess the likelihood of muscle invasion by the tumor, aiding in the accurate staging and management of bladder cancer. b) VI-RADS represents an advancement in the non-invasive evaluation of bladder cancer, offering more accurate pre-surgical staging and potential in therapy response monitoring compared to traditional methods. Its application in differentiating muscle-invasive from non-muscle-invasive bladder cancer and the utilization of deep learning for improved	Radiolonet Tokai, University of Sheffield, Regina Elena National Cancer Institute, Policlinico Umberto I, Sun Yat-Sen University

	diagnostic performance are novel aspects.	
Line-field confocal opt coherence tomogr	a) Line-field confocal optical coherence tomography (LC-OCT) is a non-invasive medical imaging technique that combines high-resolution, real-time visualization of skin tissues with deep penetration capabilities. It allows for cellular-level characterization of skin layers, improving diagnostic confidence and enabling early detection of various skin pathologies, including cancer. b) LC-OCT is novel in its integration of the high-resolution imaging of confocal microscopy with the penetration depth of OCT. It enhances diagnostic specificity, particularly in distinguishing basal cell carcinomas, and allows for 3D imaging and AI-assisted analysis, expanding its potential applications in dermatology, including pediatric care.	Université Libre de Bruxelles, University Hospital, University of Siena, Université Libre de Bruxelles-ULB, University of Catania
optoretinogrphy	a) Optoretinography is a non-invasive optical imaging technique using phase-sensitive optical coherence tomography (OCT) to detect functional changes in the retina, particularly measuring light-induced responses in photoreceptors. It provides high-resolution imaging capable of assessing photoreceptor function in health and disease, facilitating early diagnosis and monitoring of retinal degenerations. b) The novelty of optoretinography lies in its ability to image retinal function at the individual photoreceptor level, a significant advancement over traditional methods like electroretinography (ERG). It offers rapid, cellular-scale functional assessment, crucial for evaluating emerging therapies and understanding disease progression.	University of Illinois at Chicago, Howard Hughes Medical Institute, University of Pennsylvania, Ohio State University, University of Washington School of Medicine
Pix2Pix GAN	a) Pix2Pix GAN is a deep learning framework used in medical imaging to transform images from one type to another, leveraging paired datasets for training. It enhances image quality, as shown in applications like denoising myocardial perfusion SPECT images, segmenting retinal blood vessels, and augmenting CT images for improved lymph node segmentation. Pix2Pix GAN's ability to generate realistic images supports tasks where high-quality data is scarce or where image enhancement is needed for better diagnostic accuracy. b) The novelty of Pix2Pix GAN lies in its adeptness at image-to-image translations with high fidelity, especially under conditions where conventional data augmentation or image processing techniques fall short. It offers significant improvements in scenarios with limited or noisy data, such as low-light or low-dose imaging. Enhanced by features like residual modules and self-attention mechanisms in recent iterations, it demonstrates superior performance in generating detailed and contextually accurate medical images.	Qatar University, Chiao Tung University, Science and Technology Corporation, Institute for Advanced Studies, Zhongshan Hospital
radiomics nomogram	a) Radiomics nomograms are predictive tools that integrate quantitative imaging features extracted from medical scans with clinical data to forecast disease characteristics or treatment outcomes. These models assist clinicians in personalized decision-making by evaluating factors such as tumor invasion, lymph node metastasis, and survival probabilities, improving diagnostic accuracy and prognostic assessments in various cancers. b) The novelty of radiomics nomograms lies in their ability to harness advanced machine learning techniques to analyze complex imaging data, which traditional evaluation methods may not capture. This innovation provides a more nuanced and individualized prediction of patient outcomes, potentially transforming clinical workflows and enhancing precision medicine in oncology.	Chinese Academy Of Sciences, Southern Medical University, South China University of Technology, Guangdong General Hospital, Guangzhou Medical University
Magnetic Resonance Imaging radiomics	a) Magnetic Resonance Imaging (MRI) radiomics leverages advanced algorithms to extract high-dimensional data from MRI images, enhancing diagnostic accuracy in oncology. It involves deep learning for image super-resolution, providing detailed tissue characterization and predictive biomarkers, assisting in preoperative staging, and predicting therapy responses. Applications include differentiating molecular cancer subtypes, assessing genetic mutations, and informing personalized treatment strategies. b) The novelty of MRI radiomics lies in its integration of deep learning for improved image resolution and robust feature extraction, surpassing traditional visual assessments by expert radiologists. It demonstrates greater predictive performance and generalizability for various cancers, offering a non-invasive approach to understanding tumor heterogeneity and potential clinical applications across multiple centers with enhanced reproducibility.	Capital Medical University, Yonsei University, Brno University of Technology, Université de Lorraine, Liaoning Cancer Hospital and Institute
deuterium metabolic imaging	a) Deuterium metabolic imaging (DMI) is a non-invasive medical imaging technique that tracks metabolism by using deuterated compounds, such as glucose or acetate, to generate 3D metabolic maps. It leverages the unique relaxation properties of deuterium nuclei for rapid and sensitive detection, offering detailed insights into tissue metabolism, organ function, and pathophysiology. Applications include studying brain lesions, cancer metabolism, diabetic organ dysfunctions, and assessing response to therapy. b) DMI represents a significant advancement over established imaging modalities like 18FDG-PET, which is limited to assessing glucose uptake. DMI's ability to visualize metabolic processes beyond uptake, its use of non-radioactive tracers, and compatibility with existing MRI infrastructure enhance its clinical applicability. Its recent developments include improved spatial and temporal resolution, feasible implementation at clinical field strengths, and the ability to simultaneously assess multiple organ functions.	Yale University, University of Cambridge, Max Planck Institute for Biological Cybernetics, University of California, University Medical Center Utrecht

Therapeutics and Biotechnologies

Weak signal	What it is? Why is it new?	Main actors
3D printing for wound management	a) The technology ${emm_dname} encompasses the use of natural polysaccharides, nanocellulose, and advanced 3D printing techniques in medical imaging to create biocompatible scaffolds and hydrogels. These materials support cell adhesion, proliferation, and differentiation, which are critical for tissue engineering, drug delivery, wound healing, and the construction of vascularized skin constructs. Their customizable properties allow for the precise matching of implants to host tissues and controlled drug release. b) The novelty of ${emm_dname} lies in the integration of natural biopolymers and cutting-edge fabrication methods to create scaffolds with customizable geometries and functionalities. Compared to traditional biomaterials, these advanced scaffolds offer enhanced cell-material interactions, controlled drug delivery, and potential for bioactivated surfaces. The use of 3D printing and bio-electrospray technologies represents a significant advancement in the precision and customization of tissue engineering applications.	Zhejiang University, Chinese Academy Of Sciences, Marmara University, Southeast University, University of Maryland
Biology-guided radiotherapy	a) The technology ${emm_dname} encompasses Biology-guided Radiotherapy (BgRT), which utilizes real-time positron emission tomography (PET) imaging to direct radiation beams to active cancer cells, marked by radiotracers like PSMA for prostate cancer. This enables dynamic adjustment to tumor movements and metabolism, potentially increasing treatment precision and reducing damage to surrounding healthy tissue. Applications include targeting oligometastatic lesions, hypoxia management, and treatment of various cancers such as nasopharyngeal carcinoma and glioblastoma. b) The novelty of ${emm_dname} lies in its integration of functional imaging and radiation delivery, allowing for sub-second adaptation to tumor motion and biology. This real-time tracking differentiates it from conventional radiotherapy, which relies on pre-treatment imaging and may not account for changes during therapy. The BgRT technology facilitates targeted dose escalation, personalized treatment plans, and could improve outcomes in metastatic ablation and hypoxia-targeted therapies.	Stanford University, University of Melbourne, RefleXion Medical, University of Auckland, Peter MacCallum Cancer Centre
boron proton capture therapy	a) Boron proton capture therapy (BPCT) is a therapeutic approach that combines proton therapy's precision with boron-11's ability to enhance radiation's biological effectiveness. By targeting boron-accumulated cancer cells with protons, a nuclear reaction occurs, creating high-LET alpha particles that increase DNA damage, potentially improving treatment outcomes for radioresistant tumors. b) The novelty of BPCT lies in its potential to selectively increase the radiation dose within the tumor via a nuclear reaction, without affecting surrounding healthy tissue. This targeted approach aims to overcome the limitations of traditional proton therapy by enhancing its efficacy against resistant cancer cells, offering a new avenue for treatment.	National Research Centre Kurchatov Institute, Russian Academy of Sciences, Peter the Great St. Petersburg Polytechnic University, INFN, Istituto Nazionale di Fisica Nucleare
CAR macrophage therapy	a) CAR macrophage therapy involves genetically engineering macrophages to express chimeric antigen receptors (CARs), enabling them to target and phagocytose cancer cells, particularly in solid tumors. This therapy can induce a pro-inflammatory tumor microenvironment, reprogram immunosuppressive cells, and potentially provide long-lasting immunity against tumor relapse. b) The novelty of CAR macrophage therapy lies in its application to solid tumors, where traditional CAR-T cell therapies face challenges. It leverages macrophages' innate ability to infiltrate tumors, and their reprogramming could offer a two-pronged approach by directly targeting cancer cells and modulating the tumor microenvironment.	Shandong University, Harvard University, Chinese Academy Of Sciences, Cornell University, Shandong University of Traditional Chinese Medicine
CRISPR-Cas12	a) The technology CRISPR-Cas12a, also known as Cpf1, is a RNA-guided enzyme that binds and cuts DNA, primarily used in bacterial adaptive immune systems. It has been repurposed for genome editing due to its ability to create targeted, double-stranded DNA breaks. It also has indiscriminate single-stranded DNA cleavage activity, which enables sensitive DNA detection methods like DETECTR. This technology has potential applications in genetic manipulation in bacteria, gene function interrogation, cellular behavior modulation, genetic screens, epigenetic engineering, and genome imaging. b) Compared to the established CRISPR-Cas9 technology, CRISPR-Cas12a offers more precise control over genome function without gene editing. It is also capable of rapid rejection of any targets that lack a PAM or poorly match with guide-RNA and releases the DNA cleavage products unlike Cas9. However, it requires a larger sequence match for stable binding and cleavage. The main novelty lies in the combination of its ssDNase activation with isothermal amplification, enabling highly sensitive DNA detection.	Chinese Academy Of Sciences, Zhejiang University, Chinese Academy of Agricultural Sciences, University of California, Shanghai Jiao Tong University
CRISPR-Cas13	a) CRISPR-Cas13a is an RNA-guided gene editing tool, used for precise manipulation of RNA in various organisms. It has potential applications in targeted therapy for genetic diseases such as pancreatic cancer, conferring resistance against RNA viruses in plants, and rapid pathogen detection in patient samples. b) CRISPR-Cas13a is novel in its RNA-targeting capacity, offering improved specificity and	Chinese Academy Of Sciences, University of California, Massachusetts Institute of Technology, Harvard

	efficiency compared to RNA interference techniques. It can also distinguish between different viral serotypes, and region-specific strains, enabling precise diagnostic applications. This technology can also detect single-nucleotide polymorphisms, potentially revolutionizing genotyping and disease monitoring.	University, Southern Medical University
digital therapeutics	a) Digital Therapeutics (DTx) in medical imaging leverage advanced algorithms, often incorporating artificial intelligence, to analyze and interpret complex medical images. This technology application can enhance diagnostic accuracy, guide treatment plans, and monitor disease progression, thereby supporting personalized medicine and optimizing patient outcomes. b) The novelty of DTx in medical imaging lies in the integration of AI-driven analytics, which significantly surpasses traditional imaging techniques. The ability to process vast datasets with precision and adapt to new clinical scenarios presents a breakthrough in tailoring patient care and advancing digital health.	University College London, National University of Singapore, Universitätsklinik, Barts Health NHS Trust, Newcastle University,and Cumbria
fragmentomics	a) Fragmentomics is a branch of ICT that analyzes fragments of plasma DNA and proteins to identify potential biomarkers for diseases, including cancer, or for noninvasive prenatal testing. It examines fragment sizes, ends, and nucleosome footprints, revealing characteristic end motifs that can indicate the tissue of origin. b) The novelty of fragmentomics lies in its ability to provide detailed insights into the structure and function of plasma DNA and protein fragments. This approach not only enhances the diagnostic potential of liquid biopsies but also opens new avenues for studying the formation and function of these fragments in a variety of biological processes.	Chinese University of Hong Kong, University of California, Centre for Novostics, Vrije Universiteit Amsterdam, Nanjing Geneseeq Technology Inc.
immunotherapy cold tumor	a) Immunotherapy cold tumor technology aims to transform poorly immunogenic (cold) tumors into immunologically active (hot) ones, enhancing the efficacy of immunotherapies. This is achieved through various strategies like oncolytic viruses inducing immunogenic cell death, localized delivery of immunostimulants, and nanomedicine approaches that alter the tumor microenvironment and promote T cell infiltration and activation. b) The novelty of this technology lies in its multifaceted approach to modify the tumor microenvironment. Unlike traditional therapies that target tumor cells directly, these novel strategies utilize microbial vectors, nanozymes, and oncolytic viruses to provoke potent immune responses, thereby converting immunologically inert tumors into ones that are susceptible to immune attack.	Wuhan University, University of Wisconsin-Madison, University of Maryland, University of Washington, Albert Einstein College of Medicine
intermittently scanned continuous gluco	a) Intermittently scanned continuous glucose monitoring (isCGM) is a technology that allows individuals with diabetes to measure their glucose levels without the need for frequent fingerstick testing. It involves a sensor placed on the body that records glucose data, which users can access by scanning the sensor with a device. This technology aids in managing blood glucose levels by providing trends and alerts, which can improve glycemic control and reduce the incidence of hypoglycemia. b) The novelty of isCGM lies in its capability to provide glucose data on demand, coupled with a less invasive nature compared to traditional blood glucose monitoring methods. Compared to earlier glucose monitoring devices, isCGM offers optional alarms and has demonstrated improved glycemic outcomes, including time in target glucose range and reduced hypoglycemic events. It supports tailored diabetes management and enhances patient satisfaction by offering a balance between real-time data and user-initiated scanning.	University of Leeds, University Hospitals Leuven, OLV Hospital Aalst, MEDTRONIC INC, University Hospitals
metagenome assembled genome	a) Metagenome assembled genomes (MAGs) are derived from environmental DNA, enabling the analysis of microbial communities without the need for cultivation. This technology facilitates the identification of novel microbes and their genetic traits, advancing our understanding of microbial diversity and potential applications in medical imaging through the discovery of new biomarkers and therapeutic targets. b) MAGs represent a significant advancement in microbial genomics, providing access to the previously inaccessible genetic material of uncultivated organisms. This offers a much-expanded view of biodiversity and genetic resources over traditional culture-based techniques, with implications for identifying novel medical imaging biomarkers and understanding disease mechanisms.	University of California, University of Queensland, Harvard University, Michigan State University, University of Minnesota
mRNA vaccines	a) mRNA vaccines utilize synthetic messenger RNA (mRNA) encapsulated in lipid nanoparticles to instruct cells to produce antigens, such as viral proteins, which elicit an immune response. This platform can be rapidly adapted to new pathogens, as seen with SARS-CoV-2 variants, and offers potential in cancer therapeutics by targeting tumor-specific neoantigens. b) The novelty of mRNA vaccines lies in their unprecedented rapid development and flexibility. Unlike traditional vaccines, mRNA vaccines can be updated swiftly to match evolving pathogens. Their application in cancer, particularly personalized neoantigen vaccines, represents a pioneering approach in precision oncology.	University of Michigan, Vanderbilt University Medical Center, Harvard University, University of Maryland School of Medicine, University of Cambridge
Robotic bronchoscopy	a) Robotic bronchoscopy is a medical technology that improves the biopsy of lung nodules through advanced navigation and stability, often combined with real-time imaging techniques such as cone beam CT. It enables precise localization and sampling of pulmonary lesions, potentially enhancing diagnostic yield for malignancy, aiding in lung cancer staging,	Medical University of South Carolina, Mayo Clinic, Harvard University, Icahn

	and supporting parenchyma-sparing local therapies. b) The novelty of robotic bronchoscopy lies in its enhanced navigational accuracy, extended reach into peripheral lung regions, and stable platform for tissue sampling, which outperforms traditional bronchoscopy and rivals CT-guided transthoracic biopsy with lower complication rates. Developments include integration with cryobiopsy tools and potential applications in transbronchial therapies.	School of Medicine at Mount Sinai, UPMC Hamot
tele neuropsychology	a) Tele-neuropsychology (TNP) leverages audio-visual technology to administer cognitive assessments and rehabilitation remotely. It enables neuropsychologists to evaluate and treat patients in their own homes, enhancing accessibility and reducing risks associated with in-person contact, such as during the COVID-19 pandemic. TNP applications include cognitive screening, memory testing, and comprehensive neuropsychological evaluations, with established protocols and guidelines to maintain validity and reliability of assessments. b) The novelty of TNP lies in its adaptation to direct-to-home services, expanding beyond traditional clinical settings. While the technology itself is not new, the validation of remote neuropsychological test norms and the development of tailored instruments, like Tele-GEMS, for remote settings represent significant advancements. Additionally, the pandemic-induced shift to TNP has highlighted the need for new operational guidelines, informed consent procedures, and consideration of cultural and linguistic diversity in tele-assessment practices.	University of Texas Southwestern Medical Center, Private Practice, Harvard University, Columbia University, University of Michigan
transcatheter edge to edge	a) Transcatheter edge-to-edge repair (TEER) is a minimally invasive procedure for treating mitral and tricuspid valve regurgitation. It involves clipping together parts of the valve leaflets to reduce backflow of blood, improving cardiac function and patient quality of life without the need for open-heart surgery. b) The technology's novelty lies in its advancements, such as expanded clip sizes, independent grasping features, and enhanced deployment sequences. Compared to previous iterations, these developments have shown improved success rates, durability of repair, and safety profiles in high-risk patients, with substantial clinical benefits and low mortality.	Columbia University Medical Center, Cedars-Sinai Medical Center, MedStar Health Research Institute, Regional Medical Center, Scripps Clinic
virtual care	a) Virtual care encompasses telehealth services, such as video and audio consultations, remote monitoring, and digital health management tools, to provide patient care at a distance. It enables continuous access to healthcare, particularly during crises like the COVID-19 pandemic, facilitating treatment, follow-ups, and mental health support while minimizing infection risks. Its applications span from primary care adjustments to complex telemedicine, including telesurgery, in various settings. b) The novelty of virtual care lies in its rapid scaling and integration into standard practice due to the pandemic, surging from a supplementary option to a primary mode of healthcare delivery. Its extensive reach and acceptance, including for behavioral health and chronic disease management, and its role in addressing health disparities and enabling care continuity are recent developments. The technology's evolution includes the use of blockchain and AI for secure, reliable telehealth in advanced applications like telesurgery within digital environments like the metaverse.	University of Toronto, Mayo Clinic, King's University College, University of Nevada Las Vegas, University of Jordan
postbiotic	a) Postbiotics encompass inactivated microbial cells and their components/metabolites, conferring health benefits. These therapeutic agents leverage the gut microbiome-host interactions to potentially manage neurological disorders, depression, periodontitis, obesity, liver diseases, and even cancer. They offer an innovative approach to modulate bodily functions, immunity, and microbial balance with fewer side effects compared to live microbial treatments. b) The novelty of postbiotics lies in their non-viable nature, eliminating risks associated with live bacteria, such as infections. They provide a new dimension to microbiota-targeted therapies, focusing on the direct application of beneficial microbial by-products. This represents a shift from traditional probiotics and prebiotics towards a safer and potentially more controlled therapeutic option.	Tabriz University of Medical Sciences, Mashhad University of Medical Sciences, University College Cork, University of Wyoming, Institute of Agrochemistry and Food Technology
CAR NK cells	a) CAR NK cells are engineered natural killer cells equipped with chimeric antigen receptors (CARs) to target and eliminate specific cancer cells. They offer advantages over traditional therapies, such as reduced toxicity and the ability to kill both directly through the CAR and via innate mechanisms. Potential applications include treating metastatic cancers, lung adenocarcinoma, and breast cancer, particularly where resistance to existing therapies exists. b) The novelty of CAR NK cells lies in their reduced risk of cytokine release syndrome and graft-versus-host disease, the potential for off-the-shelf use, and enhanced efficacy in solid tumors through genetic modifications, such as overexpression of antioxidative enzymes. Their dual-CAR systems and cytokine armored enhancements represent innovative strategies to overcome tumor evasion and boost antitumor activity.	Harvard University, University of Texas M. D. Anderson Cancer Center, University of Houston, Dana-Farber Cancer Institute, University of São Paulo
gastruloid technology	a) Gastruloid technology utilizes three-dimensional aggregates of pluripotent stem cells to model early human embryogenesis, allowing for the study of germ layer differentiation, axial organization, and somitogenesis without requiring actual human embryos. Potential applications include researching human developmental processes, disease modeling, drug screening, and potentially guiding regenerative medicine.	University of Cambridge, University of Texas Southwestern Medical Center, Royal

	b) The novelty of gastruloid technology lies in its ability to recapitulate key aspects of human post-implantation development in vitro. Unlike previous in vitro models, gastruloids self-organize to form structures with spatial and temporal patterns of gene expression resembling early embryonic stages, offering a new avenue for ethical and accessible human developmental studies.	Netherlands Academy of Arts and Sciences, Francis Crick Institute, School of Life Sciences
Proteolysis Targeting Chimeras	a) Proteolysis Targeting Chimeras (PROTACs) are heterobifunctional molecules that induce the degradation of specific proteins by recruiting them to E3 ubiquitin ligases, marking them for degradation by the ubiquitin-proteasome system. This technology enables the targeting of previously 'undruggable' proteins, offering therapeutic applications across various diseases, including cancer, by effectively suppressing oncogenic proteins and signaling pathways. b) The novelty of PROTACs lies in their mechanism that transcends traditional inhibition, allowing for the complete and selective removal of target proteins rather than merely blocking their activity. This leads to more sustained therapeutic effects and the ability to target proteins that lack enzymatic function, expanding the range of druggable targets and offering potential improvements in efficacy, dosing, and resistance profiles compared to conventional small-molecule inhibitors.	Yale University, University of California, Nanyang Technological University, Chinese Academy Of Sciences, Central South University
spatial omics	a) Spatial Omics refers to advanced techniques in bioimaging and genomics that combine gene expression data with spatial information. These technologies enable high-resolution mapping of expression profiles within tissues, preserving the spatial context of cells, their geometry, and surrounding extracellular matrix (ECM). Applications range from enhancing our understanding of disease progression, designing cancer therapies, and studying cell-ECM interactions, to investigating fibrotic diseases and cancer biology. b) The novelty lies in its ability to provide an unprecedented level of detail about the spatial context of gene expression and cell interactions within tissues. Traditional transcriptomics and proteomics techniques offer quantitative abundance analysis of biomolecules but fall short in preserving their spatial information. Spatial Omics, however, overcomes this limitation, promising to revolutionize various fields of study, including genomics, transcriptomics, and proteomics.	Chinese Academy Of Sciences, University of California, Fudan University, Maastricht University, University of Oxford

e-Health

Weak signal	What it is? Why is it new?	Main actors
AI classified histopathology images	a) AI-classified histopathology images employ deep learning models to analyze tissue samples, significantly enhancing diagnostic precision and speed in identifying various cancer types, such as breast and oral cancers. This technology automates the classification of cancer subtypes, improves accuracy with optimized feature selection, and validates findings via advanced image analysis techniques, offering critical support in early cancer detection and personalized treatment strategies. b) The novelty lies in the multi-classification capabilities, high accuracy rates, and the use of optimized deep learning models for feature extraction. Compared to traditional methods, these AI approaches offer improved sensitivity and specificity, robust evaluation of saliency maps, and lightweight models suitable for integration with the Internet of Medical Things (IoMT), representing a significant advancement in automated medical image analysis.	University of Coimbra, Shandong University of Traditional Chinese Medicine, Maharaja Agrasen Institute of Technology, University of Applied Sciences, China Medical University Hospital
AI driven neurodegenerative dis detect	a) AI driven neurodegenerative dis detect employs deep learning models, such as Convolutional Neural Networks (CNNs), Vision Transformers, and ensemble approaches, to analyze neuroimaging data like MRI scans for early detection and classification of neurodegenerative diseases such as Alzheimer's and Parkinson's. By automating feature extraction and improving classification accuracy, these AI technologies promise to enhance diagnostic precision, facilitate early intervention, and potentially slow disease progression. b) The novelty of AI driven neurodegenerative dis detect lies in its advanced deep learning techniques, surpassing traditional machine learning by leveraging architectures like Vision Transformers and 3D ConvNets for improved image analysis. With enhanced accuracy rates in recent studies, these AI models demonstrate significant improvements over previous methods in terms of computational efficiency and the ability to work with limited datasets, signaling a substantial evolution in neurodegenerative disease detection.	University of South Dakota, Universiti Kebangsaan Malaysia, Science College, Kongu Engineering College, Central Michigan University
AI for Abdominal lesion detect/character	a) AI for Abdominal Lesion Detection/Characterization utilizes deep learning models to enhance the detection, segmentation, and characterization of abdominal lesions in medical imaging. Leveraging advancements in pattern recognition and image analysis, this technology improves diagnostic accuracy, reduces manual review times, and aids in treatment planning by identifying subtle or small lesions that may be overlooked in standard imaging practices. b) The novelty lies in the application of multi-channel 3D models, progressive generative	SIEMENS AG, Université de Lorraine, Dokuz Eylul University, IMT Atlantique, University of Tehran

	adversarial networks, and anisotropic hybrid networks to capture detailed lesion characteristics. These AI methods outperform traditional image reconstruction techniques, enabling more accurate and comprehensive analysis, particularly in detecting small lesions and understanding lesion changes over time, which is crucial for treatment efficacy assessment.	
AI for medical diagnosis	a) AI for medical diagnosis is a technology applying machine learning algorithms to interpret complex medical data, aiding in disease identification, treatment planning, and predicting disease progression. Its applications range from analyzing medical imaging and Raman spectral data for cancer detection to diagnosing cardiovascular and oral diseases, with a focus on enhancing accuracy, efficiency, and patient outcomes. b) The novelty of AI for medical diagnosis lies in its integration of advanced computational methods like chaos theory for improved spectroscopic analysis, the utilization of deep learning architectures for precise brain tumor detection, and scenario-based frameworks to mitigate biases. These innovations surpass traditional diagnostic tools by offering greater predictive power, personalized treatment simulation, and a more profound understanding of complex disease patterns.	University of Virginia, Yonsei University College of Medicine, University of Ulsan College of Medicine, Key Laboratory of Minister of Education on Process Optimization and Intelligent Decision-making, University of Ulsan
AI Instance Segmentation	AI Instance Segmentation a) AI instance segmentation utilizes deep learning to identify and delineate individual objects within digital images, facilitating precise analysis in e-health. It aids in tasks like automated analysis of medical imagery for disease diagnosis, surgical planning, and monitoring plant phenotypes for agricultural health. b) The novelty lies in integrating advanced attention mechanisms and multi-task learning to enhance accuracy and efficiency. These methods outperform traditional hand-crafted features, offering robustness against variations and enabling real-time applications, demonstrating significant improvements in both computational overhead and performance metrics.	University of California, Harbin Institute of Technology, Lamarr Institute for Machine Learning and Artificial Intelligence, SenseTime Research, Peking University
Automated Tumor characterization by AI	a) Automated Tumor Characterization by AI utilizes deep learning techniques, such as convolutional neural networks and transformers, to analyze medical imaging data for precise delineation and classification of tumors. Applications include enhancing the accuracy and speed of diagnosis, reducing inter-observer variability, and improving treatment planning in various cancers like brain and nasopharyngeal carcinomas. b) The novelty lies in the integration of advanced deep learning models, including Transformers and efficient neural architectures, to capture global image dependencies and optimize feature representation. This represents a significant advance over traditional methods, with improved segmentation accuracy, reduced manual labor, and the potential to generalize across diverse tumor types and imaging modalities.	Université Paris-Saclay, Princess Nourah Bint Abdulrahman University, Chinese Academy Of Sciences, Central South University, Southeast University
blockchain 4 electronic health record	a) Blockchain for electronic health records (EHR) is a decentralized ledger technology that enhances data security, integrity, and sharing across the healthcare sector. It employs cryptographic techniques, smart contracts, and consensus algorithms to create tamper-proof records, facilitate secure data exchange, and manage access controls, thus ensuring patient privacy and trust in EHR management. b) The novelty of blockchain-based EHR systems lies in their decentralized architecture, which eliminates reliance on centralized or third-party trust entities. Innovative integration with cloud computing, edge computing, and quantum-resistant algorithms represents cutting-edge advancements, offering unprecedented levels of security, interoperability, and efficiency compared to traditional EHR systems.	Yildiz Technical University, NORTHWESTERN POLYTECHNICAL UNIVERSITY, College of Engineering, Islamic University, Trinity Academy of Engineering
Bowel pathology analysis with AI	a) Bowel pathology analysis with AI leverages deep learning algorithms to accurately detect bowel diseases such as Crohn's disease and ulcerative colitis from medical imaging and microbiome data. Convolutional neural networks (CNNs) classify endoscopy images, while machine learning models predict disease progression using radiomics and microbiome compositions. These tools assist in early diagnosis, enhance screening effectiveness, and personalize treatment strategies. b) The novelty lies in the integration of AI into gastroenterological practice, providing high diagnostic accuracy and predictive capabilities that surpass traditional analysis methods. AI models utilize complex data patterns and biomarkers to forecast disease onset and progression, offering a paradigm shift in disease management with potential cost savings and improved patient outcomes.	University of Toronto, McMaster University, University of Manitoba, Huazhong University of Science and Technology, University of Calgary
Explainable AI in medical imaging	a) Explainable AI in medical imaging refers to techniques that make the decision-making process of AI models transparent, providing clinicians with understandable and clinically relevant insights into AI predictions. By using heatmaps, textual, or case-based explanations, AI's "black-box" nature is mitigated, enhancing trust and facilitating adoption in clinical settings for tasks such as disease diagnosis and treatment planning. b) The novelty of Explainable AI in medical imaging lies in its advanced multi-modal and multi-center data fusion techniques that address the lack of transparency in traditional AI applications. It emphasizes clinically grounded evaluation criteria, focusing on truthfulness and informative plausibility, thus aligning AI outputs with evidence-based medical practice	University of British Columbia, Simon Fraser University, University of Washington, University of Michigan, Hangzhou Ocean's Smart Boya Co.,Ltd

	and regulatory requirements.	
explainable anomaly detection	a) Explainable anomaly detection utilizes machine learning algorithms to identify deviations from normal patterns in e-health data. By extracting features and employing unsupervised methods, such as the Isolation Forest, it flags anomalous events. Techniques like SHAP provide insights into the model's decision-making, enhancing diagnosis and monitoring. b) The novelty lies in integrating interpretability into anomaly detection, enabling non-expert understanding of AI decisions in e-health. Unlike traditional black-box approaches, this provides transparent, actionable insights into anomalies, fostering trust and aiding root cause analysis in complex healthcare environments.	Tsinghua University, Basque Research and Technology Alliance (BRTA), National University of Singapore, University of Padua, STATE GRID SHANGHAI MUNICIPAL ELECTRIC POWER COMPANY
Few-shot learning in medical imaging	a) Few-shot learning in medical imaging is a machine learning approach that enables algorithms to effectively learn from a small dataset. It is particularly useful for medical applications where large annotated datasets are rare or difficult to obtain. This technology is applied to tasks like disease detection, image segmentation, and classification, using methods such as transfer learning, meta-learning, and data augmentation to achieve high accuracy with limited samples. b) The novelty of few-shot learning in medical imaging lies in its ability to overcome the data scarcity challenge that is prevalent in the medical field due to privacy concerns and annotation costs. Unlike traditional deep learning that requires extensive data, few-shot learning provides a framework for efficient model training and has demonstrated promising results in tasks like COVID-19 detection and segmentation, even across diverse imaging modalities.	Southeast University, University of Michigan, East China University of Science and Technology, University of Technology Sydney, Mayo Clinic
internet of medical things	a) The Internet of Medical Things (IoMT) integrates medical devices and applications for health monitoring and management through the Internet. Employing 5G networks, artificial intelligence, and blockchain technology, IoMT enhances remote patient care, secures medical data transmission, and facilitates real-time analysis. Applications include elder care, disease diagnosis, medical image encryption, and brain-computer interfaces for device control. b) IoMT's novelty lies in its advanced integration of 5G for high-speed, low-latency communication, AI-driven security models for robust data protection, and blockchain for decentralized, secure data management. These developments surpass traditional technologies by offering real-time, remote healthcare solutions with enhanced security and privacy, supporting the transition towards intelligent healthcare automation.	School of Information Technology and Engineering, Muthayammal Engineering College, RMK College of Engineering and Technology, College of Engineering, Prince Sultan University
AI disease prediction	AI disease prediction a) AI disease prediction leverages machine learning, including deep learning and ensemble methods, to analyze complex medical data, identifying patterns for disease identification and prognosis. It is applied in various domains, such as skin lesion classification, chronic disease management, diabetic nephropathy progression, and brain tumor detection. These systems can work with data from diverse sources, including electronic health records, medical imaging, and real-time sensor data from IoT devices, offering early diagnosis and personalized treatment strategies. b) The novelty of AI disease prediction lies in its advanced algorithms, capable of handling class imbalances, spatial heterogeneity, and high-dimensional data. The integration with metaverse and blockchain technologies for enhanced security and explainability, and the use of transformers in pathology, showcase its innovative approach to handling large-scale, complex data structures. Moreover, the convergence with the Internet of Medical Things (IoMT) indicates a shift towards real-time, continuous monitoring and prediction, setting it apart from more traditional, static data analysis methods.	University of Florida, Koneru Lakshmanah Education Foundation Green Fields, College of Engineering, Qingdao University, Institute of Technology

Environment and Agriculture

Weak signal	What it is? Why is it new?	Main actors
PFAs removal	a) PFAs removal technology employs functional adsorbent materials such as fluorinated redox-active amine-functionalized copolymers, metal-organic frameworks (MOFs), clay minerals and sewage sludge biochars, among others, to remove per- and polyfluoroalkyl substances (PFAS) from water streams. These adsorbents target short-chain PFAS, which pose a significant challenge due to their high mobility and hydrophilicity, and use cooperative molecular interactions to enhance affinity and modulate the electrochemical control of capture and release of PFAS. b) The technology's novelty lies in its tailored design to target short-chain PFAS, and its use of advanced materials like MOFs, which offer enhanced surface area, structural tunability, and improved selectivity over conventional adsorbents. Furthermore, the	University of Illinois at Urbana-Champaign, University of Louisiana at Lafayette, Swedish University of Agricultural Sciences, Beijing Jiaotong University, East China University of

	integration of these materials with electrochemical separations eliminates the need for chemical regeneration, making the technology more environmentally friendly.	Science and Technology
regenerative agriculture	a) Regenerative agriculture (RA) is a farming approach prioritizing soil conservation to regenerate multiple ecosystem services. It incorporates sustainability factors including economic, environmental, and social aspects. Key principles include maintaining soil cover, minimizing soil disturbance, increasing species diversity, integrating livestock, and limiting synthetic compounds, aiming to boost soil health, carbon sequestration, crop yield, and biodiversity. b) Compared to conventional farming, RA is a novel paradigm integrating the benefits of various sustainable agriculture narratives. It leverages innovative technologies like multi-objective optimization models and genetic engineering algorithms, addressing uncertainties in harvest planning. However, its transformative potential is underexplored, and its benefits may vary across agroecosystems, necessitating further research and empirical evidence.	Zhejiang University, Wageningen University and Research, Central South University of Forestry and Technology, Organization of African Academic
sustainable last mile delivery	a) Sustainable last mile delivery is a technology that aims to reduce environmental impact and improve efficiency in the final step of product delivery. This involves methods like cargo-bike delivery, use of electric vehicles, and unmanned aerial vehicles. Other strategies include customer engagement through social media, transparent information sharing on sustainability impacts, and integration of returns in delivery systems. b) The novelty lies in its multidimensional approach to sustainability, utilizing innovations in vehicle technology, customer engagement, and operational strategies. This includes the simultaneous use of drones and trucks for deliveries and returns, electric vehicle routing with optimized charging and discharging schedules, and leveraging data analytics for stakeholder interaction.	Jacobs University Bremen, University of Economics and Business, University of Western Ontario, Chalmers Design and Human Factors, University of Illinois at Urbana-Champaign
cultivated meat	a) Cultivated meat, also known as cell-cultured or lab-grown meat, is a novel technology where meat is produced in a lab setting from animal cells, without the need for traditional livestock farming. This technology aims to provide a sustainable, ethical, and health-conscious alternative to conventional meat, addressing environmental, animal welfare, and health concerns associated with traditional meat production. b) What sets cultivated meat apart from established technologies is its potential to drastically reduce environmental impact, including land use and emissions, compared to conventional meat production. The technology also presents a unique solution to ethical issues around animal welfare. However, it faces challenges in consumer acceptance, regulatory approval, and achieving commercial-scale production. Recent developments include serum-free media for cell growth and the creation of scaffolds to mimic the texture and structure of traditional meat.	Tufts University, San Jose State University, Maastricht University, Nanjing Agricultural University, Teagasc Food Research Centre
circular construction	a) Circular construction is an environmentally friendly approach in the building industry that focuses on waste and emissions reduction by reusing and recycling materials. The technology incorporates various methods such as life cycle assessment, green assessment tools, building information modeling, and tracking technologies for building components. It promotes efficient resource utilization and sustainable economic growth, fostering a circular economy in construction. b) The novelty of circular construction lies in its integration of advanced technologies and methods that promote resource efficiency. These include building information models, tracking technologies for components reuse, digital twins for design collaboration, and circular material passports for standardized information on material composition. Compared to traditional construction, this approach is more sustainable, reducing environmental impact while maintaining economic viability.	KTH Royal Institute of Technology, Brunel University London, Robert Gordon University, Leeds Beckett University, Leiden University
Urea electrolysis	a) Urea electrolysis is an innovative technology in environmental and agricultural sectors, effectively combining wastewater treatment with sustainable hydrogen production. It facilitates hydrogen production by oxidizing urea, a process that requires less energy than traditional water electrolysis. The technology involves the use of advanced bifunctional electrocatalysts that facilitate both the urea oxidation reaction (UOR) and hydrogen evolution reaction (HER). b) The novelty of urea electrolysis is that it provides a more energy-efficient method for hydrogen production compared to existing water electrolysis. Additionally, it offers a dual benefit of purifying urea-contaminated wastewater. Recent advancements involve the development of more efficient electrocatalysts and nanostructured materials, optimizing the energy conversion process and making it a promising avenue for large-scale, sustainable hydrogen production.	Chulalongkorn University, Tianjin University of Technology, National Tsinghua University, Hong Kong Polytechnic University, North University of China
agrophotovoltaic	a) Agrophotovoltaics is a dual land-use technology integrating farming and solar energy production on the same land area. It aids in producing renewable energy while maintaining agricultural activities, making it highly efficient in land use. This technology also helps in mitigating climate change effects and meeting global energy demands without causing land-use conflicts. Moreover, agrophotovoltaics can improve microclimatic conditions, reducing plant drought stress and solar panel heat stress.	Sun'Agri, University of Freiburg, Fraunhofer Institute for Solar Energy Systems ISE, Geisenheim University, University

	b) The novelty of agrophotovoltaics lies in its capability of merging renewable energy production with agriculture, resolving the traditional competition between food and energy production. This technology benefits from the synergistic interaction between photovoltaic panels and crops, offering potential improvements in both energy and agricultural productivity. It represents a significant innovation over conventional separated farming and energy production practices, paving the way for more sustainable and resilient land-use systems.	of Maryland
atmospheric water harvesting	a) Atmospheric water harvesting (AWH) is a technology that extracts moisture from the air to produce fresh water. This is achieved through advanced materials and structures, such as hygroscopic salt-based composite sorbents and 3D printed structures, that facilitate efficient water sorption and evaporation. The technology can be powered by solar energy and is capable of operating in various geographical locales and climatic conditions. b) AWH is a novel solution to global water scarcity, offering a sustainable, decentralized approach to freshwater production. It outperforms established technologies through enhanced device performance and improved water yield. The use of sophisticated materials and designs, such as nanoporous carbon derived from metal-organic frameworks, allows for rapid-cycling water harvesting, thereby maximizing productivity. Additionally, it leverages atmospheric conditions, making it a versatile and adaptable technology.	University of California, Humboldt-Universität zu Berlin, University of Chicago, National University of Singapore, SR Engineering College
building decarbonization	a) Building decarbonization refers to the process of reducing carbon emissions in the building sector through methods such as enhancing energy efficiency, integrating renewable energy sources, and employing advanced control systems. It is being applied in residential and commercial buildings, utilizing technologies like photovoltaic-thermal solar-assisted heat pumps, energy storage systems, and machine learning models for optimizing energy use. b) The novelty of building decarbonization lies in its integrated approach, combining traditional energy-saving methods with advanced technologies. This includes the use of machine learning models for predicting and optimizing energy use, and the integration of photovoltaic and thermal collectors in heat pump systems for enhanced efficiency. It offers a promising pathway towards achieving carbon neutrality in the building sector.	Lawrence Berkeley National Laboratory, Chongqing University, Joint Research Centre, Politecnico di Milano, Cornell University
circular food system	a) Circular food systems aim to enhance sustainability in the agri-food sector by minimizing waste and maximizing resource efficiency. This involves reusing by-products, managing risks in supply chains, and optimizing resource allocation. Applications include the transformation of farming practices, implementation of circular economy principles in food supply chains, and adjustments in food consumption patterns. b) The novelty of circular food systems lies in its systemic approach to sustainability. Unlike traditional methods that focus on individual aspects, circular food systems integrate biotechnical farming systems with socio-economic contexts. This includes the use of advanced decision-making models, innovative business models, and methods to quantify feed-food competition in aquaculture.	Wageningen University and Research, INRA, University of Helsinki, Indiana Wesleyan University, Auckland University of Technology
decarbonized chemicals	a) Decarbonized chemicals involve producing chemicals using processes powered by renewable or low-carbon sources, thereby reducing carbon emissions. Techniques include green methanol from renewable electricity, electrochemical processes, photoelectrochemical water splitting, and the use of transition metal-based catalysts. These methods are geared towards transforming the chemical industry into a carbon-neutral sector, applicable in petrochemical production, nitrogen compound production, and metal smelting. b) The novelty of decarbonized chemicals lies in the coupling of renewable energy with chemical production to significantly reduce greenhouse gas emissions. Unlike traditional petrochemical processes, these techniques utilize green hydrogen, electrocatalysis, and new catalysts like transition metal-based ones. This represents a major advancement towards the decarbonization of the chemical industry, which is a key contributor to global carbon emissions.	University of Colorado at Boulder, Northwestern University, University of California, University of Saskatchewan, University of Delaware
Direct seawater electrolysis	a) Direct seawater electrolysis is an emerging technology aimed at producing hydrogen. It works by exploiting the vast reserves of seawater to generate hydrogen gas through electrolysis, thus offering a sustainable solution for clean energy production and seawater desalination. Key advancements include the development of corrosion-resistant catalysts and techniques to improve the oxygen evolution reaction's efficiency and selectivity. b) This technology presents a novel approach to hydrogen production by bypassing the need for freshwater or pre-desalination processes typically used in conventional electrolysis. The innovative use of dual-doped catalysts and pH-asymmetric electrolyzers directly mitigates the corrosion problems and side-reactions that traditionally hinder seawater electrolysis, providing a more economically and environmentally viable option for hydrogen production.	Chinese Academy Of Sciences, University of Central Florida, Kent State University, Southeast University, University of Surrey
edge computing in	a) Edge computing in agriculture involves integrating Internet of Things (IoT),	Department of

agriculture	blockchain, and machine learning technologies to collect, process, and analyze data from agricultural sensors and devices. This enables real-time decision-making, improving crop productivity, resource management, and profitability while ensuring data security and privacy. b) The novelty of this technology lies in its synergistic use of IoT, edge computing, and blockchain for data-driven farming. Compared to traditional practices, it offers faster data processing, real-time analytics, enhanced security, and personalized decision-making, leading to increased efficiency in agricultural practices.	Computer Science and Engineering, Sona College of Technology, St. Joseph's Institute of Technology, Queen Mary University of London, Institute of Technology
e-dna metabarcoding	a) E-DNA metabarcoding is an advanced DNA sequencing tool used in ecological and conservation studies for reliable assessment and monitoring of aquatic biodiversity. The technology facilitates species detection through extracting and analyzing genetic material from environmental samples, providing comprehensive, efficient, and non-invasive biodiversity surveys. Its applications range from tracking dietary and parasitic patterns in farmland birds, revealing community structures in aquatic ecosystems, monitoring plant responses to environmental changes, to identifying pollinator species. b) The novelty of e-DNA metabarcoding lies in its ability to provide richness estimates and species inventories that are globally consistent, outperforming traditional methods in detecting more species and rare taxa. It enables the detection of species over broad temporal and spatial scales, and even allows for the estimation of relative species abundance. This technology can revolutionize ecological studies, standardized biodiversity monitoring, and conservation management. It also provides a rapid and cost-efficient tool for biodiversity monitoring, making it a next-generation tool in environmental and agricultural technologies.	Cornell University, Swiss Federal Institute of Aquatic Science and Technology, ONEMA, University of Zurich, CNRS
microplastic biodegradation	a) Microplastic biodegradation is a technology that employs specially selected or engineered microorganisms, such as bacteria or fungi, that can degrade microplastics, transforming them into harmless compounds. This technology is applied in environments contaminated with microplastics, including agricultural fields, water bodies, and wastewater treatment facilities. b) This approach is novel as it offers an eco-friendly alternative to conventional methods like landfilling, incineration, or physical removal which often fail to fully eliminate microplastics. Moreover, it broadens the potential for biodegradation beyond just naturally occurring bioplastics to petroleum-based plastics, which were previously considered resistant to degradation.	University of Malaya, University of Tehran, University of Hong Kong, Universidad Autónoma de Tlaxcala, University of Calcutta
hemispherical solar distiller	a) Hemispherical solar distillers are a form of solar desalination technology that use sunlight to evaporate water, with the vapour then condensing to produce clean water. Recent developments have aimed to enhance their efficiency and productivity through design modifications and the incorporation of materials like aluminum waste, phase change materials (PCM), and nanomaterials, which work to increase absorption of solar radiation, improve heat transfer, and provide thermal storage. b) The novelty of this technology lies in its ability to repurpose waste materials and utilize innovative design concepts to enhance performance. Compared to traditional distillation methods, these modifications can significantly increase water productivity and thermal efficiency, while also reducing the cost of freshwater production. Notably, the use of artificial neural networks to predict water productivity, the integration of evacuated tubes, and the application of nanofluid technology are among the recent innovations in this field.	Kafrelsheikh University, Tanta University, Suez University, University of El Oued, Prince Sattam Bin Abdulaziz University
food upcycling	Food upcycling technology involves converting food waste into valuable products such as nutrient-rich compost, biomass for energy production, or novel food ingredients. This approach leverages methods like 3D food printing, black soldier fly larvae composting, and waste valorization to repurpose food waste and reduce environmental impact. The novelty of food upcycling technology lies in its potential to address global issues of food waste and environmental sustainability simultaneously. Compared to traditional waste management methods, this technology enables efficient resource utilization, waste reduction, and the creation of high-value products from materials that were previously discarded.	University of Western Australia, Wageningen University and Research, National University of Singapore, Bharathidasan University, Sogang University

Energy

Weak signal	**What it is? Why is it new?**	**Main actors**
personal thermal management	a) Personal thermal management (PTM) technologies enhance individual comfort by regulating body temperature through advanced textiles and wearable devices. These innovations employ moisture-wicking, radiative cooling, and phase-change materials, alongside solar-thermal energy harnessing, to provide insulation, heat generation, and cooling effects, catering to diverse environmental conditions.	Donghua University, Huazhong University of S&T, Shandong Technology Innovation Center of Ecological Textile,

	b) The novelty lies in the integration of multifunctional capabilities such as selective optical cooling, electromagnetic interference shielding, and strain sensing into single PTM systems. Recent advances include sub-ambient cooling metafabrics, self-adaptive thermal regulation, and energy-efficient wearable electronics, surpassing traditional fabrics in thermal comfort and energy conservation.	Vision and Brain Health), Anhui Polytechnic University
Hydrogen geological storage	[a) Hydrogen geo-storage technology pertains to the storage of hydrogen in underground geological formations like depleted oil and gas fields, saline aquifers, and basaltic formations. This large-scale storage solution is essential for the transition to a hydrogen-based economy, providing a way to balance the intermittent nature of renewable energy sources. It also offers possibilities for long-duration energy storage, critical for clean power systems with high renewable energy penetration. b) The novelty of hydrogen geo-storage lies in its potential to significantly facilitate the shift towards sustainable energy systems. Unlike traditional energy storage methods, it offers vast storage capacities and the ability to effectively manage energy supply and demand. Recent advancements include the development of accurate hydrogen solubility models, investigations into the wettability of different rock formations in the presence of hydrogen, and the exploration of potential microbial interactions in subsurface storage.	Edith Cowan University, Curtin University, King Abdullah University of Science and Technology, King Fahd University of Petroleum and Minerals, University of Edinburgh
sustainable ammonia	a) Sustainable ammonia technology focuses on producing ammonia through environmentally friendly methods, such as electrocatalytic nitrogen reduction, direct ammonia fuel cells, and metal-organic frameworks for ammonia separation. This green ammonia can be used as a carbon-free fuel, in fertilizers, and for long-term energy storage, aligning with renewable energy production. b) The novelty lies in the development of efficient electrocatalysts, such as heterostructured quantum dots with metals, that surpass traditional catalysts in performance. Advances also include the use of grain boundary engineering in nickel nanoparticles and quantum molecular dynamics simulations to enhance production and the integration of renewable energy sources for ammonia synthesis.	College of Engineering, University of Technology, University of California, Duy Tan University, University of Illinois at Urbana-Champaign
turquoise hydrogen	a) Turquoise hydrogen is a novel method of hydrogen production achieved through thermal or thermo-catalytic pyrolysis of hydrocarbons, particularly methane. This process not only generates COx-free hydrogen but also produces solid carbon or graphene as valuable byproducts. In agriculture, it could provide a clean energy source; in the environment sector, it contributes to decarbonization by avoiding CO2 emissions and repurposing carbon into useful materials. b) The novelty of turquoise hydrogen lies in its lower energy intensity compared to traditional hydrogen production methods, such as steam-methane reforming or electrolysis. This technology harnesses thermal pyrolysis, potentially using renewable energy, to deliver significant reductions in carbon intensity. Its ability to produce negative carbon intensity hydrogen and generate valuable carbon byproducts distinguishes turquoise hydrogen from other hydrogen production methods.	Fraunhofer Institute, University of Technology Sydney, PSL University, Hamad Bin Khalifa University, Queen Mary University of London
green ammonia	Green ammonia a) Green ammonia is synthesized using renewable energy sources, reducing carbon emissions compared to conventional methods. It serves as a sustainable fertilizer in agriculture, a cleaner energy carrier, and a potential fuel for power generation, including in fuel cells, while also enabling waste nitrate removal. b) The novelty of green ammonia lies in its production through advanced electrocatalysis and photocatalysis techniques, enhanced by catalysts like atomically doped MoS2 and Au nanoclusters. These methods offer higher selectivity, efficiency, and lower environmental impact than the traditional Haber-Bosch process.	Lanzhou Jiaotong University, University of California, Duy Tan University, College of Engineering, University of Technology
grey hydrogen	a) Grey hydrogen is produced from natural gas through steam reforming without capturing the resulting carbon emissions, contributing to greenhouse gas (GHG) levels. Its use in energy storage, transportation, and agriculture could reduce reliance on fossil fuels but lacks environmental benefits compared to cleaner hydrogen variants. b) Grey hydrogen is not a novel technology; it is established with significant carbon footprint issues. Novelty in the hydrogen sector is currently focused on green and blue hydrogen, which offer lower emissions and align with global decarbonization goals, unlike grey hydrogen's traditional, more polluting process.	Universiti Teknologi Malaysia, Kyoto University, Saveetha University, National University of Singapore, Saveetha Dental College and Hospital
levelized cost of hydrogen	a) The levelized cost of hydrogen (LCOH) is a metric assessing the economic efficiency of hydrogen production over a system's lifecycle, accounting for capital, operational, and fuel costs. It supports decision-making in environmental and agricultural sectors by evaluating hydrogen as a sustainable energy carrier for various applications, including transport, energy storage, and ammonia production, with the potential to reduce greenhouse gas emissions. b) The novelty lies in integrating life cycle costing and assessment approaches for a holistic view of hydrogen's environmental and economic impacts. Recent advancements include optimizing renewable energy mixes for hydrogen production, developing hybrid	Ohio State University, University of Southern California, FEMTO-ST Institute, University of Twente, University of Padova

	systems to improve efficiency, and evaluating storage solutions like metal hydrides for maritime applications. These innovations offer improved cost-effectiveness and sustainability in hydrogen production compared to traditional fossil fuel-based methods.	
5th generation district heating	a) Fifth-generation district heating and cooling (5GDHC) is a versatile, energy-efficient system utilizing near-ambient temperature networks for distributing renewable heat and enabling waste heat recovery. It integrates decentralized heat pumps and renewable sources, like geothermal and solar energy, for simultaneous heating and cooling, improving energy efficiency while reducing CO2 emissions and thermal losses. b) 5GDHC is novel in its approach of operating at ambient temperatures which facilitates the integration of various low-grade renewable energy sources. Its bidirectional flow and efficiency in simultaneous heating and cooling represent advancements over traditional district heating systems, emphasizing sustainability and offering potential for sector coupling and load balancing.	Ramboll, DANFOSS AS, Institute of Engineering Thermophysics, nPro Energy GmbH, Nuremberg Tech
blue hydrogen	a) Blue hydrogen is produced from natural gas with carbon capture and storage (CCS), aiming to reduce CO2 emissions. It serves as an energy carrier and storage medium, potentially aiding in decarbonizing sectors like transport and industry. Applications extend to integrating with renewable energy sources and balancing energy systems. b) The novelty of blue hydrogen lies in its CCS aspect, which seeks to mitigate the environmental impact of hydrogen production from fossil fuels. It differs from traditional 'grey' hydrogen by potentially lowering the lifecycle greenhouse gas emissions, offering a transitional pathway towards a low-carbon economy.	University of Calgary, University of Alberta, University of Texas, Durham University, Politecnico di Milano
Direct recycling of batteries	a) Direct recycling of batteries is a process aimed at recovering and regenerating spent lithium-ion battery cathodes, enhancing their performance through methods such as doping with nickel and manganese, topotactic transformation, and molten salt treatments. These techniques restore electrochemical properties and stabilize battery structures, enabling the reintegration of recycled materials into new batteries, thus supporting environmental sustainability and resource efficiency in the electric vehicle industry. b) The novelty of direct battery recycling lies in its ability to not only recover cathode materials but also improve them for next-generation usage, contrasting with traditional methods that typically focus on material recovery without performance enhancement. Recent advancements, such as integrated pretreatment and relithiation processes, have moved direct recycling toward industrial scalability, potentially transforming battery waste management and alleviating raw material shortages.	Chinese Academy Of Sciences, Central South University, University of California, Tsinghua University, Leiden University
Direct seawater electrolysis	a) Direct seawater electrolysis is a technology that generates hydrogen fuel by applying electrical energy to seawater without prior desalination, overcoming the need for high-purity water. It involves enhanced catalysis to selectively drive the hydrogen and oxygen evolution reactions while mitigating issues like chloride corrosion and electrolyte contamination, which have traditionally limited efficiency and stability. b) The novelty lies in the development of advanced catalysts and electrolyzer designs that improve the selectivity and durability of the oxygen evolution reaction and hydrogen production while minimizing side reactions and corrosion. These innovations allow for the direct use of seawater, offering a potentially more sustainable and economically viable approach compared to conventional methods requiring desalination.	Chinese Academy Of Sciences, University of Central Florida, Kent State University, Southeast University, University of Surrey
Electrochromic energy storage	a) This technology relates to the development and application of advanced materials, primarily electroactive polymers and nanocomposites, for use in electrochromic and energy storage devices. These materials offer enhanced conductivity, electrochemical performance, and color change capabilities, enabling the creation of smart devices that can both store energy and visually indicate the level of stored energy. b) The novelty lies in the innovative fabrication methods and material combinations, such as the integration of polyanine with WO3 or the creation of Fe2O3/polypyrrole core-shell nanostructures. Compared to traditional technologies, these advances offer improved performance characteristics, such as greater optical contrast, faster switching times, and increased stability. These developments open up new possibilities for the use of electrochromic energy devices in various applications, including buildings, automobiles, and emerging electronics.	Chinese Academy Of Sciences, Nanyang Technological University, Henan University, Beihang University, Seoul National University of Science and Technology
green hydrogen	a) Green hydrogen, generated from renewable resources like wind, solar, and biomass, offers a sustainable energy carrier for sectors such as transportation, industry, and residential heating. Its production through water electrolysis or biomass processing leverages surplus renewable energy, reducing greenhouse gas emissions and providing a clean alternative to fossil fuels, with applications ranging from fuel cell vehicles to low-carbon industrial processes. b) The novelty of green hydrogen lies in its integration with intermittent renewable energy sources, utilizing advanced catalysts and electrolysis techniques to improve efficiency and reduce costs. Innovations include microwave-assisted pyrolysis for biomass, multi-objective optimization frameworks for solar-powered systems, and coupling electrolyzers with heat pumps for enhanced energy recovery, potentially	Politecnico di Milano, Hamburg University of Technology, SRM University, Cihan University-Erbil, Sejong University

	revolutionizing energy storage and distribution compared to traditional hydrogen production methods.	
osmotic energy harvesting	a) Osmotic energy harvesting utilizes salinity gradients, typically between seawater and freshwater, to generate sustainable power. This technology, centered around membrane-based systems like reverse electrodialysis, exploits ionic concentration differences to drive electric energy production. Innovations in membrane design, such as heterogeneous structures, ion-selectivity, and nanofluidic channels, enhance efficiency and power output, offering applications in renewable energy, water treatment, and smart nanodevices. b) The novelty of osmotic energy harvesting lies in the development of advanced membranes with higher power densities, surpassing commercial benchmarks. Breakthroughs include asymmetric geometry, subnanoscale channels, bio-inspired gateable ion transport, anti-biofouling properties, and enhanced mechanical stability. These improvements address past limitations such as ion concentration polarization, membrane fouling, and low energetic efficiency, representing significant strides toward practical and high-performance osmotic energy systems.	Chinese Academy Of Sciences, Qingdao University, Beihang University, National Taiwan University of Science and Technology, Zhejiang University
Gravity energy storage	a) Gravity energy storage technology utilizes gravitational potential energy by moving weights up and down to store and release energy. It can be combined with other technologies like compressed air energy storage and is especially advantageous for redeveloping abandoned deep mine shafts or marine environments. b) Compared to the established technologies like pumped hydro energy storage, gravity energy storage provides a more flexible and cost-effective solution for long-term energy storage in grids with small demand. This technology also offers unlimited cycles and the potential for higher energy storage capacity in certain topographies.	State grid Heilongjiang electric power Co ltd., State grid corporation of China, China University of Mining and Technology, North China Electric Power University, Stellenbosch University
Positive energy district	a) Positive energy district focuses on transforming urban districts into positive energy districts (PEDs). This involves creating an integrated energy system that optimizes energy consumption among buildings, implements renewable energy sources, and uses innovative business models. The technology allows for improved urban planning, enhanced sustainability, and better quality of life for citizens. b) The novelty lies in the ability to scale energy-efficient solutions from individual buildings to entire urban districts. This approach goes beyond traditional energy management, incorporating elements of microclimate mitigation, co-creation, and open innovation. It also enables the development of a common energy market and considers social aspects of energy use.	VTT Technical Research Centre of Finland, NTNU-Norwegian University of Science and Technology, Dalarna University, STIFTELSEN SINTEF, IREC Catalonia Institute for Energy Research
Smart local energy system	[a) Smart Local Energy Systems (SLES) leverages ICT to create decentralized, efficient, and intelligent energy networks. SLES employs tools like Pattern-IT, OPEN, and other smart platforms to manage and optimize energy generation, storage, and use. It incorporates smart technologies, energy storage, grid connection, and multi-vector integration, enabling diverse applications such as electric vehicles, peer-to-peer energy trading, and real-time energy services. b) Novelty in SLES arises from its approach to energy management. Unlike traditional centralized systems, SLES focuses on local, integrated, and adaptable energy solutions. It offers an open-source platform for developing new energy management applications, provides real-time control of local energy systems, and incorporates user engagement. Moreover, SLES considers social, economic, and regulatory contexts, addressing challenges of diversity, uncertainty, and integration in energy systems.	University of Strathclyde, University College London, University of Edinburgh, Newcastle University, University of Exeter
Zinc-ion hybrid supercapacitor	[a) Zinc-ion hybrid supercapacitors are flexible and self-healing energy storage devices that combine the merits of batteries and supercapacitors. They offer high energy density, excellent rate capability, and superb cyclability. They are ideal for wearable electronics and potentially large-scale energy storage. b) The novelty of ZHSs lies in their use of zinc, a resource-abundant and safe element, and their unique design that includes a redox iodide ion in the electrolyte for high energy density and a polyvinyl alcohol/nanocellulose hydrogel for mechanical stability and self-healing feature. This makes them safer, more environmentally friendly, and potentially more cost-effective than existing energy storage technologies	Chinese Academy Of Sciences, Xinjiang University, Anhui University, Anhui University of Technology, City University of Hong Kong

Quantum and Cryptography

Weak signal	What it is? Why is it new?	Main actors
Classic McEliece encryption	a) Classic McEliece encryption is a code-based quantum-resistant cryptographic algorithm. It relies on the hardness of the syndrome decoding problem, using Goppa codes to secure data against quantum computer attacks. With fast encapsulation/decapsulation and small ciphertexts, it offers strong security assurances and has advanced to the NIST PQC standardization process's fourth round. b) The novelty of Classic McEliece lies in its resistance to quantum attacks due to its foundation on code-based problems, which remain hard even for quantum computers. Compared to traditional schemes like RSA, threatened by quantum computing, Classic McEliece offers robust security, although it faces challenges such as large key sizes and slower key generation.	CNRS, University of Illinois at Urbana-Champaign, University of Toulouse, University of Rouen, Institut de Mathématiques de Bordeaux
gate based quantum computing	a) Gate-based quantum computing harnesses the principles of quantum mechanics to manipulate information using quantum bits (qubits). It employs quantum logic gates to perform operations, exploiting superposition and entanglement to process data in ways unattainable by classical computers. This technology is pivotal for advancements in quantum communication, sensing, optimization, and machine learning. b) The novelty of gate-based quantum computing lies in its use of quantum phenomena and scalable qubit architectures to achieve exponential speedups in certain computations, such as Grover's algorithm for search problems. Recent developments include the construction of exciton-based gates, adiabatic state transfer in spin qubits, and extended coherence times in fluxonium qubits, contributing to the progress toward fault-tolerant quantum computing.	Purdue University, Boise State University, Technology University, University of Toronto, Center for Emergent Matter Science
HHL algorithm	a) The HHL algorithm is a quantum computing method that solves linear systems exponentially faster than classical computers in certain instances, relying on quantum superposition and entanglement. It is a critical subroutine for quantum machine learning, with applications in optimization, electromagnetic simulations, and quantum-based artificial intelligence. b) The novelty of the HHL algorithm lies in its utilization of quantum mechanical principles for computational speedup, contrasting the polynomial time complexity of classical solvers. Recent advances focus on reducing quantum circuit complexity, optimizing for near-term quantum devices, and expanding practical applications, such as power systems and thermal dynamics simulations.	Tsinghua University, Indian Institute of Technology, QUANTUM CORP, Stony Brook University, Delft University of Technology
kyber digital signature algorithm	a) The Kyber Digital Signature Algorithm is a post-quantum cryptographic method designed to secure digital communications against potential quantum computer attacks. This lattice-based algorithm relies on the hardness of the learning-with-errors problem over module lattices, offering encryption and key encapsulation resistant to quantum decryption strategies. b) The novelty of this technology lies in its quantum resistance, where traditional algorithms like RSA and ECC would fail. Unlike these, Kyber's module-lattice structure and quantum-safe properties make it a cutting-edge solution for secure communications in the emerging era of quantum computing, aligning with NIST's standards for post-quantum cryptography.	Politecnico di Torino, Chinese Academy Of Sciences, Tsinghua University, Indraprastha Institute of Information Technology, IIT
lattice-based quantum cryptography	a) Lattice-based quantum cryptography leverages the mathematical complexity of lattice problems to create cryptographic schemes that are secure against quantum computer attacks. This technology applies efficient algorithms like the Number-theoretic transform (NTT) for operations such as polynomial multiplication, which is critical for systems like Kyber, a standardized key encapsulation mechanism. Its versatility allows for robust implementations on platforms like FPGAs and IoT devices, offering secure group signatures and encrypting data with high efficiency and low overhead. b) The novelty of lattice-based quantum cryptography lies in its quantum-resistant properties and the ability to implement it efficiently on conventional hardware. While traditional cryptosystems rely on problems like integer factorization, which quantum computers can solve quickly, lattice-based cryptography offers a viable alternative with simple and efficient structures. Recent advancements include custom hardware architectures, optimized polynomial multiplication methods, and error detection schemes, which enhance the reliability and performance of cryptographic applications in anticipation of the quantum era.	Huazhong University of Science and Technology, Queen's University Belfast, University of Cyril and Methodius, Marymount University, George Mason University
Parameterized quantum circuits	a) Parameterized quantum circuits (PQCs) are quantum-classical hybrid systems leveraging tunable gates for tasks like machine learning (ML) and quantum simulation. By iteratively adjusting parameters during training with limited datasets, PQCs can generalize learning for applications including state classification, error correction, and dynamical simulations. b) The novelty of PQCs lies in their adaptability and resilience to noise, a departure from traditional, static quantum circuits. Recent methodologies enable verification of	Yale University, Los Alamos National Laboratory, Massachusetts Institute of Technology, University of Taxes at Austin, Shanghai Jiao Tong University

	circuit equivalence and noise-adaptive optimizations, enhancing robustness and accuracy on noisy intermediate-scale quantum (NISQ) devices, potentially accelerating the quest for quantum advantage.	
quantum autoencoders	a) Quantum autoencoders are advanced quantum algorithms designed to compress quantum information into a lower-dimensional space, akin to their classical counterparts. They are trained to efficiently encode and decode quantum states, leveraging variational quantum circuits and classical optimization techniques. Potential applications include quantum simulation, enhancing quantum error correction, optimizing quantum control, and anomaly detection in high-energy physics. b) The novelty of quantum autoencoders lies in their ability to handle quantum data directly, providing a compression mechanism that classical algorithms cannot achieve. They utilize the unique properties of quantum mechanics, such as superposition and entanglement, to discover new logical encodings and potentially offer exponential improvements in training costs and data processing for quantum systems.	University of New South Wales, Durham University, Harvard University, Australian National University, University of Science and Technology of China
quantum battery	a) Quantum batteries are advanced energy storage systems leveraging quantum properties like entanglement and coherence to deposit and extract energy more efficiently than classical batteries. They utilize ensembles of quantum systems and entangling operations for superior charging speeds, showing potential for enhanced performance in energy capture, storage, and transfer applications. b) The novelty of quantum batteries lies in their exploitation of quantum correlations and collective phenomena, such as superabsorption and entanglement, to achieve faster charging rates and higher work extraction than possible with traditional energy storage. Their development marks a significant shift towards harnessing quantum mechanics for practical energy solutions.	University of Gdańsk, Institute for Basic Science, National University of Singapore, Monash University, Northwest Normal University
quantum blockchain	a) Quantum blockchain is a technology that enhances traditional blockchain security by incorporating post-quantum cryptographic algorithms to withstand quantum computer attacks. It uses quantum-resistant techniques like quantum key distribution (QKD), quantum signatures, and entanglement-based protocols to secure data integrity and enable trust in decentralized systems. b) The novelty of quantum blockchain lies in its ability to safeguard distributed ledger technologies against quantum threats. Its implementation in existing networks without starting from scratch, the use of quantum entropy for key generation, and the development of on-chain verification of quantum signatures are cutting-edge advancements over conventional blockchain security measures.	Nanjing University of Information Science and Technology (NUST), Hubei University of Science and Technology, Halmstad University, National Center, LACChain-Global Alliance for the Development of the Blockchain Ecosystem in LAC
quantum classifier	a) Quantum classifiers use quantum computing principles, like superposition and entanglement, to categorize data. They operate on quantumly encoded data and can exploit quantum speed-ups for tasks like pattern recognition, potentially exceeding classical machine learning capabilities in efficiency and accuracy, especially for complex or entangled datasets. b) The novelty lies in their ability to leverage quantum mechanics for classification tasks, potentially offering speed-ups based on complex quantum feature spaces and kernel methods. They demonstrate resilience to noise and promise advantages in solving problems intractable for classical computers, such as those with high-dimensional feature spaces.	IBM Corp, QUANTUM CORP, National University of Singapore, Zagazig University, Johns Hopkins University
quantum cloud computing	a) Quantum cloud computing integrates quantum computing's super-fast processing, based on quantum physics principles, with cloud computing's as-a-service model. It enables scalable quantum data centers and infrastructure, offering users remote access to quantum resources for various applications, including artificial intelligence, machine learning, robotics, and secure data processing. b) The novelty of quantum cloud computing lies in its potential to provide powerful quantum computational capabilities without requiring users to own quantum hardware. This emerging technology addresses current cloud computing challenges by promising enhanced processing speeds, stronger security through blind computing protocols, and optimized resource allocation, signifying a paradigm shift in data processing and security.	National University of Singapore, Jain (Deemed to be) University, Peking University, University of Bristol, University of Hong Kong
quantum compiler	a) Quantum compilers translate high-level quantum algorithms into hardware-native operations, considering device-specific constraints like qubit connectivity and gate alphabets. They optimize circuits for execution fidelity on noisy intermediate-scale quantum (NISQ) devices, which lack error correction, by employing techniques like diverse qubit mapping, error mitigation strategies, and resource-efficient gate constructions. b) The novelty lies in advanced error mitigation techniques like Ensemble of Diverse Mappings (EDM) and Invert-and-Measure, optimization-aware routing algorithms like NASSC, and variational hybrid compiling approaches. These developments enable more reliable and efficient quantum computation, reducing gate overhead and enhancing algorithm fidelity on current quantum hardware.	Chinese Academy Of Sciences, Georgia Institute Technology, Los Alamos National Laboratory, University of Chicago, Alma Mater Studiorum
quantum drug	a) Quantum drug discovery leverages quantum computing to simulate and analyze	Harvard University,

discovery	molecular interactions at unprecedented speeds and accuracies, enabling the identification of novel drug candidates and the optimization of their properties. It combines quantum algorithms, machine learning, and AI to improve the efficiency and success rates of the drug design process. b) Compared to classical computational methods, quantum drug discovery is novel in its potential to process complex quantum chemistry problems more efficiently, thereby reducing the time, cost, and computational resources required for drug development. It also promises to enhance the predictive power of QSAR models and overcome limitations of current drug discovery platforms.	University of Cape Town, University of Toronto, MONTE GROUP LIMITED, Insilico Medicine Shanghai Ltd
quantum generative adversarial network	a) A quantum generative adversarial network (QGAN) is a quantum-enhanced machine learning framework where a quantum generator creates data mimicking a true dataset, while a quantum discriminator distinguishes between true and fake data. This adversarial process optimizes both parties using quantum information processors and can handle quantum states or classical data, potentially offering an exponential advantage in high-dimensional spaces and reducing the number of required parameters for learning. b) The novelty of QGANs lies in their utilization of quantum states and quantum computation to improve learning efficiency and data synthesis quality. Unlike classical GANs, QGANs can leverage quantum superposition and entanglement to process complex distributions more effectively, offering stable convergence and performance enhancements with fewer parameters. They also show promise in handling noise and can be implemented on near-term quantum devices, marking a significant advancement over traditional machine learning techniques.	CERN, IBM Corp, Ecole Polytechnique Fédérale de Lausanne EPFL, Xanadu, Kent State University
Quantum microscopy	a) Quantum microscopy leverages entangled photon pairs and quantum states of light to enhance imaging resolution beyond classical limits, enabling precise phase estimation and low-photon-level imaging while reducing sample damage. It utilizes properties like photon antibunching, spatial correlations, and quantum interference to achieve super-resolution and high-contrast imaging, with applications in nondestructive bioimaging and material characterization. b) Compared to traditional microscopy, quantum microscopy introduces the ability to image at the Heisenberg limit, offers sub-wavelength resolution, and operates with significantly reduced light intensities. Innovations include intrinsic spatial differentiation, real-time feedback control for ab initio phase estimation, and quantum-enhanced detectors, which enable novel imaging techniques like full-field, scan-free imaging and high-dimensional entangled state transmission through disordered media.	Politecnico di Milano, Sorbonne University, University of Glasgow, Institut de Ciències Fotòniques, Hunan University
Quantum neural networks	a) Quantum neural networks (QNNs) are a hybrid of classical neural network concepts and quantum computing principles, designed to leverage quantum properties such as superposition and entanglement to process information. They have potential applications in quantum simulation, machine learning tasks like image classification, and collaborative optimization problems, such as coordinating unmanned aerial vehicles. QNNs aim to mitigate complexity and enhance performance in data-rich environments compared to classical approaches. b) The novelty of QNN technology lies in its ability to potentially overcome limitations of classical neural networks, such as the scaling of complexity with large parameter spaces. Recent advances include noise-adaptive optimization for better performance on current quantum hardware, strategies to avoid training stagnation due to barren plateaus, and the use of quantum properties to improve training efficiency and generalization capabilities. These developments position QNNs as a promising avenue toward achieving quantum advantage in processing and learning from data.	Los Alamos National Laboratory, California Institute of Technology, Center for Nonlinear Studies, LANCASTER UNIVERSITY, Ajou University
quantum phase estimation algorithms	a) Quantum phase estimation algorithms (QPEAs) utilize quantum computers to estimate eigenvalues of operators, crucial for simulating quantum systems. They involve coherent evolution, ancilla qubits, and sometimes classical optimization for state preparation, aiming to achieve Heisenberg-limited precision. QPEAs enable calculations intractable for classical computers, such as molecular energy levels and material properties, with applications in chemistry, battery technology, and pharmaceuticals. b) The novelty lies in QPEAs' ability to start from classically hard Hamiltonians, their reduced coherence time requirements, and alternative techniques like Krylov subspace methods avoiding costly gates. Recent advances have dramatically cut quantum resource needs, enabling complex simulations on near-term devices and foreshadowing significant impacts on computational chemistry and material simulations.	VOLKSWAGEN AG, Xanadu, Emory University, Indian Institute of Technology Bombay, Northwestern University
quantum reinforcement learning	a) Quantum reinforcement learning (QRL) employs variational quantum circuits within quantum-classical hybrid systems to optimize sequential decision-making tasks. Unlike traditional RL, QRL can theoretically offer computational speed-ups and potentially tackle tasks intractable for classical models, such as mission planning for Earth-imaging satellites or control and coordination in smart factories.	Leiden University, Wells Fargo, Korea University, Fraunhofer Institute for Integrated Circuits IIS, Friedrich-Alexander

	b) The novelty of QRL lies in its integration of quantum computing with reinforcement learning, promising advantages over classical algorithms in efficiency and problem-solving capabilities. The potential to solve complex benchmark environments and demonstrate theoretical advantages in specific learning tasks represents a significant breakthrough in the field.	University Erlangen-Nuremberg
quantum reservoir computing	a) Quantum reservoir computing (QRC) leverages the complex dynamics of quantum systems for temporal machine learning tasks by utilizing large Hilbert spaces and quantum properties. It employs dissipative quantum elements that naturally incorporate noise as a computational resource, aiming to process information in real-time and potentially outperform classical approaches. b) The novelty of QRC stems from its use of inherent quantum noise and dynamics as computational advantages, contrasting with traditional methods that view noise as an obstacle. It offers a unique approach to temporal data processing with the promise of quantum advantage in specific tasks, facilitated by current quantum technologies.	IFISC, University of Tokyo, Keio University, CNR, Mitsubishi Group
quantum resistant algorithm	a) Quantum resistant algorithms are cryptographic protocols designed to secure data against the computational power of quantum computers, which can break traditional schemes such as RSA. These algorithms utilize complex mathematical problems that quantum computers struggle to solve, employing techniques like lattice-based cryptography, multivariate polynomial equations, and hash-based signatures to protect digital communications and assets. b) The novelty of quantum resistant algorithms lies in their ability to withstand attacks from quantum computers, a feat that current cryptographic methods cannot achieve. They incorporate advanced mathematical structures and leverage the unique properties of quantum mechanics, offering a new layer of security for applications ranging from blockchain networks to secure communications within the Industrial Internet of Things (IIoT).	School of Informatics Computing and Cyber Systems, LACChain-Global Alliance for the Development of the Blockchain Ecosystem in LAC, Indian Institute of Technology Delhi, Center for Cyber Security Systems & Networks, Institute of Technology
quantum sdk	a) Quantum software development kits (SDKs) facilitate the encoding, compilation, and execution of quantum applications on quantum computers. These SDKs enable the integration of quantum circuits with classical systems, allowing for automated deployment and orchestration, simulation of hybrid quantum-classical systems, and the development of quantum encryption schemes. They support various quantum hardware platforms and provide tools for optimization and error correction to enhance performance and fidelity. b) The novelty of these quantum SDKs lies in their advanced optimization techniques, such as reinforcement learning frameworks for circuit compilation and Pauli-based graph representations for circuit optimization. They represent a significant departure from traditional classical compilers by addressing the unique challenges of quantum computing, including hardware-specific tailoring, hybrid system simulation, and the encryption of quantum states. This innovation paves the way for more efficient quantum applications and the potential realization of a secure quantum internet.	Quantropi Inc., Michigan State University, Intel Labs, University of Chicago, Technical University of Munich
quantum support vector	a) Quantum support vector machines (QSVMs) leverage quantum computing to process and classify complex datasets with potentially exponential speedup over classical algorithms. By using quantum circuits to define kernel functions and perform matrix inversions, QSVMs can improve classification accuracy and efficiency, particularly in large-scale and high-dimensional data scenarios. b) The novelty of QSVMs lies in their utilization of quantum mechanics to accelerate the training of machine learning models. This approach offers a significant computational advantage for specific datasets, addressing the challenges of big data and high-dimensional spaces that classical SVMs face, thereby enhancing performance in fields like particle physics, network security, and healthcare.	Indian Institute of Technology, QUANTUM CORP, Massachusetts Institute of Technology, University of Iceland, Institute for High Energy Physics
quantum transduction	a) Quantum transduction entails the conversion of quantum signals across different energy domains, like microwaves to photons, enabling long-distance quantum communication and linking disparate quantum systems. It involves coherent interactions, such as exciton-magnon coupling in solids or opto-electro-mechanical processes, to transfer quantum information with high fidelity. b) The novelty of quantum transduction lies in achieving high conversion efficiency and low noise at millikelvin temperatures, crucial for quantum networks. Recent advances include enhanced control over coupling mechanisms, significant efficiency improvements, and the integration of quantum systems for potential applications in quantum computing, sensing, and communication.	University of Washington, University of Chicago, Institute of Science and Technology Austria, University of Wisconsin-Madison, Argonne National Laboratory
Quantum Variational Algorithms	a) Quantum Variational Algorithms (VQAs) employ parameterized quantum circuits, optimized classically, to solve problems on noisy intermediate-scale quantum (NISQ) devices. They leverage high-fidelity control of qubits and are used for tasks like calculating molecular energies, machine learning, and feature selection, despite challenges in circuit depth and noise. b) The novelty lies in VQAs' hybrid classical-quantum approach, suitable for NISQ	Delft University of Technology, PRESTO, Osaka University, Center for Nonlinear Studies, Los Alamos National Laboratory

	computers, and their adaptability to current hardware limitations. They represent a shift from traditional algorithms towards methods that can operate amid noise, offering potential quantum advantages in certain computational tasks earlier than fully fault-tolerant quantum computers.	
shallow quantum circuits	a) Shallow quantum circuits leverage limited quantum depth to perform computations that intertwine quantum and classical processing. These circuits, which operate with fewer layers of quantum gates, can solve certain search problems, assist in quantum machine learning, simulate nonequilibrium physics, and facilitate the characterization of quantum states. They are particularly suited to the constraints of current noisy intermediate-scale quantum (NISQ) devices and have applications in variational algorithms, quantum neural networks, and hybrid quantum-classical algorithms. b) The novelty of shallow quantum circuits lies in their ability to execute meaningful quantum computations with minimal quantum resources, contrasting with deeper circuits that are often unfeasible on current hardware due to noise and decoherence. Their development marks progress in quantum algorithms by offering new frameworks for proving quantum computational depth, limitations on quantum optimization algorithms, and efficient methods for learning and simulation that are tailored for NISQ-era technologies.	Harvard University, QUANTUM CORP, Zapata Computing Inc., Institute of Nanotechnology, University College London
superconducting quantum processors	a) Superconducting quantum processors leverage low-temperature conductors to create qubits for quantum computing. They enable high-fidelity gate operations, error correction, and exploration of quantum states, promising unprecedented computational power and insights into quantum mechanics for applications like optimization and quantum simulations. b) This technology represents a leap from classical computing, enabling quantum advantage through scalable qubit architectures and novel error mitigation techniques. It offers a platform for implementing complex algorithms and studying many-body quantum phenomena, which cannot be efficiently replicated with existing classical systems.	University of California, University of Science and Technology of China, QUANTUM CORP, IBM Corp, University of Massachusetts
variational quantum circuits	a) Variational quantum circuits (VQCs) are quantum algorithms that leverage parameterized quantum gates to process and classify quantum-encoded data. They facilitate quantum optimization and machine learning by predicting class labels through observable measurements. VQCs utilize quantum properties like entanglement to efficiently handle large data sets and feature spaces, offering robustness to quantum noise. Their hybrid quantum-classical nature allows for reduced model sizes and faster convergence compared to classical counterparts, addressing challenges in image classification, sequence modeling, and computational chemistry. b) The novelty of VQCs lies in their ability to directly manipulate quantum states for machine learning, offering a more flexible and expressive approach than traditional variational algorithms. VQCs reduce the computational cost by exploiting symmetries and structure in data. The technology is particularly innovative in its use of quantum-enhanced feature spaces and noise-adaptive circuit design, pushing the boundaries of what's possible on Noisy Intermediate-Scale Quantum (NISQ) computers and demonstrating potential for quantum advantage in various machine learning tasks.	University of Chicago, Massachusetts Institute of Technology, Yale University, Brookhaven National Laboratory, University of KwaZulu-Natal
NISQ devices	a) NISQ devices, or Noisy Intermediate-Scale Quantum devices, are early-stage quantum processors with 50-100 qubits capable of surpassing some classical computing tasks despite inherent noise and error rates. They employ variational circuits and hybrid quantum-classical algorithms for applications in quantum simulation, machine learning, and optimization, though they aren't yet fault-tolerant. b) NISQ technology is novel for its use of current semiconductor technologies to achieve qubit fidelities above 99%, a significant step towards fault tolerance. It innovates by optimizing quantum circuits for noise resilience and represents a transition phase, harnessing quantum advantages with limited qubit coherence and without full error correction.	Massachusetts Institute of Technology, Delft University of Technology, Harvard University, NL ORGANISATIE VOOR TOEGEPAST NATUURWETENSCHAPPELIJK ONDERZOEK TNO, National University of Singapore

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