European Commission

AI in Science

Harnessing the power of AI to accelerate discovery and foster innovation

POLICY BRIEF

Research and Innovation

AI in Science

Harnessing the power of AI to accelerate discovery and foster innovation

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EUROPEAN COMMISSION

AI in Science

Harnessing the power of AI to accelerate discovery and foster innovation

Policy brief

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FOREWORD BY COMMISSIONER IVANOVA

Artificial Intelligence (AI) is a powerful force for transformation. It also has the potential to be a major disruptor, with the potential to redefine the vast realm of science and to impact many aspects of human life. This seismic shift underscores the urgency for a tailored European research policy dedicated to AI in science.

Existing policy initiatives at the European level already acknowledge the strategic importance of AI, laying out a comprehensive strategy to foster the right framework conditions for AI in Europe. This policy brief is grounded in the EU's AI strategy, and focuses on science, guided by the dual principle of trustworthy AI and excellence in AI.

AI's growing role in science spans various fields, it acts as a catalyst for scientific breakthroughs and a key instrument in the scientific process. This heralds a new era of accelerated results; it pushes scientific frontiers and produces outcomes beyond the reach of current tools. This acceleration can help us tackle the most pressing societal challenges, such as the green and digital transitions, it will also help keep Europe at the cutting edge of scientific progress. EU-funded researchers are already harnessing AI in ground-breaking ways, from improving cancer treatments to solving environmental issues and improving earthquake predictions.

However, the wide application and success of AI in science also has geopolitical consequences. Leadership in AI-powered science will translate into leadership in discovery and innovation, which is essential for Europe's competitive edge, prosperity, and technological sovereignty. Current trends suggest that leading countries will continue to outpace their competitors, intensifying the 'winner-takes-all' dynamic. In this landscape, it is imperative for the EU to maintain its open strategic autonomy, to ensure its security and to uphold its values. Missing this opportunity risks being sidelined in the race for future discoveries and technologies.

This policy brief addresses science-specific AI challenges such as preserving scientific integrity, preventing technology misuse and capitalising on the power of data. In shaping a strategy together with the European scientific community, our goal is twofold: to harness AI's vast potential while addressing the concerns of our citizens. Achieving this depends on the collective commitment of all stakeholders in European science and research.

The policy brief is a contribution to a dialogue on optimising AI to bolster the future of European science. Expert consultations are already in progress, and I look forward to receiving the Opinion of the Scientific Advice Mechanism in early 2024.

I sincerely hope that this policy brief sparks a wide debate within the European scientific community. Your insights are invaluable in this endeavour.

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AI IN SCIENCE

Executive Summary

Science increasingly relies on Artificial Intelligence (AI) to progress, innovate, and deliver solutions to societal challenges.

This policy brief advocates **for a tailored European Research Area policy to harness the power of AI to accelerate research capabilities, fostering innovation and driving economic growth.** It addresses science-specific needs related to AI, building on and complementing existing AI and R&I policies. It sketches first policy ideas to initiate the debate with R&I stakeholders. These ideas will be further developed based on the recommendations of the Scientific Advisory Mechanism on how to accelerate the responsible integration of AI in science.

With the forthcoming AI Act, the EU takes the global lead in setting the framework conditions for an excellent and trustworthy AI. We underscore the need to grasp the opportunities arising from an excellent and trustworthy AI for science in order to compete globally and capitalise on future breakthroughs and technologies.

Integrating AI in scientific discovery is crucial for enhancing the EU's competitive edge in the global scientific arena. Leadership in AI-powered science will translate into leadership in discovery and innovation, essential for economic and social prosperity and strategic autonomy.

AI is transforming the scientific landscape across every stage of research, assisting scientists, processing large-scale data, making predictions, automating tasks. Furthermore, AI can boost scientific productivity and deliver solutions to global challenges like climate change and antimicrobial resistance. In medicine, AI is advancing diagnostics, drug discovery, and understanding the human brain. New advanced materials, digital twins, brain-like AI, and harnessing nuclear fusion's power for carbon-free sustainable energy all present exciting opportunities, which AI-powered science can deliver for the benefit of humanity.

Nevertheless, **AI innovation brings specific challenges for science** like preserving the integrity of science, improving public trust in science, attracting and keeping scientific talent, using the power of data, ensuring diversity and reducing regional disparities.

While AI amplifies researchers' abilities rather than replacing them, in the future it could become a scientific force in its own right. The prospect of AI Scientists, capable of making major discoveries, may not be too far ahead. Such evolution could fundamentally reshape scientific processes and redefine the role of scientists.

As policy makers, our goal (and challenge) is to turn the potential of AI as "a force for good" into a reality by building the right framework conditions to accelerate and responsibly integrate this technology in science. We highlight the following **areas for action**:

- **Vision and governance.** We propose a vision for policy designed to enable a diverse community of European scientists to make the best use of AI for scientific breakthroughs and ultimately to maintain EU's leadership in science, with the creation of value for the economy and society. A policy for AI in Science needs an ecosystem approach in its governance, in coordination with digital and AI policy, education policy and cohesion policy.

- **Talent.** EU has a strong scientific base and is a hot-spot for trust and excellence in AI research. However, brain drain and barriers in the academic career framework represent challenges. The adoption of AI in science requires developing the right enablers to attract and retain talent such as research engineers, and train researchers for AI-driven science. In addition, it is crucial to understand the impact of AI on the work and lives of researchers and pave new ways of doing science.

- **Data, compute, AI assets ecosystem.** The completion of the data spaces, including of the European Open Science Cloud (EOSC), will be a key competitive advantage for the EU. Accelerating the uptake of AI in Science is required to upgrade the current EU initiatives into an environment that enables further automation in AI-driven research. This includes access to quality datasets and high-performance computing tailored to AI.

- **Funding and R&I system**. To accelerate scientific breakthroughs, it is crucial to establish a portfolio of strategic R&I investments for using AI to solve scientific challenges and increase the productivity of science. This portfolio should encompass fundamental research and the facilitation of the road to market of these breakthroughs. Creating enabling conditions for researchers to embrace interdisciplinarity and knowledge sharing will also be a key priority.

- **Enabling framework.** AI amplifies ethical issues like the difficulty to explain and reproduce scientific results. Furthermore, it could mirror the lack of diversity in some domains of science in its final outcomes. Taking action on these aspects would help preserve trust in science. In the long run, the scientific community and policy makers must remain vigilant about potential technology misuse in science. While the EU is at the forefront of AI regulation and ethical enforcement, effectively countering potential risks may require more agile mechanisms and international collaboration.

The challenges and drivers of change brought by AI emphasize the necessity for EU-level action and initiatives to develop an enabling ecosystem for AI in science. Thus, **the policy for AI in Science will**:

1. Accelerate AI uptake by scientists in the EU to harness AI's transformative impact in science for societal benefits and global competitiveness. This involves reducing barriers to adoption, strengthening the data and compute ecosystem, identifying strategic R&I investments for the use of AI in science and developing the right policy enablers.

2. Monitor and steer the impact of AI in the scientific process. This includes monitoring the impact of AI on research careers, addressing ethical challenges and risks of misuse. Citizens engagement and pro-active communication, monitoring and evaluation actions will be important to preserve public trust in AI-driven science.

This policy brief will be followed by stakeholder consultations to inform future policy measures.

1. Introduction

Artificial Intelligence (AI) holds enormous potential for science and our goal (and challenge) as policymakers is to turn this potential into reality by building the right framework conditions for an accelerated and responsible AI adoption in science, and scaling up of AI technologies for research, development and innovation.

As the impact of AI on science is constantly evolving, this policy brief has as its primary objectives to:

- **Set out the need for tailored policy to address science-specific needs related to AI**. It will build on and complement existing AI policy, amplifying their positive impact particularly on science and the scientific community.

- **Highlight current and future capabilities and risks of AI in advancing scientific discovery** and in strengthening the role of science in solving global challenges.

- **Initiate an EU-wide discussion** with stakeholders to understand how AI affects the dynamics of the European research ecosystem.

- **Sketch policy ideas** to facilitate fast and responsible integration of AI in the scientific process in order to enable science to benefit from AI's full potential.

By AI in science, we consider both the application of available AI tools in the scientific process but also the development of AI specifically designed for scientific needs and use. While they are interlinked, the focus of this document is less on the development of fundamental AI and more on **the application of AI in the scientific process as a means to drive discovery and breakthroughs in science**. We also acknowledge that the role of R&I policy for AI in Science ranges from the early stages of research to support for innovation and the take-up of the AI-based scientific results or of new AI-based research tools in the market. We also consider the importance of the **ecosystem around the development and use of AI in science** in the EU, with a central focus on researchers, empowering them to unleash their full potential both as AI developers and users.

Overview of chapters in the document: Chapter 2 provides the technology context of AI; **Chapter 3** outlines the overarching AI policy context in the Commission; **Chapter 4** sets out the need for a dedicated policy for AI in Science; **Chapter 5** showcases key applications of AI in the scientific process and illustrates how AI can help science solve global challenges and deliver on Europe's strategic priorities; **Chapter 6** takes a glimpse into possible future applications of AI in science; **Chapter 7** discusses AI-related challenges for science; **Chapter 8** details policy ideas; **Chapter 9** offers a summary and next steps.

2. Technology context

AI is not a new technology. Its definition and scope of techniques have evolved through time: from simulating human experts' judgment (expert systems), through to learning from data (machine learning), to the dominating, data-driven technology at present, based on neural networks (deep learning). The abundance of digitised data and the growth of computing capacity have played an important role in the success of data-driven AI[1].

What is AI?

Most AI definitions[2] converge in their focus on machines or software systems that: (i) possess learning capabilities, (ii) make intelligent decisions, (iii) influence the environment, (iv) improve tasks autonomously, and (v) exhibit human-like cognitive functions.

Most recently, as part of its AI Act, the EU defines an artificial intelligence system as "a machine-based system designed to operate with varying levels of autonomy and that may exhibit adaptiveness after deployment and that, for explicit or implicit objectives, infers, from the input it receives, how to generate outputs such as predictions, content, recommendations, or decisions that can influence physical or virtual environments".

2022 was a milestone year for AI, marked by the uptake of Generative AI[3], capable of producing and interpreting text, images, and more. The most exemplary of generative AI tools - ChatGPT -- turned into the fastest technology to reach 100 million users[4] and unleashed a world-wide debate on the impact of AI on every aspect of human life, including science.

AI is a key enabling technology for science. While science has shaped AI's foundation through mathematics and statistics underpinning its algorithms, and electronics powering its processors, AI is reciprocally aiding scientific research. Its use has seen significant growth across various scientific domains, accounting for over 60% of all AI publications in 2021 and growing at 34% on a yearly basis since 2017 (Arranz et al., 2023). AI helps solve complex scientific challenges and puzzles, thus driving forward its own improvement and opening new opportunities for exploration.

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[1] AI and compute, https://openai.com/research/ai-and-compute
[2] More existing definitions AI Watch. Defining Artificial Intelligence 2.0 (europa.eu)
[3] *HAI_AI-Index-Report-2023_CHAPTER_2.pdf (stanford.edu)
[4] https://www.reuters.com/technology/chatgpt-sets-record-fastest-growing-user-base-analyst-note-2023-02-01/

3. EU policy context framing the future policy approach on AI in Science

A policy for accelerated adoption of AI in science will integrate into the overarching framework set by the EU's AI strategy, the Coordinated Plan on AI and the European Research Area.

The EU recognises the strategic importance of AI and has a comprehensive strategy[5] to build an enabling environment for AI in Europe. In her 2023 State of the Union Address, the President of the Commission, Ursula von der Leyen, highlighted the potential societal benefits of AI, while also acknowledging their risks. This duality is reflected in the two pillars of the EU AI strategy:

- **Trustworthy AI:** This pillar addresses key challenges associated with AI, particularly concerning fundamental rights in different dimensions: ethical, security, privacy, etc. It establishes a regulatory framework to ensure a human-centric approach and certainty for companies and consumers, while fostering innovation. This pillar includes key elements like the ethical guidelines for AI systems[6], or the EU's AI Act [7].

  The AI Act is a ground-breaking piece of legislation that establishes a comprehensive regulatory framework for the development, deployment, and use of AI systems in the EU. The AI Act's primary objectives are to foster innovation and trust in AI while safeguarding fundamental rights and ensuring the safety and well-being of individuals. Research is excluded from the scope of the AI Act.

- **Excellence in AI**: This pillar ensures that the EU reaps the benefits of AI, such as increased productivity or providing the tools to deal with societal challenges like climate change. This pillar focuses on the investments and the conditions needed for the successful uptake of the technology (like building the essential infrastructure for AI – high performing computers, etc).

The 'Coordinated Plan on AI'[8] is the instrument developed with the Member States, to build EU leadership in trustworthy AI, accelerate investments and align policies. **A targeted policy for AI in Science will put the enabling measures proposed in the Coordinated plan (access to infrastructure, data, building of skills) into the scientific context** and translate them into benefits for scientific research and the scientific community.

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[5] https://digital-strategy.ec.europa.eu/en/policies/european-approach-artificial-intelligence
[6] https://digital-strategy.ec.europa.eu/en/library/ethics-guidelines-trustworthy-ai
[7] At the moment of the drafting of this document, trilogue negotiations on the proposal are taking place. The original proposal of the Commission can be found here https://digital-strategy.ec.europa.eu/en/library/proposal-regulation-laying-down-harmonised-rules-artificial-intelligence
[8] https://digital-strategy.ec.europa.eu/en/library/coordinated-plan-artificial-intelligence-2021-review

The **European Research Area (ERA)** is the EU's **framework governing the EU Research & Innovation system**.[9] It aims to create a single market for research and innovation, fostering free movement of researchers, scientific knowledge and innovation, and encouraging a more competitive European industry. The ERA also offers a platform for coordination and co-design of innovation policy with the Member States, guided by the 2021 European Council Pact for the European Research Area, which covers among its principles: 'Ethics and integrity of research and innovation' and 'Value creation and societal and economic impact'.[10] Initiatives under a dedicated policy for AI in Science would contribute significantly to the achievement of all ERA priorities.

Furthermore, a policy for AI in Science:

- aligns with the objectives of the **New European Innovation Agenda**[11] to position Europe at the forefront of deep tech innovation and start-ups and to foster talent and new technologies to address societal challenges.

- complements the objectives outlined in **the European economic security strategy**[12] to promote economic competitiveness and technological leadership and to mitigate possible risks of misuse of AI, placing them in the context of science.

Implementing a future policy for AI in Science will require collaboration **across research, digital, education and cohesion policies**. The public research and education sector, scientific organisations, the private sector, civil society, regional and national players will be essential partners.

[9] European Commission, 2023: European Research Area
[10] European Commission, 2021: Pact for the European Research Area
[11] The New European Innovation Agenda (europa.eu)
[12] An EU approach to enhance economic security (europa.eu)

4. Why the EU needs a policy for AI in Science

The existing AI policy framework primarily views science as a contributor to AI development. However, it is vital to acknowledge that science itself increasingly relies on AI to progress, innovate, and deliver on societal challenges. **As AI is likely to be the main driver of discovery and innovation in the future, supporting science to effectively integrate AI represents an area for improvement in the current policy framework.**

A distinct science-oriented AI policy is crucial to contextualise and focus existing measures, amplify their impact and ensure coherent use of resources. It is **needed to address AI risks and challenges in science, while harnessing its potential for discovery, innovation and the future of science.**

Without a policy particularly for AI in science, there is a risk of missing out on significant AI opportunities for science and even more importantly – benefits that AI-boosted science could bring to the European economy, society and EU's role in the world.

Moreover, **several pressing factors underscore the urgency of such policy** for AI in Science:

4.1 Global competition is under way to harness the AI's potential in science

Leadership in AI-powered science translates into leadership in discovery and innovation, essential for economic and social prosperity and strategic autonomy.

Global AI companies (like DeepMind, MetaAI, OpenAI) recognise AI's potential to solve scientific challenges, sparking new business opportunities (new deep-tech companies, spin-offs and joint ventures) and market power. A powerful example to illustrate the potential of AI in science is Deep Mind's AlphaFold, which solved the protein folding problem and paved the way to new research and discoveries[13], new products and business ideas and a new family of similar AI tools.

Global governmental players see in AI an opportunity to rebalance the innovation dominance of existing global companies[14] and are positioning themselves for the competition. The US is deploying a network of resources under the NAIRR (National AI Research Resource) facilitating AI's development and application in scientific domains. China has recently relaxed its rules on

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[13] https://unfolded.deepmind.com/ and 'A Pandora's box': map of protein-structure families delights scientists (nature.com)

[14] Australia: Artificial Intelligence for Science report (CSIRO): https://www.csiro.au/en/research/technology-space/ai/artificial-intelligence-for-science-report; UK: Transforming our world with AI (UKRI): https://www.ukri.org/who-we-are/our-vision-and-strategy/strategies-and-reviews/ai-review-transforming-our-world-with-ai/; US: The National AI Initiative (National Science Foundation): https://www.nsf.gov/cise/national-ai.jsp

generative AI in order to support innovation and be more competitive with the US[15]. The global frontrunners in AI scientific production and publications are China, the US and the EU, with China already taking the lead and growing faster (Arranz et al., 2023).[16]

Through Horizon Europe and the Digital Europe programme the Commission invests €1 billion per year in AI, aiming for a total annual investment volume (public and private combined) of €20 billion over the digital decade up to 2030[17]. In the US, public investment in R&D is approximately at $1.8 billion in 2023 (Stanford University, 2023)[18].

4.2 The EU needs to enhance its competitive edge

Strengthening its excellent scientific base with AI technologies, needed to solve big scientific challenges, could be a powerful strategy for the EU to enhance its unique competitive edge in the global scientific arena. Advancing AI for scientific discovery (including AI-powered robotic systems) aligns with the goal of developing excellent "European-made" AI and equips science with the technology to progress and address societal challenges, while improving its technology sovereignty.

With a population of only 6% of the world, the EU is well positioned in global research: it produced a fifth of the top 10% scientific publications and a fifth of total patent applications in the world, with less than a fifth of the global R&D expenditure (EC, 2022). Nevertheless, with China increasing its scientific outputs in the past years, and the US still dominating the research quality and impact ranking (ibid), the EU needs to take a pro-active approach to keep its competitive position in science internationally.

The EU has technological advantages in the areas of advanced manufacturing and advanced materials but risks dependencies on foreign suppliers in complex fields such as AI, big data, and robotics, among others (EC, 2022). The application of **AI in science offers a route to technology sovereignty.**

For the applications of AI for science, the EU holds an advantage owing to its reputable and diverse scientific base and talent across different scientific fields; its values-based approach to science, and its multilingualism. Moreover, **the EU is the global leader in terms of laboratory robots and lab automation**

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[15] https://www.lexpress.fr/monde/asie/contenus-generes-par-lia-cette-nouvelle-reglementation-instauree-en-chine-IWAOHFELXJDMXB5BURGYLVEXA4

[16] The data analysed in that paper are taken from the Web of Science (WoS) Core Collection. The analysis considers all scientific articles published in peer-reviewed journals and conference proceedings, and some residual categories, including books, series, etc.

[17] https://digital-strategy.ec.europa.eu/en/library/coordinated-plan-artificial-intelligence-2021-review

[18] U.S. Federal Budget for Nondefense AI R&D.

exports[19]. When strengthened with AI's prowess, the EU's scientific performance can transform into a one-of-a-kind asset. With high-performance computing, access to data spaces and strategic funding, this can catalyse the development of ground-breaking AI systems and models tailored to scientific needs, designed to solve scientific challenges and deliver long awaited breakthroughs.

4.3 AI-boosted science can deliver economic growth and solutions to societal challenges

The application of AI can significantly increase efficiency and problem-solving abilities in research and innovation (Van Noorden & Perkel, 2023) and thus accelerate scientific discovery. It holds the potential to better address societal challenges and deliver better quality of economic growth that considers the wellbeing of people and the planet.

A recent OECD publication suggests that "accelerating the productivity of research could be the most economically and socially valuable of all the uses of artificial intelligence (AI)" (OECD, 2023). Leveraging AI in science can contribute to the accomplishment of the United Nations Sustainable Development Goals (SDGs) (Oliveira, 2022) and the EU's commitment to the twin green and digital transition.

Since AI is shown to also amplify private R&D capacities (ARISA, 2023), **developing AI-based research tools presents an important market opportunity and solution to boost EU companies' innovation and growth.**

This requires a dedicated policy for AI in Science to reap these benefits and reinforce the objective set by the Commission and Member States in the Coordinated Plan on AI to build strategic leadership in high-impact sectors such as environment, health and robotics.

4.4 AI in science comes with new challenges, risks and ethical considerations

Despite the EU being at the forefront of ethics, AI brings new challenges for science that could reshape the scientific process and strain the current R&I infrastructures and resources available to scientists in the EU. Researchers' talent and skills need to evolve, research organisations and governments need to be agile. A comprehensive policy for AI in Science coupled with improved governance mechanisms would help boost the EU ecosystem for AI in science.

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[19] Observatory of Economic Complexity, 2023: Professional, scientific and controlling instruments and apparatus, n.e.s. | OEC - The Observatory of Economic Complexity

A dedicated policy for AI in Science would monitor and steer the impact of AI in the scientific process on how the use of AI in research affects key principles such as methodological rigour, verifiability of outputs, research integrity and ethics.

Thus, measures and principles should be considered to avoid potential misuse of the technology (for instance in fields such as biology or drugs discovery), including the unwanted transfer of critical technologies or potential dual-use applications that might cause ethical concerns and undermine the EU’s security. As AI's role grows in EU research and innovation funding, such safeguards become vital, aligning with the EU's Economic and Security Strategy and the adoption of the Recommendation on critical technology areas for the EU's economic security[20], in which AI technologies are considered as highly likely to present the most sensitive and immediate risks related to technology security and technology leakage.

All these developments underscore the urgency for promoting policy and facilitating the adoption of AI across scientific domains.

[20] https://ec.europa.eu/commission/presscorner/detail/en/ip_23_4735

5. What AI can do for science

Understanding the world and our place in it, is a central goal of science. Scientists are driven by the quest to unravel the mysteries of nature, people and society.

They do so by employing their observation, creativity, curiosity and intuition to new scientific investigations. Depending on the domain of science, this process could involve conducting background research, forming hypotheses and predicting an outcome, testing them through experimentation, analysing the collected data, thereby reaching conclusions and communicating the scientific findings. Fresh inquiries, hypotheses, and experiments can emerge from the outcomes and deductions of prior investigations. This iterative nature of the scientific process allows for the refinement and improvement of scientific understanding over time.

Artificial intelligence is already making an impact on every stage of the scientific process (Wang et al., 2023). AI has the potential to become a dominant driver of scientific innovation by assisting in the scientific process (section 5.1), leading to transformative breakthroughs (section 5.2), and facilitating interdisciplinary collaboration (section 5.3). Further integration of AI could significantly automate scientific work, fundamentally changing how science is conducted and the role of scientists. Success in harnessing AI's potential for positive disruption in science depends on scientists' ability to embrace and understand AI's capabilities and limitations in their work.

5.1 AI in science: a tool for accelerated discovery

AI presents a wealth of opportunities for innovation and scientific discovery and most scientists surveyed by *Nature*, see the usefulness of AI tools in their research, with the top three impacts of AI on researchers' work being the faster processing of data, accelerated computations and saving researchers time or money (Van Noorden & Perkel, 2023).

AI applications in science encompass various techniques. The following represent the most prevalent AI applications in science, spanning the spectrum from information retrieval to ground-breaking discoveries and effective communication (Arranz et al., 2023):

- **AI as a research assistant** available around the clock, with access to the vast expanse of human knowledge or possessing specialized expertise within specific scientific domains. Generative AI, with its ability to create and interpret content, assist scientists by inspiring creativity, aiding in brainstorming, accessing knowledge, and visualizing ideas.

  A *Nature* survey shows researchers already adopting generative AI, particularly for writing code, research brainstorming, writing manuscripts and conducting literature reviews. (Van Noorden & Perkel, 2023).

- **Automating (or partially automating) the literature review process**. AI powered chatbots, like ChatGPT or Elicit, assist in comprehensive literature reviews, summarizing papers, and identifying relevant studies amidst the ever-expanding volume of scholarly content. On average, a scientist reads 264 scholarly papers per year (Van Noorden, 2014), while, for comparison, only between 1 January and 30 June 2020, there were more than 23,000 unique documents on COVID-19. (Teixeira et al., 2021).

- **Making predictions**: AI learns from data patterns, relationships, and trends to make predictions about new or unseen data. These predictions can take different forms: predicting in which disease category a medical record should fall, predicting an outcome based on various input factors (like tomorrow's temperature based on historical weather data) or predicting the next word in a sentence or the likelihood of a word or phrase occurring in a given context – a technique used in the large language models.

  A prominent example is AlphaFold, which employs deep learning (neural networks), alongside other AI techniques, to predict protein structures with unprecedented accuracy[21]. This helps scientists understand the functions and interactions of proteins in living organisms, essential for many biological processes and diseases.

- **Transforming input data to improve its quality or make the maximum of the data.** Based on data provided by the Event Horizon Telescope, scientists used image reconstruction algorithm to sharpen the first ever portrait of the supermassive black hole at the center of galaxy M87, which made headlines around the world in 2019[22] .

- **Optimising experiments.** This approach may learn from data but can also be applied to vast search spaces of multiple options when data is limited or unavailable, or when human expertise is critical for making decisions. By employing deep reinforcement learning, scientists were able to configure tokamaks used for nuclear fusion and model and maintain a high-temperature plasma state within the tokamak vessel—a challenge once believed to be impossible to solve. (Delgrave et al., 2022).

- **Mining historic literature archives for new discoveries.** Literature-based discovery (LBD) employs AI to uncover concealed connections within existing studies[23], turning archives into fertile ground for formulating fresh hypotheses. Machine reading comprehension systems can identify gaps, propose variations to existing experiments and piece together evidence scattered in different scientific papers. Nevertheless, integrating these analyses into real-world

[21] AlphaFold developers win US$3-million Breakthrough Prize (nature.com)
[22] *https://iopscience.iop.org/article/10.3847/2041-8213/acc32d*
[23] Could AI transform science itself? (economist.com)

scientific workflows underscore the need for open access to data and for collaborations between scientists and AI experts (Smalheiser et al., 2023).

- **Laboratory automation**. AI combined with robotics can assist researchers with everyday tasks like media and buffer preparation or pipetting. AI-powered robots can run experiments day and night, in sequence or in parallel, with speed and precision unmatched by humans. Furthermore, AI systems could monitor and maintain optimal conditions (like temperature and humidity levels) for scientific experiments or maintain the expensive laboratory equipment, thus saving money, time and effort.

  Looking ahead, AI in self-driving laboratories would generate hypotheses, robots would test them, outcomes would be generated for AI to learn from them and refine them, robots would test anew; the iterative loop continues[24]. This trajectory is poised to redefine the future of research[25] and the role of scientists.

- **Assisting scientific communication**. Effective communication of scientific findings is crucial for advancing knowledge. Scientists communicate their work through publications, presentations, conferences. Generative AI tools can automate the generation of reports, visualizations, and summaries. They can improve the researchers' prose, especially in English (important factor for scientific publications and therefore for the democratisation of science and scientists' careers[26]) or generate layman-friendly explanations and translations, facilitating communication to broader audiences. However, this also raises concerns of already strained peer reviewers about the multiplying scientific papers written with the undeclared assistance of generative AI tools[27].

In summary, **AI helps scientists accelerate discovery, increase productivity and quality of research and achieve goals that were previously beyond reach.** Nevertheless, we should not forget that currently AI lacks genuine understanding of the world's underlying mechanisms and causal relationships, which science exists to establish and explain. Relying on pattern recognition without understanding is what scientists' see as the key negative impact of AI in science (Van Noorden & Perkel, 2023). Hence, **AI is presently viewed as a tool to amplify human abilities rather than replace them.** The expertise, judgment, creativity, and critical thinking of human scientists remain crucial to maintaining the integrity and reliability of scientific work (more on the AI-associated risks and challenges – in Chapter 7).

5.2 AI helping science solve global challenges

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[24] Artificial Intelligence and Scientific Discovery: A Model of Prioritized Search (nber.org)
[25] Eric Schmidt: This is how AI will transform how science gets done | MIT Technology Review)
[26] Scientists who don't speak fluent English get little help from journals, study finds (nature.com),: https://doi.org/10.1038/d41586-023-02529-1
[27] Scientific sleuths spot dishonest ChatGPT use in papers (nature.com)

As AI is likely to drive forthcoming scientific breakthroughs, AI models designed for scientific discovery can advance solutions to global challenges and deliver on Europe's strategic priorities. This section provides a non-exhaustive list of examples of critical issues that AI-powered science is already helping to solve.

- **Fighting climate change and reaching climate neutrality by 2050** is a top priority for the EU. Climate and environment-oriented goals are also part of the internationally agreed Sustainable Development Goals (SDGs)[28]. Incorporating AI into various areas of climate science can help **understand, assess and combat climate change** and minimize its devastating effects on our planet. Scientists are already using AI to **enhance climate models and predict extreme weather events** and their consequences (wildfires, floods)[29], thus improving **ecosystem monitoring.** AI employed in the analyses of satellite images can **identify pollution,** deforestation or degradation of land, soil or biodiversity (Vinuesa et al., 2020). **Destination Earth (DestinE)**[30] is a flagship initiative of the European Commission to develop a highly accurate **digital model of the Earth** on a global scale. It leverages AI and high-performance computers to bolster disaster response and climate change preparedness.

- **Antimicrobial resistance (AMR) is one of the top 10 global public health threats** facing humanity[31]**.** Without effective antimicrobials, the success of modern medicine in treating infections, including during major surgery and cancer chemotherapy, would put patients at increased risk. A recent AI-powered breakthrough showcases how this powerful technology can revolutionise medicine and help overcome the challenge of AMR. By narrowing down thousands of potential chemical combinations to a handful of promising ones to be tested, AI helped scientists identify a potential new powerful antibiotic – Abaucin, which can kill one of the most problematic species of bacteria[32].

- **Advancing (personalised) medicine**. AI has been making remarkable progress in medical science. Convolutional neural networks, a neural network architecture for processing images, are often used to analyse magnetic resonance images (MRI)[33] and **predict potential cancer**[34]. They can be employed for more intricate tasks like reconstructing the 3D geometry of arteries to characterise the plaque that accumulates and narrows (or

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[28] THE 17 GOALS | Sustainable Development (un.org)
[29] Infusing AI into Earth Observation: ushering in a new era in climate response | DeepCube Project | Results in brief | H2020 | CORDIS | European Commission (europa.eu)
[30] Destination Earth | Shaping Europe's digital future (europa.eu)
[31] Antimicrobial resistance (who.int)
[32] New superbug-killing antibiotic discovered using AI - BBC News
[33] Check the Cancer Image Europe platform EUCAIM Dashboard (cancerimage.eu)
[34] Radiation risk appraisal for detrimental effects from medical exposure during management of patients with lymphoma or brain tumour | SINFONIA | Project | Fact sheet | H2020 | CORDIS | European Commission (europa.eu)

blocks) the neck arteries, thus providing better predictions into the risks and treatment of carotid artery disease[35].

- AI also enables **personalised drugs development,** as illustrated by the EU-funded DrugComb project. It employs AI for innovative drug combinations, which can develop more effective and **tailored treatments to cancer patients[36]**, Furthermore, AI has made previously unattainable advances in **understanding biological brains**[37]**.**

  Addressing the challenge of data privacy, scientists are constantly improving **patients' privacy-preserving machine learning** (Kaissis et al., 2020)

- **Developing new advanced materials** can strengthen Europe's **resilience, competitiveness and industrial leadership**. Innovation in sectors like energy, transport, health, electronics relies on new materials discovery. AI plays a crucial role in materials science, facilitating the discovery and design of novel materials and the prediction of material properties[38]. A model case is the EU-funded TopMechMat project which focuses on the design of topological materials with unique properties that remain stable under various deformations. By combining quantum chemistry principles with AI-driven optimization algorithms, the project has advanced the creation of topological materials, uncovering previously unseen topological structures[39].

- **Improving crisis preparedness by anticipating the consequences of natural disasters** is where AI can save lives and livelihoods. This is illustrated by the EU-funded F-IMAGE project, which applies probabilistic seismic hazard assessment, an AI technique, to explore large datasets to probabilistically describe the ground motion expected for specific earthquakes[40] and anticipate the consequences of such disasters in concrete locations.

- **Preparing planetary explorations.** AI is already being tested for future challenging robotic exploration missions on planetary surfaces unattainable by humans (like underground planetary caves on the Moon or on Mars). In situations where a reliable connection to the command centre is not available,

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[35] AI in precision medicine: Better risk identification, prevention and treatment of carotid artery disease | TAXINOMISIS Project | Results in brief | H2020 | CORDIS | European Commission (europa.eu)

[36] Unlocking the future of personalised cancer treatment with the help of AI | DrugComb Project | Results in brief | H2020 | CORDIS | European Commission (europa.eu)

[37] COG-TOM project: https://cordis.europa.eu/article/id/446031-decoding-the-mind-with-the-help-of-ai

[38] How scientists are using artificial intelligence (economist.com)

[39] Topological Mechanical Metamaterials | TopMechMat | Project | Fact sheet | H2020 | CORDIS | European Commission (europa.eu)

[40] F-Image project: https://cordis.europa.eu/article/id/446036-ai-could-help-anticipate-catastrophic-effects-of-future-earthquakes and another similar project: Awareness and resilience through European multi sensor system | artEmis | Project | Fact sheet | HORIZON | CORDIS | European Commission (europa.eu)

AI-integrated collaborative robots[41] work autonomously to explore and prepare these sites for human astronauts.

- **Driving ground-breaking serendipity.** AI can inspire new conceptual understandings by identifying patterns in vast datasets but also by revealing "surprises" - outliers, unexpected clusters, anomalies (Krenn et al., 2022) which sometimes unveil secrets about the universe. For example, using AI to cluster the images of tens of millions of unrelated stars, researchers identified a large sample of free-floating planets - a discovery with important implications for star and planet formation and early planet evolution theories[42].

AI empowers scientists to push scientific boundaries and addresses global challenges. A recent selection of successful EU-funded projects offers more examples of the transformative potential of AI for science[43]. To fully leverage this potential, the EU needs a dedicated policy for AI in Science.

5.3 AI-Driven Collaboration: Unlocking Innovation

Interdisciplinary teams working with AI have the potential to enhance each other's knowledge and methodologies in numerous ways.

For example, researchers working on the development of vaccines borrowed methodologies from computational linguistics to design mRNA sequences with shapes and structures more intricate than those used in current vaccines[44].

AI developers can draw from domain scientists' rigorous research and testing, contributing to mitigating risks of misuse of the technology. For example, OpenAI, during the development of ChatGPT4, stated an intention to engage experts "*from domains such as AI alignment risks, cybersecurity, biorisk, trust and safety, and international security to adversarially test the model*."[45]

Such collaborations can lead to better understanding of the needs of domain experts and inspire AI solutions **designed to tackle scientific challenges, boosting Europe's competitiveness.**

It is also worth acknowledging how **AI-devised strategies can influence scientists**. When in 2022, DeepMind introduced their AlphaTensor, an AI system identifying faster matrix multiplication algorithms[46] (an important achievement for computational efficiency), two Austrian researchers challenged the machine and

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[41] Mission accoMission accomplished: AI gives autonomy to space robots | CoRob-X Project | Results in brief | H2020 | CORDIS | European Commission (europa.eu)
[42] CosmicDance project: https://cordis.europa.eu/article/id/446033-machine-learning-illuminates-the-celestial-stage-spotting-new-objects-amid-the-cosmic-crowd
[43] Artificial intelligence: expanding scientific boundaries and enhancing innovation (europa.eu)
[44] 'Remarkable' AI tool designs mRNA vaccines that are more potent and stable (nature.com)
[45] GPT-4 (openai.com)
[46] DeepMind AI invents faster algorithms to solve tough maths puzzles (nature.com)

took its breakthrough a step further[47], developing an algorithm, designed to find even more efficient methods for multiplying even bigger matrices.

This illustrates how AI strategies could inspire scientists to adopt new methods, explore uncharted territory, and uncover insights overlooked by conventional approaches. The power of collective AI-human intelligence could usher in a new era of problem-solving, accelerating discoveries and driving revolutionary advancements.

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[47] Meet the Researchers who beat DeepMind at Matrix Multiplication (analyticsindiamag.com)

6. A glimpse into the future: AI from toolbox to "brainbox"

From its inception, the ambition of AI has been to match or exceed the abilities of human intelligence. "Solving intelligence"[48], getting to artificial general intelligence[49] (AGI) and even to superintelligence[50], seem to be the ultimate goals of global AI companies. As AI has been going from strength to strength[51], it is clear that **today's AI breakthroughs merely scratch the surface of its potential,** suggesting that AI could evolve into a scientific force on its own, a powerful "brainbox" for science.

This section presents illustrative examples of visionary scientific concepts that AI can help deliver in the future, with the associated benefits and challenges.

- **Convergence of AI and scientific knowledge.** Historically, AI wavers between pre-engineered knowledge and data-driven deep learning. Neither approach has provided a definitive solution on its own. While human knowledge is limited and subject to bias, deep learning demands extensive data and resources, struggles with explainability and reinforces bias. To address these challenges researchers are adopting carefully structured models **incorporating both domain expertise but also allowing systems to learn**. (Wang, et al., 2023; Johnson et al., 2022; Cornelio et al., 2023). This approach has been gaining prominence and application[52] also in EU-funded projects[53]. Further developing the idea of merging domain knowledge and AI as competitive future perspectives is the concept of **multi-disciplinary AI** where AI is trained on a wide assortment of scientific simulations; researchers can then use the pre-trained AI as a starting point for their own projects. (Sumner, 2023).

- **AI Scientist.** The Nobel Turing Challenge[54] envisions an autonomous AI and robotics system (an AI Scientist), capable of making major scientific discoveries, worthy of the Nobel Prize still this century. Not constrained by the limitations of human cognition or intuition, an AI Scientist would exhaust a vast hypothesis space, maximizing the likelihood of making discoveries. This unbiased approach to exploration could be of particular use for fields with extensive hypothesis generation and verification like chemical synthesis and material sciences (Kitano, 2021).

  Following a similar trend, research workflows integrating access to data, AI tools and computing resources could become increasingly automated. This would accelerate the iteration of the scientific process from observations, experiment

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[48] About (deepmind.com)
[49] Planning for AGI and beyond (openai.com)
[50] What OpenAI Really Wants | WIRED
[51] Professor Sir Nigel Shadbolt, (https://youtu.be/jocWJiztxYA)
[52] Designing an AI physicist – CERN Courier
[53] Project breaks new grounds in AI to create 'DNA of language' | MOUSSE Project | Results in brief | H2020 | CORDIS | European Commission (europa.eu)
[54] Nobel Turing Challenge

design and simulations, to data collecting, analysis, learning, and iterative improvements. (National Academies of Sciences, Engineering, and Medicine, 2022).

- **Digital twins and modelling of complex systems** like the Earth, the human brain and body[55], planetary-scale weather modelling or human evolutionary simulation (Conklin et al., 2023). If successfully developed, these projects could advance medicine, science and technology, enrich our understanding of the world, and shape the future of humanity either on Earth or on other planets.

- **Brain-like AI.** Drawing from the strides in brain modelling, a possible next step in AI points to systems that mimic the brain's ability to learn and adapt on the go and try to achieve characteristics of the brain's processing, like parallelism (running simultaneous tasks), adaptability, explainability and energy efficiency. Brain-like AI holds potential also for autonomous robots (Bartolozzi et al., 2022). Brain-like AI is a highly competitive area globally[56].

- **Harnessing nuclear fusion's power** is a promising option for a sustainable global energy supply. The EU is investing in ITER's[57] mission to build the world's largest tokamak, a magnetic fusion device, designed to prove the feasibility of fusion as a large-scale and carbon-free source of energy based on the same principle that powers the Sun and stars. AI, and particularly deep reinforcement learning, has made it possible to configure tokamaks and model and maintain a high-temperature plasma state within the tokamak vessel, solving a once unsumountable challenge on the way to harnessing a powerful energy source for humanity. (Delgrave et al., 2022).

Some of these advancements require immense computational power and advanced algorithms to process the vast amount of data involved. **Today's computers are reaching their physical limits and the limits of our available resources.** SPRIN-D[58] estimates that global energy consumption for computing and communications could take up the entire global capacity for energy production as early as 2040.

According to (Conklin et al. (2023), solving major computing problems would require substantial improvements in computing energy. Since prevailing digital processors will not be able to support our computing needs for the rest of the century, we are likely to see **computational technology evolve** past digital computers**.** The authors recommend a sustained investment in new approaches to computing which exploit new physics to compute and rely on new algorithms.

[55] What do clinicians think about the Virtual Twin? (vph-institute.org)
[56] China AI-Brain Research - Center for Security and Emerging Technology (georgetown.edu)
[57] What is ITER?
[58] New Computing Concepts Challenge | SPRIND

7. What new challenges from AI in science?

AI offers significant benefits to scientific work but also comes with ethical considerations and challenges, specific to science.

7.1 AI amplifies ethical issues in science

Preserving the integrity of science is a concern raised by the wide-spread use of AI as an aid to draft scientific papers, peer reviews and even public tender proposals. The majority of scientists (55%), interviewed by Nature are concerned that AI tools could make fraud easier. (Van Noorden & Perkel, 2023). In the case of generative AI, models could reproduce bias, fallacies or inaccuracies, refer researchers to less or not at all relevant and updated sources, or even make up content (hallucinations) (Sanderson, 2023). Researchers warn against over-relying on generative AI for literature review and summaries, as AI systems may overlook important nuances, contradictions, uncertainties or alternative perspectives that human researchers can spot (Van Noorden, 2022).

Furthermore, the majority of generative AI tools do not disclose information on their sources of data and images. This lack of transparency raises concerns that copyright-protected works are being used to train generative AI without the consent of the authors[59], an issue especially pertinent for the arts and humanities in science. Researchers also argue that open-source AI models are the needed ethical solution for science (Spirling, 2023). Emerging European tech companies such as Aleph Alpha and Mistral.AI have taken an approach focused on more transparency.

The maturity of AI models and tools needs to advance to align with the rigour of the scientific process. These challenges influence negatively researchers' trust in AI models[60]:

- **The robustness challenge:** If the training data used to build an AI model is not diverse or representative enough of the real-world scenarios, the model might lack robustness when faced with inputs it has not encountered during training. This is linked to:

- **The reproducibility challenge** when researchers attempt to conduct the same experiments or analyses using the same data and methods but do not obtain consistent or identical results.

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[59] These 183,000 Books Are Fueling the Biggest Fight in Publishing and Tech - The Atlantic
[60] See also a 2023 survey by Nature with over 1,600 scientists on the problems of using generative AI in research, AI and science: what 1,600 researchers think (nature.com)

- **The bias challenge.** AI predictions can be skewed by uncertainty and biases in training data, leading to inaccurate or biased outcomes and, as a result, to incorrect experimental design or decision-making.

- **The "black box" challenge** is another common issue with data-driven AI. Many successful machine learning algorithms, such as most of the deep learning examples, result in models whose decision-making process is incomprehensible to humans. While the system can provide accurate predictions, it lacks transparency on how and why results were generated. In many use cases explainability is not absolutely necessary but in critical fields like medicine, the lack of transparency in the inner workings of a model could prevent the application of the technology (Tjoa et al., 2021). This concern has spurred efforts for explainable AI (XAI), which aims to provide predictions along with explanations of their reasoning. Efforts in explainable AI involve infusing domain expertise into AI design, training, and optimization strategies[61].

Potential misuse of AI in science is high on the list of scientists' concerns (Van Noorden & Perkel, 2023). While the fast adoption of AI may empower more people to contribute to scientific breakthroughs ("citizen scientists"), it may also lower the barrier for rogue players to develop own science labs producing biohazards threatening human lives, the environment, or even the current world order (Suleyman, 2023).

The role of the scientists is being redefined by the increasing automation of scientific processes through AI and the emergence of autonomous AI scientists in the future. While AI technology can significantly accelerate research and experimentation, there is a risk of human scientists, especially young researchers, being left out of the loop or becoming overly reliant on automation, potentially diminishing their critical thinking and creativity.

7.2 The challenge of public trust in AI-driven science

Without public trust, science cannot effectively serve its purposes and society's needs. (Parikh, 2021). The ethical challenges, identified in the preceding section could significantly damage public trust in AI-driven science.

The role of mis- and disinformation surrounding complex or controversial topics should also be considered. After the COVID-19 pandemic, which witnessed anti-scientific movements62 aimed at undermining public trust in innovative vaccines, *the growing prominence of AI in scientific research and innovation presents fresh challenges to trust in science.* ***For example, would***

[61] Infusing AI into Earth Observation: ushering in a new era in climate response | DeepCube Project | Results in brief | H2020 | CORDIS | European Commission (europa.eu)

people trust medical products and vaccines that rely on AI assistance, or inventions attributed to AI scientists? Would patients follow medical advice prescribed by AI or attribute blame for potential errors? Would society be able to keep up with a faster pace of discovery and innovation?

A 2021 Eurobarometer Survey on European citizens' knowledge and attitudes towards science and technology shows that 86% of EU citizens see the positive overall influence of science and technology, with 61% expecting AI to have a positive effect in the future. However, more than half of respondents think that science makes our way of life change too fast (57%), and that the applications of science and technology can threaten human rights (52%). Furthermore, half of respondents (50%) agree that scientists can no longer be trusted to tell the truth about controversial scientific and technological issues because they depend more and more on money from industry (21% disagree). These are already **alerting trends, identified long before the 2022 surge in generative AI and the ensuing debates, which need to be addressed through a targeted policy.**

7.3 Talent and education system challenges

Attracting and keeping scientific talent, especially in AI research, is a major challenge worldwide (Stanford AI Index, 2023). The current international landscape shows that the US and China are leading in terms of attracting top-tier AI researchers. The US is building its talent strength based on a strategy of attracting international talent[63]. **The EU faces a significant brain drain problem**: 20% of top EU AI researchers went to the US for their graduate school, and a further 14% left for their post-graduate work.[64]

Diverse skills and new roles are essential to advance AI-based science, but supply falls short of demand. Researchers outside the AI field often lack the necessary computational and data-handling skills to be able to incorporate AI in their work (Van Noorden & Perkel, 2023). Systematic upskilling is relevant to enable inclusive access and proficient use of AI throughout the scientific community. Furthermore, AI-driven science requires experts with **hybrid skills**, combining AI and a specific scientific domain knowledge**.** Roles like **research engineers, data scientists and data stewards** are increasingly important to enable the advanced use of AI in research.

The demand for AI, hybrid and engineering skills is bound to grow, but hard to fill. **EU universities and research institutions are facing barriers to attract researchers with the skills needed for AI-driven research**, when competing with the attractive job offers and research opportunities in the private sector, as

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[63] The Global AI Talent Tracker, 2023: [The Global AI Talent Tracker - MacroPolo]
[64] ibid

many skilled professionals prefer the private sector and do not find the right framework for a career in academia (Timans et al, forthcoming).

The skills shortage is also linked to the educational approach at all levels, which tends to compartmentalize skills between those inclined toward STEM[65] disciplines and those favouring the social sciences and humanities.[66] This hampers interdisciplinarity, the building of hybrid skills and often further reproduces existing imbalances like the misrepresentation of women in STEMs. Related challenges in AI-driven interdisciplinary research also involve:

- **Cultural differences** and lack of "common language".
- **Mismatched goals:** while computer scientists are more interested in solving methodological and algorithms-related issues, domain scientists focus on solving scientific problems.
- **Lack of awareness of AI's potential,** preventing researchers from exploring new research avenues.

7.4 Challenges related to data, resources and infrastructures

Accessing data and computing resources is a key requirement for advanced AI-driven research and poses a significant challenge for researchers, as voiced by scientists in a recent Nature survey (Van Noorden & Perkel, 2023) and in our stakeholder consultation**. Data, AI tools and computing resources should be considered as "strategic assets"** for the development of AI in science, as they represent the critical enablers for the application of Ai in science.

Researchers require large-scale and high quality, domain-specific data in fields like medicine, physics, chemistry, materials science. Stakeholder consultations reveal that there are barriers to data access and use for AI-based research due to a variety of reasons, such as:

- **Access to data** is hampered in various ways, depending on the scientific domain. For instance, in the field of health, stakeholders report medical datasets owned by hospitals and public health systems are fragmented, not easily shared and multiplying bias. At the same time, the issue of access to data is known to the Commission, and there are promising solutions in development, such the European Health Data Space or the European Cancer Imaging Initiative.
- **Imbalance between public and private actors in accessing data.** Platform-based business models have created competitive advantages in terms of data access for AI-based research in the private sector (JRC, 2021). Nevertheless,

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[65] STEM: **S**cience, **T**echnology, **E**ngineering, **M**athematics

[66] Digital Education Action Plan (2021-2027) | European Education Area (europa.eu)

recent EU initiatives such as the Digital Services Act could improve this imbalance and allow vetted researchers to access privately held data for scientific purposes.[67]

- **The costs associated with data annotation, labelling and in general data curation to ensure quality and accessibility** make it difficult for researchers to share data and hinder open science, as the perception is, universities do not have proper processes or personnel to support researchers, or funding programmes do not include such tasks as eligible for funding.

- **Managing the growing volume of specialised data** is becoming a hard task, which requires technical expertise but does not get much recognition in an academic setting (Hey, 2023).

- In some sensitive cases, like clinical research, which depend on patients' personal data, FAIR (findable, accessible, interoperable, reusable) data creation and management is difficult because of privacy requirements. Technology-based solutions such as "privacy tech" are emerging, and their use of data sharing also depends on developing awareness of such solutions, and improving the culture for open science and open data.

Similarly, various AI applications in science have **diverse computational requirements.** Substantial computing capacity is essential for tasks like machine learning, model training, and inference, whereas applications using pre-trained AI models for scientific problem-solving or symbolic AI systems demand less computational power (OECD, 2023b).

Further science-specific needs were identified in terms of compute activities, confirmed by stakeholder workshops:

- Domain research making use of AI models at a more intense level (e.g. through model training or inference) requires constant access to large-scale computing resources (OECD, 2023b), whose availability is not taken for granted for researchers from non-core-AI domains, across the EU.

- The availability of compute resources for AI-driven research workflows as well as personnel capacities and skills (engineers, specialised hardware skills for AI) in universities and research institutes need reinforcing (OECD, 2023b).

- EU-based researchers are seldomly aware of the availability of these facilities and that the EU is investing in them.

Evidence points to the **fragmentation of the data and models sharing and compute ecosystem for AI in Science in EU.** While the EU provides a range of support structures that seem *"to have the key ingredients*", there is "*a lack of*

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[67] See European Commission, Digital Services Act, https://digital-strategy.ec.europa.eu/en/policies/digital-services-act-package

alignment and outreach between elements of data, computing power and models, which are hampering uptake" (Timans et al., forthcoming). Moreover, several platforms have emerged for different fields of science, but the current fragmentation of the landscape makes it **difficult to understand which scientific fields are well served for data and model sharing, and which fields would need more support.** Some of the structures also over-rely on a variety of short-term EU-funded projects that struggle to survive beyond their funding periods. Uptake of the shared AI models is not monitored, and AI-interoperability is considered another barrier to their wider application by scientists. Moreover, simply developing repositories of data and model sharing is not sufficient for ensuring uptake (Timans et al., forthcoming).

7.5 The diversity challenge

AI's transformative potential can only be fully realised when it is underpinned by values of equality, diversity, and non-discrimination.

In a male-dominated environment, AI may not always be designed and developed in a way that reflects the diversity of society. More is needed to mitigate bias and promote gender equality in AI-driven scientific collaboration to ensure that research outcomes are free from discrimination.

7.6 Regional disparities in the integration of AI in science

Not all European regions are well-positioned to excel in the emerging AI-driven science landscape. In Europe, top AI research and expertise is concentrated in specific regions, with limited geographic diversity (Balland, 2022). France is the largest hub of top-tier AI researchers in Europe (31%), followed by Germany (17%) and Switzerland (15%)[68]. R&I ecosystems in the "old" Member States rely more on public research for AI, while Eastern European ecosystems concentrate AI expertise in start-ups and private sector (EURITO, 2019).

More developed regions in Germany and Italy have prioritised AI in their smart specialisation strategies.[69] This confirms that not all regions are close enough in their existing specialisations to directly jump into the new wave of AI-driven science to produce excellence (Balland, 2022; EURITO, 2019). The regional imbalance in AI development in EU may affect the competitiveness of EU regions across other scientific fields as well.

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[68] The State of European AI Talent - MacroPolo

[69] For example, Baden Württemberg, Rheinland-Pfalz, Emilia-Romagna and Valle d'Aosta

8. Policy ideas to enable AI in science

The challenges and drivers of change brought by AI identified in the previous sections emphasize the necessity for EU-level action and initiatives for an enabling ecosystem for AI in Science.

This chapter explores ideas to strengthen this ecosystem. It **builds on existing AI and R&I policies in the EU**, and identifies potential ways to amplify them, tailor them to the emerging needs of the scientific community, or complement them with new measures. We sketch these policy ideas with the objective to initiate stakeholder consultations and map needs for further evidence gathering.

8.1 Vision and governance for AI in Science

This policy brief for AI in Science proposes a vision to **enable a diverse community of European scientists to make the best use of AI for scientific breakthroughs and ultimately to maintain EU's leadership in science**, **with the creation of value for the economy and society**. The recommendations of the Scientific Advisory Mechanism[70] (SAM) on how to accelerate the adoption of AI in science, together with further feedback from stakeholders, will shape the final vision of the policy, particularly in the areas where SAM will focus its evidence gathering: 1) the vision for AI in Science, 2) AI's impact on the scientific process, 3) AI's impact on the scientific community, and 4) policy design for AI in Science.

The AI in Science policy aligns with the concept of **"AI as a force for good"** outlined in the White Paper for AI[71]. Furthermore, it supports the objectives of the Coordinated Plan on AI to promote the widespread adoption of human-centric, inclusive and trustworthy AI across Europe, on the protection of EU values and fundamental rights, and the sustainable and efficient use of resources, enhancing Europe's global competitiveness and leadership.

The policy for AI in Science therefore will **integrate into the overarching European governance for AI** (provided by the Coordinated Plan for AI) **and for R&I policy** (provided by the European Research Area and New European Innovation Agenda), as well as create synergies with EU's education and cohesion policy.

8.2 Monitoring and ensuring the positive impact of AI on science

The EU is one of the few global research funders prioritising ethical AI research. The Commission already recognises its role to facilitate the efforts of the scientific community to establish and adhere to common rules and principles in the implementation of AI in scientific work (see Box 1).

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[70] European Commission, 2023: Scientific Advice Mechanism on Artificial Intelligence in Science [Artificial Intelligence in science in the EU (europa.eu)]

[71] [White Paper on Artificial Intelligence: a European approach to excellence and trust (europa.eu)]

Box 1: European Commission's work on the AI ethics in research

AI was included as one of the ethics categories to be monitored in Horizon Europe projects 2021[72]. The European Commission has developed **Guidelines for Horizon Europe projects**[73] to incorporate ethical principles into the AI technology design process, and address issues early on in the research activities. The Commission will also publish further Guidance Notes on AI ethics in research that contain up-to-date, comprehensive guidelines for applicants and beneficiaries of Horizon Europe funding in areas like informed consent, explainable AI, AI bias, and ethics audits and provide advice how to achieve trustworthy AI research. These guidelines will provide a framework for ethical decision-making during the development, deployment, and adoption of AI-based solutions. Further operational guidelines for AI systems that build on the study of human cognition and behaviour will be developed under Horizon Europe funded projects.

The **European Commission Ethics Review Mechanism** is constantly working on reviewing AI-related scientific projects from an ethical perspective and on guiding researchers on the ethical soundness of their work. Through the elaboration of the aforementioned guidelines, the training of ethics experts on AI ethics issues and the management of scientific projects that focus on the ethical dimension of AI, the European Commission is shaping the ethical pathway that AI in science should follow in order to comply with norms and principles.

It is important for the European Commission to participate actively to all regional and multilateral fora where the ethical governance of AI is discussed and take stock of the ongoing international dialogue and the relevant multi-level initiatives in this domain. For that purpose, a concerted approach is needed that will safeguard EU's coordinated and well-informed presence in all relevant international fora and will ensure consistency.

Furthermore, the EU is at the forefront of global efforts to understand the impact of AI and prevent possible risks from very powerful AI models. The AI Safety Summit, in November 2023, acknowledged the importance of international collaboration to meet the most significant challenges posed by AI[74]. The European Commission President Ursula von der Leyen emphasized the crucial role of a *thriving and independent scientific community,* to evaluate the risks of AI, supported by *public funding and access to the best supercomputers*. The President underscored the need for *internationally accepted procedures and standards for testing AI safety*, a standard procedure to report and follow-up on every significant

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[72] European Commission, 2021: How to complete your ethics self-assessment in Horizon Europe Projects

[73] See European Commission, 2021, Ethics By Design and Ethics of Use Approaches for Artificial Intelligence

[74] Countries agree to safe and responsible development of frontier AI in landmark Bletchley Declaration - GOV.UK (www.gov.uk)

incident caused by errors or misuse of AI and *an international system of alerts fed by trusted flaggers*[75].

Measures to amplify the existing framework. Policymakers could collaborate with the scientific community to formulate and maintain comprehensive principles that uphold the integrity of research and prevent some of the AI-associated challenges in science, like the undeclared use of generative AI. These principles could draw inspiration from similar initiatives and guidelines in academia[76], of esteemed media organisations[77], which have long been using AI to aid content creation and curation[78] (such as AP's guidelines[79]), as well as from international (UNESCO[80], WHO[81]) and professional[82] organisations and intergovernmental fora[83].

Furthermore, guidance could be provided to European universities and research organisations on the potential risks from international collaborations in projects related to AI, as a follow-up to the European Commission's Toolkit on Tackling Foreign Interference[84].

The approach to addressing AI risks and challenges should build on a culture of responsibility and a system of safety procedures and checks, guided by existing oversight mechanisms and international collaboration, especially in specific cases like the misuse of AI in fields like biotechnology (see also Rand Europe, 2023).

Preserving public trust in science is crucial for the success of scientific endeavours, especially in a future of accelerated AI-driven advancements, often going beyond human comprehension. Public concerns and sentiments should be regularly measured through Eurobarometer surveys. Science engagement from early school age, promotion of AI-enabled science results and pro-active communication should be fostered to anticipate or address anti-scientific sentiment, ensuring that AI-driven science continues to serve the common good while maintaining public confidence.

Trust in science is a shared responsibility. It can be maintained when the enabling framework, the relevant research organisations and funders, as well as researchers themselves are able to **ensure research integrity and avoid bias and discrimination**. Research funding needs to be awarded based on trustworthy criteria and processes. **Evaluations of AI models,** creating

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75 Remarks of President von der Leyen at the AI Safety Summit (europa.eu)
76 Living guidelines for generative AI — why scientists must oversee its use (nature.com)
77 AFP and Other Leading Media Organizations Call for Global AI Policy to Protect Editorial Integrity | AFP.com
78 Artificial Intelligence | AP
79 AP Definitive Source | Standards around generative AI
80 Ethics of Artificial Intelligence | UNESCO
81 WHO issues first global report on Artificial Intelligence (AI) in health and six guiding principles for its design and use
82 ead-prioritizing-people-planet.pdf (ieee.org)
83 Hiroshima Process International Guiding Principles for Advanced AI system | Shaping Europe's digital future (europa.eu)
84 European Commission's Toolkit on Tackling Foreign Interference

benchmarks that are reliable, complete, sustainable, and that avoid hypes would be part of this process as well. Inclusive design, development, deployment and use of AI technologies should be ensured to **avoid 'digital exclusion'**. This is why, end-users such as researchers in different fields, who would be using different AI tools or laboratory robots need to be involved in the process of co-creation of such tools. Efforts to **increase the reproducibility and robustness of AI in applications in science** are also crucial. This includes opening up methodologies, code and data (especially learning data), using models cards/info sheets, or developing community reporting standards.

With the rising uptake of AI in the scientific process, applications have also appeared for using AI in **research assessment** practices, including in peer reviews.[85] Understanding **implications for publishers and peer reviewers** and what tools and expertise are needed to combat plagiarism and unclear intellectual property rights is crucial to ensure the quality and integrity of scientific outputs (OECD, 2023).

As AI adoption in science is evolving, there is a need to also **understand the potential AI impacts on research productivity and on the scientific workforce.** This requires more work to understand how research impact and research productivity is defined, in the context of the changes that AI is bringing to accelerating the scientific process (OECD, 2023). Potential changes to scientific roles, skills needed and impact on the researchers' labour market also need policy attention. Regular monitoring and foresight of technology capabilities and potential risks, in collaboration with stakeholders will be useful.

8.3 Strengthening the data, assets sharing and compute ecosystem

The existing EU support for data and compute access. The EU has an overarching **Data Strategy** aiming to create a single market for data that will ensure Europe's global competitiveness and data sovereignty.[86] Enabling legislation is being passed to support the creation of **data spaces** as "sovereign, trustworthy and interoperable data sharing environments where data can flow within and across sectors, in full respect of European ambitions, rules and values" (European Commission, 2023). Data spaces will offer the availability of large pools of data, infrastructure to use and exchange data and appropriate governance mechanisms (ibid).

While the ambition is to complete the EU data spaces as part of the Digital Decade commitments by 2030, the EU currently offers a range of diverse platforms enabling access to data and software to researchers. As part of the Data Spaces initiative, the EU is investing in the development of the European Open Science Cloud (EOSC) the data space for science, research and innovation, to enable open science and access to research data under FAIR principles for researchers.

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[85] Should AI have a role in assessing research quality? (nature.com)
[86] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52020DC0066

Consulted stakeholders clearly indicated that **building the data spaces will be a strong competitive advantage for the EU**. Ensuring the completion of data spaces in full coherence between the different sectors, and especially allowing researchers to have access to high-quality data ready for seamless integration into AI-driven scientific workflows is **of paramount importance for EU's data and technology sovereignty**.

In the EU, 17 countries host supercomputers, making up 21% of existing supercomputers globally, which can be accessed through the **EuroHPC Joint Undertaking.** Right now, the two most advanced supercomputers, LUMI (in Finland) and Leonardo (in Italy), operational since 2022, can handle AI workloads. Two more advanced supercomputers are planned to open in Spain and Germany (the EU's first exascale supercomputer) within 2023-24.

Annex II provides more details on the EU-level support services and infrastructures offered for access to compute, data and sharing of AI models resources.

Ideas to amplify existing actions for AI-based workflows in different domains of science. While the above existing and planned measures strongly reinforce the compute ecosystem in the EU, collected stakeholder evidence shows that currently available resources are insufficient and too fragmented to match the ambitions of EU to remain a global player in the future landscape of AI-driven science**.**

Scaling up AI applications in science requires that EU researchers from public research organisations and across scientific disciplines benefit from the existing initiatives at EU level, with the objective to:

- **Increase access to compute resources for researchers across EU for applications of AI in science**. This could help tackle the compute divide across EU, especially for currently under-served areas. It would also help bridge the gap between the public research organisations' and private sector's access to compute resources. The **national AI strategies of EU Member States could take into account the needs of the research sector** for integrating AI in science, when assessing the overall compute capacities and potential new investments. This requires more specific assessment of the needs and capacities (including skills) of the research sector for accessing compute resources for AI-driven science in different fields, across the EU (OECD, 2023b).

- **Increase access to high quality data** for science: through the data spaces and EOSC, with more focus on an integrated approach to enable AI-driven research, overcoming the current fragmented landscape, pooling resources, and expanding some of the existing initiatives like AI4EOSC[87]. Better communication actions could ensure that EU researchers are aware of the facilities offered through these infrastructures.

- **Remove barriers to automated research workflows**. Solutions are needed to automate the creation of FAIR research data and further enable inter-operability and reuse of data (OECD, 2023). Moreover, scientists also suggest establishing

[87] AI4EOSC: https://ai4eosc.eu/

FAIR principles for sharing AI models to accelerate scientific discovery, including FAIR approaches to automating the production, standardization, and publication of AI models (Ravi et al., 2022).

Further complementary actions for AI in Science. The EU can also further invest in **developing open knowledge networks** focused on building knowledge graphs in different scientific domains, mapping existing scientific concepts and contextualising them (Forbus, 2023). Initiatives could foresee the integration of this structured information with Large Language Models and, vice versa, the use of LLMs to improve/enhance knowledge graphs. These can be solutions to boost interdisciplinarity, while also tackling the issue of access to specific expertise and resource pooling across the EU, but also pave the way for the further adoption of AI in future research workflows.

The idea of a **research facility for AI in science** has been mentioned in consultation with stakeholders as a potential solution accelerate scientific productivity and solve big scientific challenges. It could host a range of AI-based laboratory tools for scientific experimentation in a diverse array of fields, from materials science, to life sciences. It would need to be combined with access to very large graphics processing unit (GPU) and crowd server, suitable for AI-based research, and could act as a "commons" for the scientific community[88]. This idea requires further assessment and discussion.

8.4 Funding for AI-driven science

Existing EU funding for research at the intersection between AI and specific scientific fields includes a range of instruments. For example, the ERC Synergy Grants aim to tackle ambitious scientific challenges. The EU also funds Networks of AI Excellence (NoE) such as AI4Media, ELISE, ELSA, euROBIN, HUMANE-AI-Net, and TAILOR, and since 2023 ELIAS (European Lighthouse of AI for Sustainability), dAIEDGE (A network of excellence for distributed, trustworthy, efficient and scalable AI at the Edge), ENFIELD (European Lighthouse to Manifest Trustworthy and Green AI). These NoEs bring together more than 1000 scientists to address key scientific challenges in AI.

The Networks of Excellence are also linked to the **AI, Data and Robotics Partnership (Adra)**, which unites Europe's leading research organisations in AI, AI associations (CLAIRE, ELLIS, and EurAI), robotics associations (euRobotics), the Big Data Value Association (BDVA) and industry sectors. ADRA is financed with 2.6 billion euros of public and private investments for the period 2021-2030 to address

[88] There are diverse examples of such facilities in the US, Canada or UK. For instance, the US-based Argonne Lab combines supercomputing and X-rays experimentation equipment to supercharge scientific breakthroughs. US-based private cloud labs such as Emerald Cloud Lab or Strateos provide access to cloud-based experimentation services worldwide. The global Acceleration Consortium, a network of self-driving labs for materials science has one member from the EU (Forschungszentrum Jülich GmbH – Helmholtz Institute, Germany).

the key challenges in European AI, Data and Robotics[89]. The AI-on-demand platform (AIoD) serves as the backbone of these networks.

The European Commission plans more investment in fundamental AI development. Advances in core AI research will be instrumental in progressing in integrating AI systems in the scientific process (e.g. AutoML, privacy-enhancing technologies as well as further advances in reproducibility and robustness). The EU's AI policy places emphasis on achieving technology sovereignty and promotes the development of AI models "made in Europe" that are less cost and energy intense, and that could support science tackling some of the limitations of the current foundational models.

Ideas to amplify existing actions in the domains of science. Based on DG RTD data, projects funded by Horizon Europe and the European Innovation Council have seen a marked increase in AI take-up in 2021-2022. More strategic funding for integrating scientific knowledge into AI models can open some of the next frontiers in AI-driven science and strengthen Europe's competitive edge. Public funding to accelerate adoption of AI in science would enable significant returns for society and the economy at large. The opportunity costs of not investing in such solutions is very high in terms of technology sovereignty and competitiveness.

A strategic portfolio of R&I investments in the future could consider different funding approaches to advance science with the help of AI, for example:

- **Scientific challenge-driven:** policy can identify and fund research to tackle scientific problems that are ripe for solving with the help of AI (similar to the challenge of identifying the protein structure, which was solved by AlphaFold); This approach could be underpinned by a **portfolio of priority scientific challenges in different domains that can be accelerated with AI under different Clusters of Horizon Europe.** This should rely on a more in-depth analysis of the state-of-the-art in different scientific domains, and the expected potential for AI to solve those specific scientific challenges.

- **Scientific process-driven**: Integrating AI techniques that can **make the scientific process more efficient and effective.** These may range from AI-powered research assistants, automated literature reviews, laboratory automation and self-driving labs for science (see Chapter 4), and need collaboration between AI developers and researchers in different domains to be tailored to the needs of the researchers. It is important to assess how to make the best of AI in future-oriented research, such as through using **human-AI collaboration in scientific research**, or AI systems that **enable collective intelligence, and integrate it in the scientific process.**

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[89] See Joint Strategic Research Innovation and Deployment Agenda (SRIDA) for the Artificial Intelligence, Data and Robotics partnership that was released September 2021.

Defining a taxonomy for the use of AI in science is a key step to better target funding for AI-driven science. International actors, such as the US, have already moved to define the most important kind of AI-driven research as "**use-inspired" AI research**, meaning *"research that has use for society in mind. Use-inspired research seeks new methods and understanding in AI by situating the research in a domain of application to simultaneously inform progress in AI and solve particular use cases."*[90]

It is clear that there is also a **need for enhanced public-private collaboration in AI-powered R&D in different fields of science** (OECD, 2023). Knowledge transfer and creating conditions for accelerating the AI-based scientific solutions to market would be important.

The **role of deep-tech start-ups** and **academic-industry collaborations** can be key in **accelerating the road to market of AI-enabled scientific results**, as well as **facilitating the scientific process.** In recent years, start-ups have already started launching AI-based research tools and assistants on the market (e.g. Elicit.org, rayyan.ai etc), and there is further potential for developing specialised robot scientists for different scientific fields. Strategic choices in the fields where AI-based science would be the most promising for market uptake could be made and **connected to scale-up efforts under existing EU initiatives such as the European Innovation Council.**

Synergies with EU Member States' efforts and investments, as well as private actors, would be crucial, in order to create economies of scale and avoid fragmentation. Stakeholders also called for a long-term bottom-up funding approach to be prioritised.

8.5 Enhancing capacities for AI-driven interdisciplinary research

In order to remain competitive at EU and global level, university and research departments need to prepare their organisational processes, staff and researchers for more intense use of AI in science and increased cross-disciplinary work. Embedding **interdisciplinarity in the structure of the research groups to strengthen cooperation between core-AI researchers, engineers and domain scientists** (e.g. computational researchers working with health researchers) can be a way to do this. At national level, some EU Member States such as France (see box below) took the initiative to create conditions and opportunities for AI and domain scientists willing to do AI-driven interdisciplinary research.

Box 2: Fostering interdisciplinarity between AI and different scientific fields

CNRS France: Centre for AI for Science and Sciences for AI Pluridisciplinary research centre (ASSAI),[91] was launched in 2021 and is a national initiative in

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[90] National Artificial Intelligence (AI) Research Institutes (nsf23610) | NSF - National Science Foundation

[91] Le centre Artificial intelligence for science, science for artificial intelligence (AISSAI) | CNRS

France to promote interactions between different disciplines and AI research. It also aims to enable the progress of AI technologies in strategic domains that can support the scientific process (e.g. explainability, frugal models, incorporating scientific knowledge into AI models). Several initiatives that support interdisciplinary dialogue include thematic semesters for domain researchers to learn AI techniques, fellowships for guest scientists, training sessions, summer schools, multidisciplinary AI-driven research projects.

Other initiatives can be introduced across universities and research hubs to **enable matchmaking between scientists and cross-pollination of ideas across core-AI and other scientific disciplines**. Consultancy or project idea assessment would support researchers to identify the appropriateness of the scientific challenge in applying AI techniques to solve it. International examples could be of inspiration, such as the US National Science Foundation Convergence Accelerator[92] and the Alan Turing Institute Data Study Groups, where expert hackathons bring together data scientists from different institutions to work on real-world data science challenges[93].

Given the wide variation in the strengths of R&I ecosystems across EU, it is important to also focus on maintaining a level-playing field and **build the capabilities across EU Member States and regions for research actors to adopt AI in their scientific endeavours.** Research actors in regions with less expertise in AI will need to take strategic decisions for cooperation in order to build know-how in AI-driven science. A policy for AI in Science should result in better participation in AI-driven research across Europe's diverse regions. **Updating regional smart specialisation strategies (S3) to prioritise investments in AI and infrastructures for the uptake of AI in science is crucial**, as at the moment only few regions are including them as a priority**.** Targeted policies for **inter-regional collaborations and policy learning on AI in Science,** as well as exchanges in experience at Member State level would be beneficial.

8.6 Education and skills, attracting talent

The EU has been taking action to foster education and skills for AI, which are relevant for AI-based research. This is illustrated through different initiatives under Horizon Europe, the European Institute of Innovation and Technology Knowledge and Innovation Communities (EIT KICs), the European Innovation Council and the Erasmus+ programme (see Annex II). For instance:

- Horizon Europe funding such as **Marie-Sklodowska Curie Actions** for doctoral and post-doctoral training (MSCA), as well as interdisciplinary staff exchanges is strongly supporting the development and intake of artificial intelligence. Thanks to the bottom-up dimension of the programme that covers all research

[92] Convergence Accelerator | NSF - National Science Foundation
[93] Data Study Groups | The Alan Turing Institute

fields, participating researchers are increasingly opting for an AI focus for skills development at all stages of their careers.

- The EU Networks of Excellence in AI are also funding a range of PhD programmes and networking initiatives.

- The **Next Generation Talent** is a forthcoming EIC initiative aimed at linking scientist and deeptech startups in a way that fosters mutually beneficial spillover effects for the academic and business community. The scheme increases synergies between MSCA, ERC, EIT and EIC Pathfinder programmes and aims to address the scarcity of highly qualified talents on the European innovation job market, while enabling researchers/innovators to get a 'real entrepreneurial feel' and facilitate their future career orientation.

- Together with the European Institute of Innovation and Technology (EIT), the Commission launched the **Deep Tech Talent Initiative** in October 2022. The initiative aims at up- and re-skilling at least 1 million deep tech talents in Europe in the next three years. The targeted areas of the deep tech talent initiative are high growth and innovation potential deep tech fields, such as artificial intelligence and Machine Learning, including Big Data. The training programmes under this initiative are open to a broad array of beneficiaries, including students, researchers, workers, executives.

Ideas to amplify existing actions to build skills for AI in science. One of the key priorities will be to **strengthen the EU's visibility and potential to become a stronger hot-spot, attracting top-tier researchers and engineers for AI-driven science in different fields**. Some areas of action include:

- Upgrading the researchers' careers' incentives to motivate interdisciplinary work and an academic path, and more attractive incentives for research engineers to support the AI-based scientific process are key priorities.

- Monitoring and assessing the impact of AI on scientific careers is an effort foreseen as part of the forthcoming EU-OECD Research Careers Observatory.

- Understanding mismatches between the skills offered by the education system and the skills needed in AI--driven science is important. For instance, based on a US analysis, while fields like materials science, chemistry or environmental sciences have large potential for AI-based research, the academic curricula is not teaching sufficient AI-based skills.

- The EU is already financing the ERA Chairs initiative in Widening Countries to attract excellent researchers in host organisations. A similar initiative could be explored across the EU to give top talent the opportunity to establish new departments to perform cutting-edge research in an interdisciplinary way with the help of AI in widening countries, or beyond.

- **The European Institute of Technology (EIT)** is already funding a variety of training programmes for students to upgrade their digital skills, or gain mastery in AI (see Annex II). The **EIT AI Community provides several services for companies, which could also be tailored to be offered to researchers**: AI skills for professionals – an AI-powered tool for professionals to chart skills ; organising AI Challenges in 2022 and 2023, offering SMEs and corporates a service to connect them with suitable AI solution providers.

A future where science collaborates with artificial intelligence and machines, **calls for significant focus on how we are preparing the future generations of scientists from early school onwards**. The EU is already taking wide-reaching actions such as the Digital Education Action Plan 2021-2027[94], underpinning the vision and work with Member States to adapt educational systems to the digital age. Promoting the use of generative AI from primary schools, and critical engagement and "train the trainer" approaches of using the technology have shown positive results[95]. Integrating new approaches to active and life-long learning, focusing on creativity, curiosity, self-leadership and more exposure to technologies from early on is key. Actions to promote science and the reasoned use of AI-based resources to arouse vocations and retain talent, especially among girls will be key.

8.7 Promoting diversity in AI in science

An inclusive policy approach to AI in science should be reflected in both the application of existing AI tools in the scientific processes and the development of AI specifically designed for scientific needs. Such an approach ensures that AI tools are not only accessible to all, regardless of gender, age, or socio-economic background, but also that these tools are designed and developed in a way that respects and reflects this diversity. Promoting an inclusive approach for AI in science ensures that our scientific advancements are fair, innovative, and truly representative of our diverse society. This, in turn, helps address the needs of all citizens and enhances the societal relevance of the knowledge, technologies, and innovations produced. This approach aligns with the European AI overarching policy's goal to develop a "European approach to AI that is human-centric, trustworthy, secure, sustainable, and inclusive, in full respect of our core European values". It also supports the EU Gender Equality Strategy for 2020–2025[96], which recognises AI as an area of strategic importance and a key driver of economic progress.

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[94] https://education.ec.europa.eu/focus-topics/digital-education/action-plan
[95] Learning to Prompt in the Classroom to Understand AI Limits: A pilot study https://arxiv.org/ftp/arxiv/papers/2307/2307.01540.pdf
[96] Gender equality strategy (europa.eu)

The EU already supports research in tackling various biases in AI. EU-funded projects address the risk of discrimination in AI applications by detecting, assessing, mitigating and preventing bias in these systems[97].

[97] Check EU-funded projects FINDHR (Fairness and Intersectional Non-Discrimination in Human Recommendation | FINDHR | Project | Fact sheet | HORIZON | CORDIS | European Commission (europa.eu)), MAMMOth (Multi-Attribute, Multimodal Bias Mitigation in AI Systems | MAMMOth | Project | Fact sheet | HORIZON | CORDIS | European Commission (europa.eu)), AEQUITAS (ASSESSMENT AND ENGINEERING OF EQUITABLE, UNBIASED, IMPARTIAL AND TRUSTWORTHY AI SYSTEMS | AEQUITAS | Project | Fact sheet | HORIZON | CORDIS | European Commission (europa.eu)), BIAS (Mitigating Diversity Biases of AI in the Labor Market | BIAS | Project | Fact sheet | HORIZON | CORDIS | European Commission (europa.eu))

9. Conclusions

The accelerated development of AI, the need to tap into the opportunities it brings for science and the wide-scoping socio-economic implications of its deployment in science call for a targeted European Research Area policy on AI in Science. AI-driven science can contribute to competitiveness, economic security and solving societal challenges. Prioritising the adoption of AI technologies for scientific discovery could be the EU's unique competitive edge.

The AI in Science policy will be developed in **synergy with EU's digital and AI policy, education and cohesion policies**, by mobilising the AI in science ecosystem, including researchers, public and private R&I players. **Synergies with EU Member States' efforts and investments, as well as private actors** would help to create economies of scale and avoid fragmentation.

Next steps

The recommendations of the **Scientific Advice Mechanism** on how to accelerate a responsible uptake of AI in science, together with contributions from the expert group on the economic and societal impact of research and innovation (ESIR) as well as the with feedback from stakeholders will inform the policy conceptualisation for AI in Science. In essence, this policy will:

1. **Accelerate AI uptake by scientists in the EU**, with the goal to harness AI's transformative impact in science for societal benefits and help ensure the EU's competitiveness. This means to prioritise work on:

- Reducing barriers to adoption, and developing the right enablers for attraction of talent and training of researchers for AI-driven science.

- A portfolio of R&I investments upgrading existing funding instruments, focusing on AI for solving scientific challenges and making the scientific process more effective and efficient.

- Strengthening the compute, data and AI models sharing ecosystem for the adoption and development of AI for scientific purposes. Boosting the development of FAIR and high-quality research data, better access to research and computing infrastructures, leveraging initiatives such as the European Open Science Cloud (EOSC) and the other data spaces, reducing dependencies on non-EU actors will be key.

- Engaging with Member States, included through ERA and the Coordinated Plan on AI, to develop and design similar policies at national level, focusing on enabling conditions for researchers to favour more AI-based research, interdisciplinarity and knowledge sharing.

2. **Monitor and steer the impact of AI in the scientific process.** This includes:

- Understanding AI's impact on the work and life of scientists and preparing the scientific sector for new ways of doing science (both "accelerating science" and allowing for "slow" scientific work, introducing diverse incentives beyond publications targets).

- Addressing AI challenges to research integrity, methodological rigour, verifiability of outputs.

- The potential for misuse of the technology in fields such as biology or drugs discovery.

- Preserving public trust in AI-driven science through pro-active communication actions.

The concrete actions to support the accelerated adoption of AI in science will be outlined in a policy roadmap and a staff working document for AI in Science in 2024. Regular revision of the policy and its governance mechanism over, will be crucial given the fast pace of AI progress.

GLOSSARY

Artificial intelligence (AI)	See different definitions in the JRC Glossary of human-centric artificial intelligence
explainable AI (XAI)	An AI system that is intelligible to non-experts; its functionality and operations can be explained non-technically to a person not skilled in the art. Source: Based on HLEG AI, Assessment List for Trustworthy AI (ALTAI)
generative AI	Generative AI systems create new content—including text, image, audio, and video—based on their training data and in response to prompts. Source: OECD, Initial policy considerations for generative artificial intelligence
human-centric AI	The human-centric approach to AI strives to ensure that human values are central to the way in which AI systems are developed, deployed, used and monitored, by ensuring respect for fundamental rights. Source: Based on HLEG AI, Ethics Guidelines for Trustworthy AI
symbolic AI	Symbolic AI is the collective name for all AI research methods that rely on high-level "symbolic" representations of problems, mathematical logic, and search. Source: Based on JRC, Glossary of human-centric artificial intelligence
Deep (neural network) learning	Deep learning is a subset of machine learning; an approach to creating rich hierarchical representations through the training of neural networks with many hidden layers. Source: Based on ISO/IEC 22989:2022(en)
Deep tech	Deep tech is technology that is based on cutting-edge scientific advances and discoveries and is characterised by the need to stay at the technological forefront by constant interaction with new ideas and results from the lab. Deep tech is distinct from 'high tech' which tends to refer only to R&D intensity.

	Source: EIC, Work Programme 2023
Expert system	An AI system that accumulates, combines and encapsulates knowledge provided by a human expert or experts in a specific domain to infer solutions to problems. Source: ISO/IEC 22989:2022(en)
(Large) language models (LLM)	Language models are a key component of natural language processing (NLP), a field of AI focused on enabling computers to understand and generate human language. Language models and other NLP approaches involve developing algorithms and models that can process, analyse, and generate natural language text or speech trained on vast amounts of data using techniques ranging from rule-based approaches to statistical models and deep learning. The application of language models is diverse and includes text completion, text-to-speech conversion, language translation, chatbots, virtual assistants, and speech recognition. Source: OECD, AI language models: technological, socio-economic and policy considerations
Machine learning (ML)	Machine learning is a branch of AI and computer science which focuses on development of systems that are able to learn and adapt without following explicit instructions imitating the way that humans learn, gradually improving its accuracy, by using algorithms and statistical models to analyse and draw inferences from patterns in data. Source: JRC, Glossary of human-centric artificial intelligence
Robot scientist Self-driving laboratories	A technology that combines robotics with AI to automate the scientific process. Robot scientists go by different names, such as closed-loop platform, AI scientist, high-throughput experimentation platform and self-driving labs. Source: Based on OECD, Artificial Intelligence in Science: Challenges, Opportunities and the Future of Research

ANNEX I EXISTING EU ECOSYSTEM ENABLERS FOR AI IN SCIENCE

This section presents relevant ongoing initiatives at EU level supporting the development and uptake of AI in science.

EU platforms for data, compute and AI models sharing and experimentation

- The European Data Strategy includes the development of **Data spaces**, which "will allow data from across the EU - from the public sector, businesses and individuals as well as research institutions and other types of organisations (e.g. non-profit organisations) - to be made available and exchanged in a trustworthy and secure manner."[98] Data spaces are planned in the fields of:

- The EU's Open Science policy and the **European Open Science Cloud (EOSC)**[99] are important efforts that **promote open and FAIR data,,** along with support for enhancing data quality and verification. Within this framework, the **AI4EOSC** project aims to deliver an enhanced software ecosystem and set of services for the development of AI, machine learning and deep learning models and applications for different stakeholders.

- **AI on Demand** is an online platform to provide AI knowledge through services, training, software and experts especially to businesses, but also to research actors. It aims to build an AI on-demand repository of experts, AI tools, and services. Researchers are encouraged to share other assets such as events, open calls, news, AI assets, research results, or use cases. AI-related project results (e.g. algorithms, codes) will be uploaded on the platform in the next stage of the platform.

- The EU is funding access to supercomputing resources through the **EuroHPC network**, comprising eight supercomputers, two supercomputers still to be deployed and six quantum computers. In a future where the adoption of AI intensifies through the application of AI to domain scientific research, the current resources of EuroHPC for scientists need to be re-assessed. Interviewed researchers emphasize the need for supercomputing resources and workflows tailored to AI research.[100]

- The European Cancer Imaging Initiative aims to harness the potential of data sharing and digital technologies such as AI and high-performance computing to support cancer diagnosis, treatment and care. It has developed the **Cancer**

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[98] European Commission, 2022: Staff Working Document on Data Spaces
[99] See European Commission, 2023, Open Science
[100] See also CLAIRE, 2023, CLAIRE Statement on Future of AI in Europe 2023 | CLAIRE - Confederation of Laboratories for Artificial Intelligence Research in Europe Confederation of Laboratories forArtificial Intelligence Research in Europe (claire-ai.org)

Image Europe Platform as a digital infrastructure pooling and making medical images accessible.[101]

- **Testing and Experimentation Facilities** (TEF) will offer a combination of physical and virtual facilities, in which technology providers can get support to test their latest AI-based soft-/hardware technologies in real-world environments. This will include support for full integration, testing and experimentation of latest AI-based technologies to solve issues/improve solutions in a given application sector, including validation and demonstration. They will focus on testing mature AI–based technologies (TRL 6-8) and solutions that have already been tested in labs, and have to be tested in real-world environments. Selected TEF projects in the areas of agri-food, healthcare, manufacturing and smart cities & communities started on 11 January 2023 and will be funded for a period of five years with a budget of €40-60 million per project, under co-funding between European Commission (Digital Europe Programme) and Member States.

EU programmes offering funding for AI in science

- The ERC Synergy Grants, which allow proposals to be submitted by 2 to 4 scientists together, aiming to tackle a truly ambitious scientific challenge. Interviews with scientists suggested the need to provide similar funding for higher levels of technology readiness as well.

- Networks of AI Excellence: AI4Media, ELISE, ELSA, euROBIN, HUMANE-AI-Net, and TAILOR, and, starting since 2023 ELIAS (European Lighthouse of AI for Sustainability), dAIEDGE (A network of excellence for distributed, trustworthy, efficient and scalable AI at the Edge), ENFIELD (European Lighthouse to Manifest Trustworthy and Green AI). These NoEs bring together more than 1000 researchers to address key scientific challenges in AI.

- EU Partnership on AI, Data and Robotics, focusing on deploying AI research results to industry settings.

- Horizon Europe Pillar II funding calls in different Clusters of Horizon Europe outside Cluster 4 has included funding at the convergence between AI and e.g.,., life sciences, earth systems observation, nuclear science or social sciences and humanities among others.

- The European Innovation Council (EIC) is a one-stop-shop for breakthrough innovators, providing support from the idea to the market, from early advanced research to commercialisation and scale-up. The EIC supports breakthrough technologies and disruptive start-ups in any field as well as targeting support on strategic challenges through three instruments:

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[101] https://digital-strategy.ec.europa.eu/en/policies/cancer-imaging

- **The EIC Pathfinder** focuses on high-risk research projects exploring radically new and innovative technologies.
- **EIC Transition** bridges the gap between research and innovation and supports the maturation and validation of novel technologies alongside the development of a business case for commercialisation.
- **The EIC Accelerator** supports start-ups and SMEs to develop and scale up deep-tech and disruptive innovations through a combination of grant financing and equity investments, with the aim of crowding in other investors.

EU programmes supporting researchers' training, mobility and research organisations' networking

- The Marie-Sklodowska Curie Actions (MSCA) facilitate doctoral and post-doctoral training, as well as interdisciplinary staff exchanges. This includes substantial training in digital skills to adequately prepare researchers for the evolving AI developments, notably within its Doctoral Networks and COFUND doctoral programmes. Moreover, the fellows' Career Development Plan (CDP) can be an additional tool for enhancing the AI uptake by researchers. Under Horizon Europe, the CDP is an obligatory deliverable in most MSCA actions. In calls for proposals, no specific research topic is specified given the bottom-up nature of MSCA. Research topics are chosen by the researchers and reflect the existing trends in the research community. Due to the growing importance of AI, it is expected that projects will increasingly revolve around AI from various angles (technical, legal, sociological, ethical, and others).

- The European Universities Initiative via Erasmus+ supports the networking of transnational alliances through calls for proposals, covering education opportunities and the link with research and innovation.

- The Erasmus+ programme contains key actions for different target groups such as mobility for higher education students and staff (K1), cooperation between organisations and institutions (K2) as well as support for policy development and coordination (K3).

- European Institute of Innovation and Technology (EIT) Initiatives on AI

    - The **EIT and its Knowledge and Innovation Communities** (KICs) has partnered up with leading education institutions, research organisations and businesses to boost the EU's technological and industrial capacity in AI, empower the education systems to pre-empt the socio-economic changes that will come with the rise of AI and modernize training and talent management systems that support the labour market and increase the employability of trainees. The **EIT Digital Master School**, **EIT Digital Summer School**, and the **EIT AI Skills for professionals' tool**, among others, concretely support the building of a European talent pool fit for the virtual world.

- The EIT also coordinates the **Deep Tech Talent Initiative.** With the support of institutional and financing partners, as well as education providers, it will train one million Europeans by the end of 2025 in the skills needed to enter deep tech fields like AI, machine learning, quantum computing, robotics, virtual reality, augmented reality, metaverse, and so on.
- An **EIT AI Community** has also been set up by six KICs (EIT Digital, EIT Health, EIT Manufacturing, EIT Climate KIC, EIT InnoEnergy and EIT Food) to foster collaboration in, education about, and uptake of Artificial Intelligence by European enterprises and society. The EIT Community already provides several services for companies, but which could be more tailored to researchers: an AI Maturity tool for self-assessment of the AI maturity of a company; AI skills for professionals – an AI-powered tool for professionals to chart skills; organising AI Challenges in 2022 and 2023, offering SMEs and companies a service to connect them with suitable AI solution providers.

- The **Erasmus+ Alliances for Innovation** aim to strengthen Europe's innovation capacity through cooperation and exchange of knowledge among higher education, vocational education, and training stakeholders, and the broader socio-economic environment, including research. One of the Alliances funded under Lot 2 (Alliances for Sectoral Cooperation on Skills) is the Artificial Intelligence Skills Alliance (ARISA). The project (2022-2026) will support the implementation of the Pact for Skills by developing a sectoral skills strategy on AI. This strategy aims for systemic and structural impact on reducing skills shortages, gaps, and mismatches, as well as ensuring appropriate quality and levels of skills. They have already published an **AI Skills Needs Analysis report** highlighting the need for technical but also soft, ethical and legal skills in the field of AI.

- The Skills Partnership that enables the up- and re-skilling of workers and seeks to attract more people to the digital industry, is part of the Pact for Skills, with the support of the European Commission, EU associations, companies, organisations, trade unions, universities, training providers and national federations.

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