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SUSTAINABLE DEVELOPMENT GOALS

Bridging the AI Divide

EMPOWERING DEVELOPING COUNTRIES THROUGH MANUFACTURING

UNIDO REPORT. DECEMBER 2024

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The preparation of this report was conducted under the overall guidance of **Ciyong Zou**, Deputy to the Director General and Managing Director, Technical Cooperation and Sustainable Industrial Development Directorate of UNIDO, whose thought leadership in inclusive and sustainable industrial development through technological advancement has greatly shaped the scope and objectives of this work. The report was prepared in the Digital Transformation and Artificial Intelligence Division, led by **Ana Paula Nishio De Sousa**, Chief, who guided and oversaw the overall development of the report. **Aleksei Savrasov** conceptualized this report, steered its development, coordinated internal and external consultations, and provided oversight throughout the preparation. We would like to thank the team: **Oliver Authried, Ashraf Abushady, Aleksandar Filiposki** and **Ekaterina Glagoleva** for their technical input and support.

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ACRONYMS

ADPT	Advanced Digital Production Technologies
AI	Artificial Intelligence
AIDA	Artificial Intelligence and Data Act
CAD	Computer-Aided Design
CAM	Computer-Aided Manufacturing
CNN	Convoluted Neural Network
CPU	Central Processing Unit
EU	European Union
GAN	Generative Adversarial Network
GDC	Global Digital Compact
GDPR	General Data Protection Regulation
GenAI	Generative AI
GPT	General-Purpose Technology
GPU	Graphical Processing Unit
IfM	Institute for Manufacturing
IoT	Internet of Things
LLM	Large-Language Model
MNC	Multinational Company
NPU	Neural Processing Unit
OECD	Organisation for Economic Co-operation and Development
PIPL	Personal Information Protection Law
RNN	Recurrent Neural Network
R&D	Research and Development
SME	Small and Medium-sized Enterprises
TPU	Tensor Processing Unit
UN	United Nations
UNIDO	United Nations Industrial Development Organization
US	United States
USPTO	United States Patent and Trademark Office
WTO	World Trade Organization

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FOREWORD

As technological advancements accelerate, artificial intelligence (AI) emerges as a critical enabler, reshaping economies, industries, societies and our daily lives. Yet, the AI revolution remains uneven, with significant challenges and opportunities existing side by side. It is within this duality that the role of the United Nations Industrial Development Organization (UNIDO) becomes central: to ensure that AI, as a transformative technology, empowers all nations, particularly developing economies, in realizing inclusive and sustainable industrial development.

"Bridging the AI divide: empowering developing countries through manufacturing" is a landmark report that provides a roadmap for developing countries to harness the power of AI in manufacturing — an industry vital to economic growth, job creation, and social resilience. Through practical insights and policy recommendations, it highlights how AI can foster economic productivity and industrial competitiveness. However, it also acknowledges the complex challenges these technologies bring, including risks to employment, data security, and ethical integrity.

At UNIDO, we believe that AI's true potential lies in its ability to support equitable industrialization and economic growth. The adoption of Global Digital Compact, with UNIDO co-leading Objective 2 - to 'expand inclusion in and benefits from the digital economy for all' – marks a crucial step forward in this effort. Through initiatives like the AIM Global Alliance, a multilateral platform for knowledge-sharing and promoting responsible AI governance, UNIDO is helping Member States access the tools and expertise needed to advance AI in a way that is both ethical and sustainable. This report underscores UNIDO's commitment to leading the global dialogue on AI in industry that prioritizes inclusivity, resilience, and fairness.

In presenting this report, UNIDO aims to provide its member states and partners with recommendations towards a strategic framework for adopting AI in industry in ways that align with local development needs and contribute to a balanced global AI ecosystem. I am confident that it will serve as an invaluable resource, fostering a future where AI not only transforms industries but also empowers individuals, communities, and nations to thrive in a digital age.

Mr. Ciyong Zou
Deputy to the Director General and Managing Director

Executive summary

Artificial intelligence (AI) is rapidly transforming industries worldwide, particularly in manufacturing, where it promises to drive unprecedented efficiency, innovation, and growth. However, this AI revolution has exposed a divide between developed and developing economies. While industrialized nations advance swiftly in AI adoption, many developing countries face barriers that prevent them from fully harnessing these transformative technologies. Addressing this gap is essential for fostering global economic equity and supporting sustainable industrial development.

The "Bridging the AI Divide" report, developed in partnership between the United Nations Industrial Development Organization (UNIDO) and the Center for Science, Technology and Innovation Policy at the University of Cambridge, provides an in-depth analysis of the opportunities and challenges AI brings to the manufacturing sectors of developing countries. This report outlines a comprehensive framework for enabling developing economies to leverage AI effectively, with a focus on maximizing industrial competitiveness, productivity, and social benefits while mitigating associated risks.

Key insights and findings

1. **The potential of AI in manufacturing for developing countries:** AI offers significant potential to enhance productivity, optimize supply chains, and drive innovation within manufacturing sectors. For developing countries, adopting AI in manufacturing can spur economic diversification, increase export capabilities, and create new job opportunities. However, unlocking these benefits requires investments in digital infrastructure, skills development, and robust governance frameworks. A foundational prerequisite is an active innovation system, where academia, research, government, and the private manufacturing sector collaborate effectively. Regions with strong manufacturing activity often excel in STEM fields, which, in turn, enhance their capacity to adopt and develop AI. Strengthening one sector naturally reinforces the other, creating a synergistic pathway for progress in both manufacturing and AI.

2. **Challenges in AI adoption:** Developing countries face numerous barriers to AI adoption, including limited digital infrastructure, low levels of digital literacy, regulatory gaps, and concerns about data privacy and security. Additionally, the integration of AI raises ethical concerns, particularly regarding labor market shifts, data ownership, and responsible use. The report highlights the need for comprehensive policies to address these barriers and promote inclusive growth. Strengthening manufacturing capacities can similarly boost regional innovation activities and readiness for new technologies, essential for adopting rapidly evolving AI. Regions with underdeveloped manufacturing capabilities likely face even greater challenges in embracing AI technologies.

3. **Strategic pathways for bridging the AI divide:** The report identifies a set of strategic pathways to support developing countries in adopting AI sustainably:

   - Strengthening AI governance: Developing robust policies and regulatory frameworks to ensure safe, ethical, and equitable AI deployment.
   - Building human capital: Focusing on skills development and capacity building to prepare a workforce that can engage with and manage AI technologies.
   - Enhancing digital infrastructure: Expanding digital networks and infrastructure as foundational requirements for AI integration.
   - Fostering public-private partnerships: Engaging both private and public sectors to promote shared responsibility in AI development and deployment.
   - Promoting knowledge sharing: Leveraging platforms like UNIDO's AIM Global Alliance to foster international collaboration and knowledge transfer.

UNIDO AIM Global role and strategic contributions

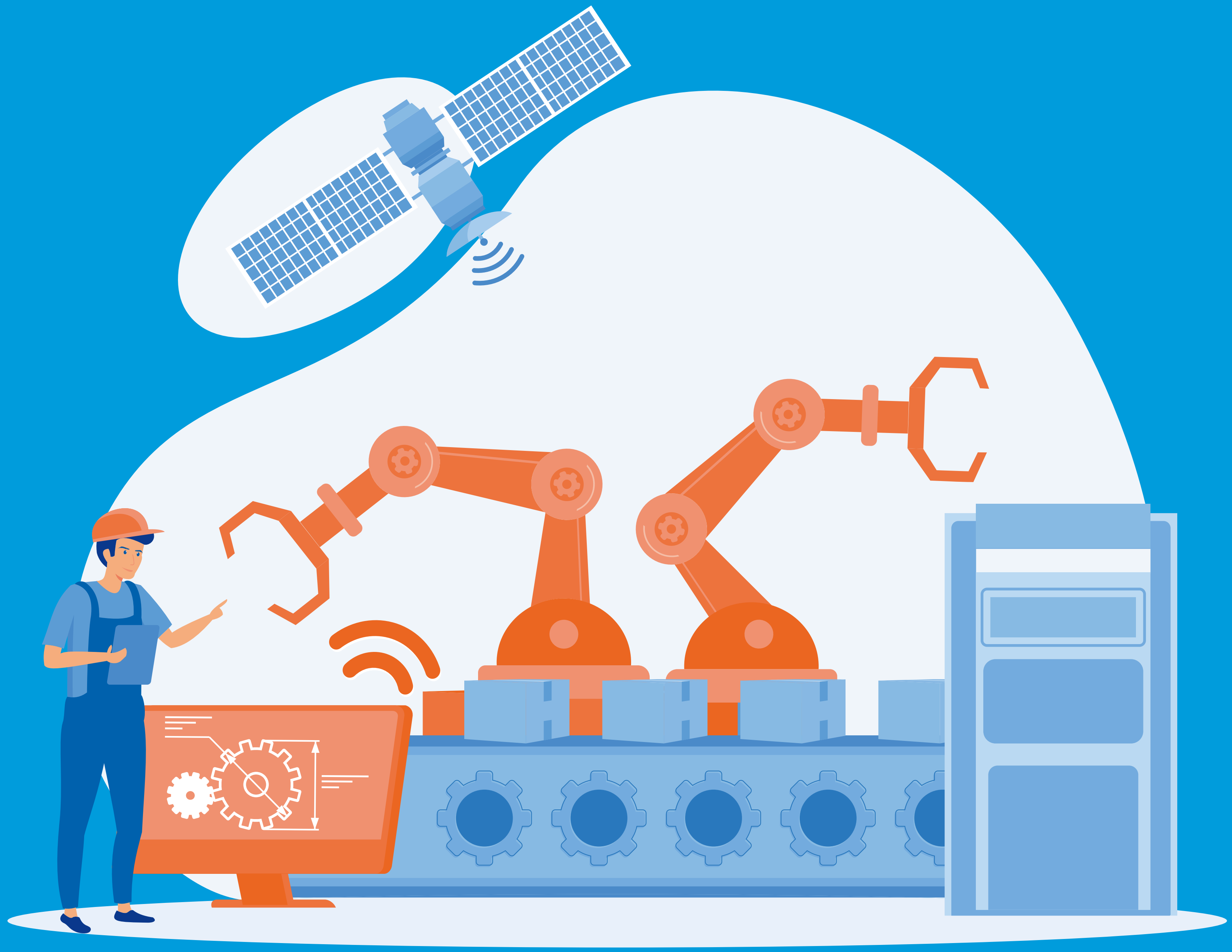
UNIDO, through its AIM Global Alliance, is positioned to lead the charge in promoting inclusive AI adoption in the manufacturing sectors of developing countries. AIM Global provides a multilateral platform for sharing best practices, offering technical assistance, and fostering collaboration among stakeholders from the public, private, and academic sectors. The report highlights UNIDO's commitment to ensuring that AI is developed and deployed in ways that support sustainable industrial development and reduce socioeconomic disparities.

CALL TO ACTION

"Bridging the AI Divide" serves as both a guide and a call to action for policymakers, industry leaders, and international organizations to work collaboratively in advancing AI for the inclusive growth of developing countries. By implementing the strategies outlined in this report, stakeholders can ensure that AI becomes a tool for equitable industrial growth and a driver of sustainable development. This report not only underscores the importance of AI in future-ready manufacturing but also reaffirms the role of international cooperation in building a fair, resilient, and inclusive global economy.

Key recommendations for policymakers

- **Strengthening AI governance:** Develop robust policies and regulatory frameworks to ensure the safe, ethical, and equitable deployment of AI technologies.
- **Building human capital:** Focus on skills development and capacity building to prepare a workforce that can engage with and manage AI technologies. Invest in education and training programs to enhance digital literacy and technical skills.
- **Enhancing digital infrastructure:** Expand digital networks and infrastructure as foundational requirements for AI integration. Improve internet connectivity, data storage facilities, and access to advanced computing resources.
- **Fostering Public-private partnerships:** Engage both private and public sectors to promote shared responsibility in AI development and deployment. Collaboration between governments, businesses, and academic institutions can drive innovation and ensure the practical application of AI technologies.
- **Promoting knowledge sharing:** Leverage platforms like UNIDO's AIM Global Alliance to foster international collaboration and knowledge transfer. Sharing best practices, technical expertise, and research findings can help developing countries overcome barriers to AI adoption.
- **Addressing ethical concerns:** Develop comprehensive policies to address ethical concerns related to AI, such as labor market shifts, data ownership, and responsible use. Ensure that AI technologies are used in ways that benefit society and minimize negative impacts.
- **Supporting innovation and research:** Encourage research and development in AI technologies tailored to the specific needs and contexts of developing countries. Support local innovation ecosystems and provide funding for AI-related projects.
- **Ensuring inclusive growth:** Implement policies that promote the equitable distribution of AI benefits across society. Create opportunities for marginalized groups, such as women and youth, to participate in the AI-driven economy.



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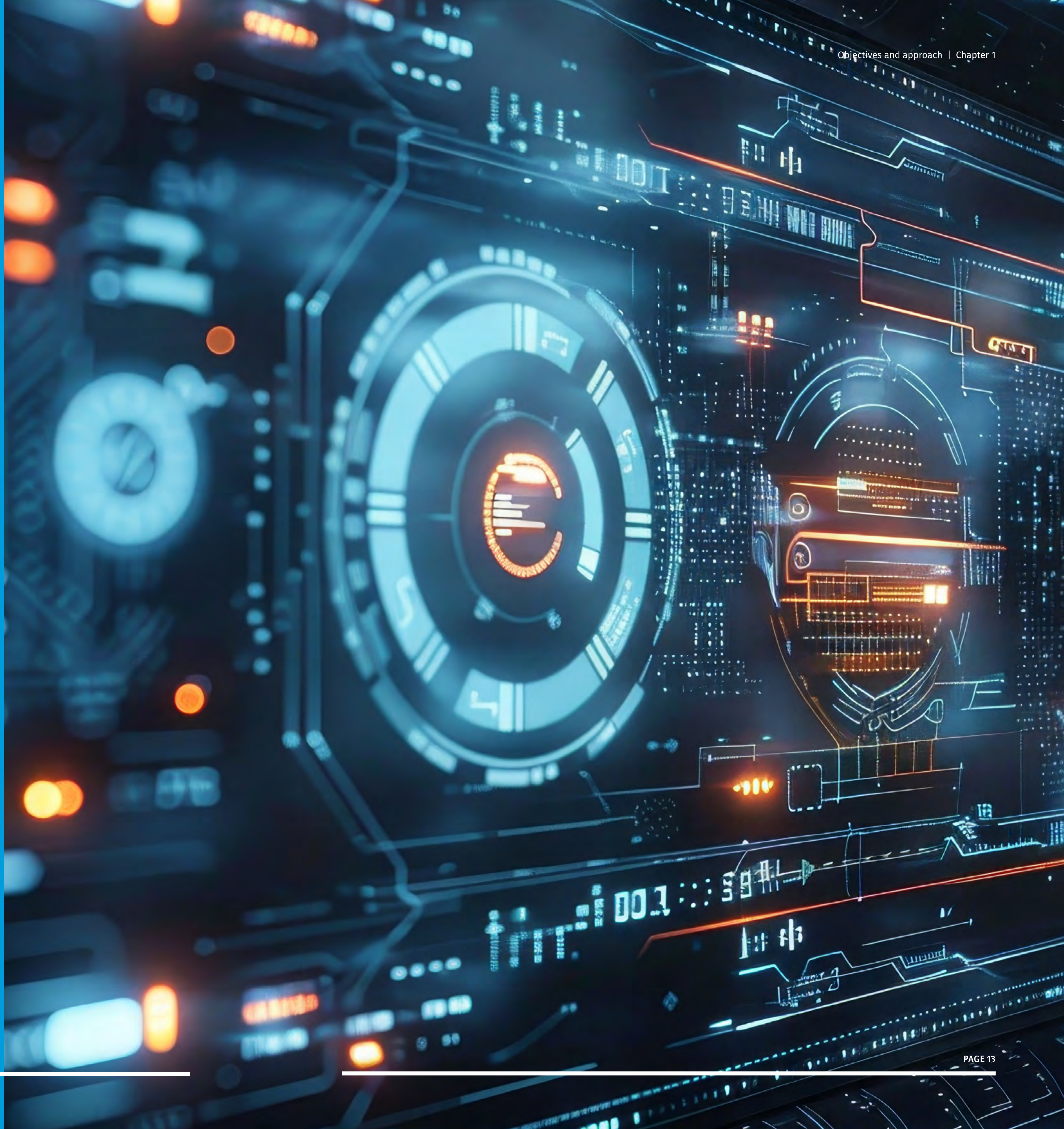
Objectives and approach



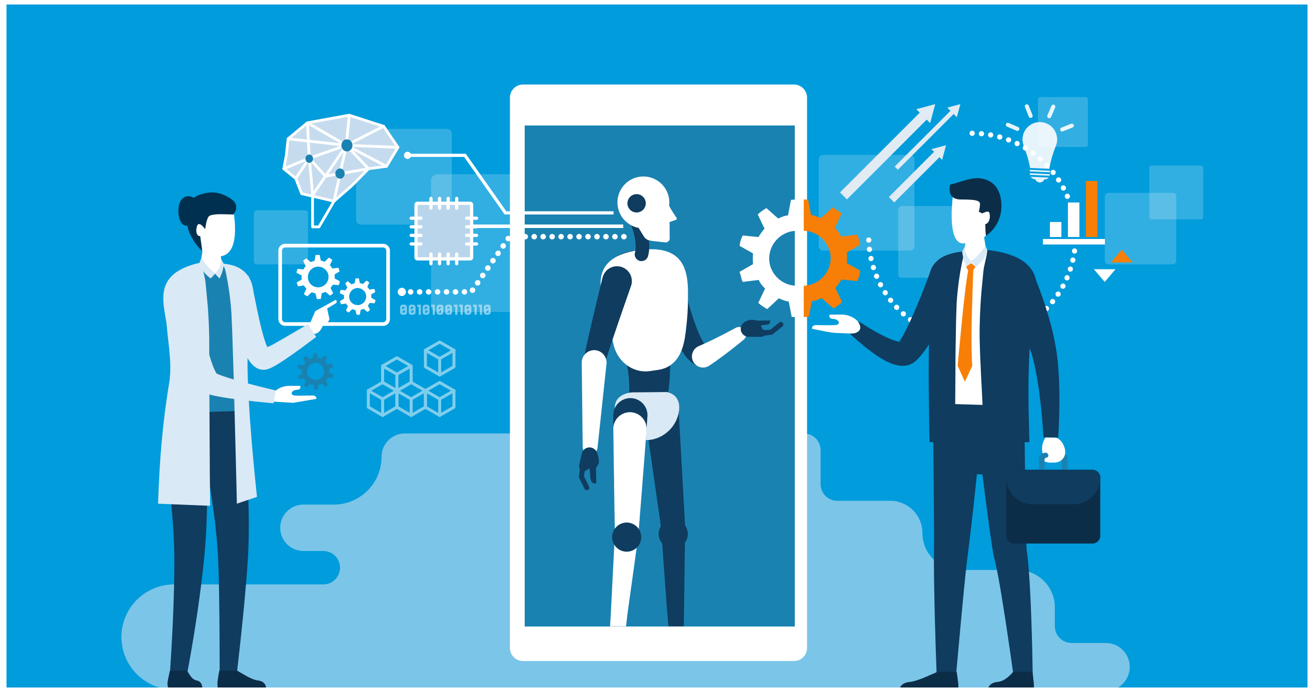
Over the past decade, the innovation and the development of digital production technologies have reached results which were unthinkable at the beginning of this century. Many different terms have come to define the recent waves of technological innovation, from broad concepts such as the "fourth industrial revolution" - meaning the broader socio-economic impact of new technologies - to more narrow concepts such as "Industry 4.0" (Sung 2018), which focuses on the manner in which digital technologies are changing the nature of production (mainly targeting the changes in the manufacturing process). Following a mounting interest in this field, Artificial Intelligence is emerging as one of the most disruptive technologies, causing both enthusiasm and fear at the same time.

Despite the hype which Industry 4.0 and related technologies, such as AI, have been receiving at both the policy and academic levels, one of their most critical elements is their need to be adopted and used in a highly interrelated and efficient way in order to reach the full potential of their use. We note that most of the technologies involved in this discussion, for example industrial robots, 3D printing, Internet of Things, and even the hardware and software components of AI, were invented decades ago. For example, the first robot was manufactured back in 1960 by Unimate and implemented at Ford, yet the technology was only widely adopted in the last three decades; similarly, 3D printing was developed in the 1980s but only adopted and developed at the industrial level in the 2000s. The real game changer has been the increased sophistication of hardware, software and connectivity, and especially the interconnection between different technologies which have become increasingly able to communicate, monitor, collect and analyze an ever larger amount of data. As for AI, its hardware and software technologies were invented respectively in the early 2000s when GPUs were first introduced by NVIDIA in computer graphics for videogames, and deep learning techniques have been evolving since the early 1990s, yet the breakthrough came with Alexnet and the invention of CNNs (convoluted neural networks) in 2012 (Krizhevsky et al. 2012).

The concept of technology fusion, which has been critical in the development of commercial technologies such as mechatronics and optoelectronics (Kodama 2014), is again useful to understanding the complexity of digital technologies; indeed, the novelty around it arises from the fusion of different layers of technologies, which are the main source of added value in the process of digitalization and technological upgrade (Andreoni et al. 2021).

While it has always been the case that technologies never work in isolation (Rosenberg, 1963), the interrelation of different digital production technologies has made interconnection a requirement in order fully to exploit the windows of opportunity which could emerge for different countries, sectors and firms. Here, the key to the effective use of digital production technologies is the development of a series of foundational capabilities, both productive and organizational, which would also entail an effective retrofitting of existing production plants. For example, if we consider industrial robots (an advanced digital production technology), their adoption as well as their effective use across different sectors (from automotive to semiconductors) depends on the existence of strong manufacturing capabilities which are embedded into firms' organization of their production processes (Anzolin and Androeni, 2024; Pillai et al., 2022; Anzolin et al., 2022; Usai et al., 2021). Such capabilities are critical in order to enable integrated digital production technologies to create value-adding processes; King (2015) has grouped together four main groups of such processes: (i) revenue improvement and (ii) cost reduction, which would fall into the profit drivers; (iii) fixed capital and (iv) working capital, which fall into the higher capital utilization.

The upgrade and the effective deployment of digital technologies would make it possible to unblock a series of bottlenecks for firms in both advanced and emerging economies. Nonetheless the challenges remain significant, especially for emerging economies, since digital technologies are likely to increase the technological gap between advanced firms – which tend to be fewer in number and MNCs/foreign firms – and the rest of the local production system. Addressing this gap and these challenges would require policies able to promote the required enabling factors at the firm and system levels.



This report reviews the current state of one of the most debated types of digital technology, which has gained an unparalleled level of attention in the policy environments of both advanced and emerging economies. We will delve into Artificial Intelligence (AI) and the relationship between AI and manufacturing in various areas, such as AI foundational technologies and its adoption across different countries, as well as innovation processes around AI and their use at the firm and sectoral levels. We will also provide insights on the available evidence regarding the impact of AI adoption on jobs and production. Stepping back from the sensational announcements regarding AI, this report will analyze current AI trends with the aim of better understanding its diffusion and the main opportunities and challenges associated with the increased use and rapid development of the technologies at its core. The report also focuses on analyzing the current regulatory and policy space, and identifying the main challenges faced by governments in the regulation of AI technologies, providing an overview of the key discussions regarding AI and ethics. In the spirit of the UNIDO mandate, and whenever possible given data constraints, we will focus on emerging economies, with a particular emphasis on Latin America and Africa. To this aim, this report analyzes data from different sources, bringing in production, innovation and scientific publication data collected by various organizations.

This report's objective is to analyze AI's impact on manufacturing in developing economies, and to provide policy recommendations to enhance AI adoption and mitigate associated risks. Expected outcomes include a comprehensive understanding of AI's role in economic growth, and actionable strategies for policymakers. By focusing on both opportunities and challenges, the report aims to offer a balanced perspective which can inform effective policymaking. Additionally, the report intends to identify key sectors where AI can have the most transformative impact and provide a roadmap for capacity building and infrastructure development.

The report is structured as follows:

Section 2 builds a bridge between existing discussions on advanced digital production technologies and the specificities of AI technologies.

Section 3 digs into AI, by analyzing the main technologies at its core, where they are produced, and which are the main countries involved in their innovation process, and also provides an overview of the main sectors and applications where AI is growing.

Section 4 looks at the current impact of AI on both production and labour.

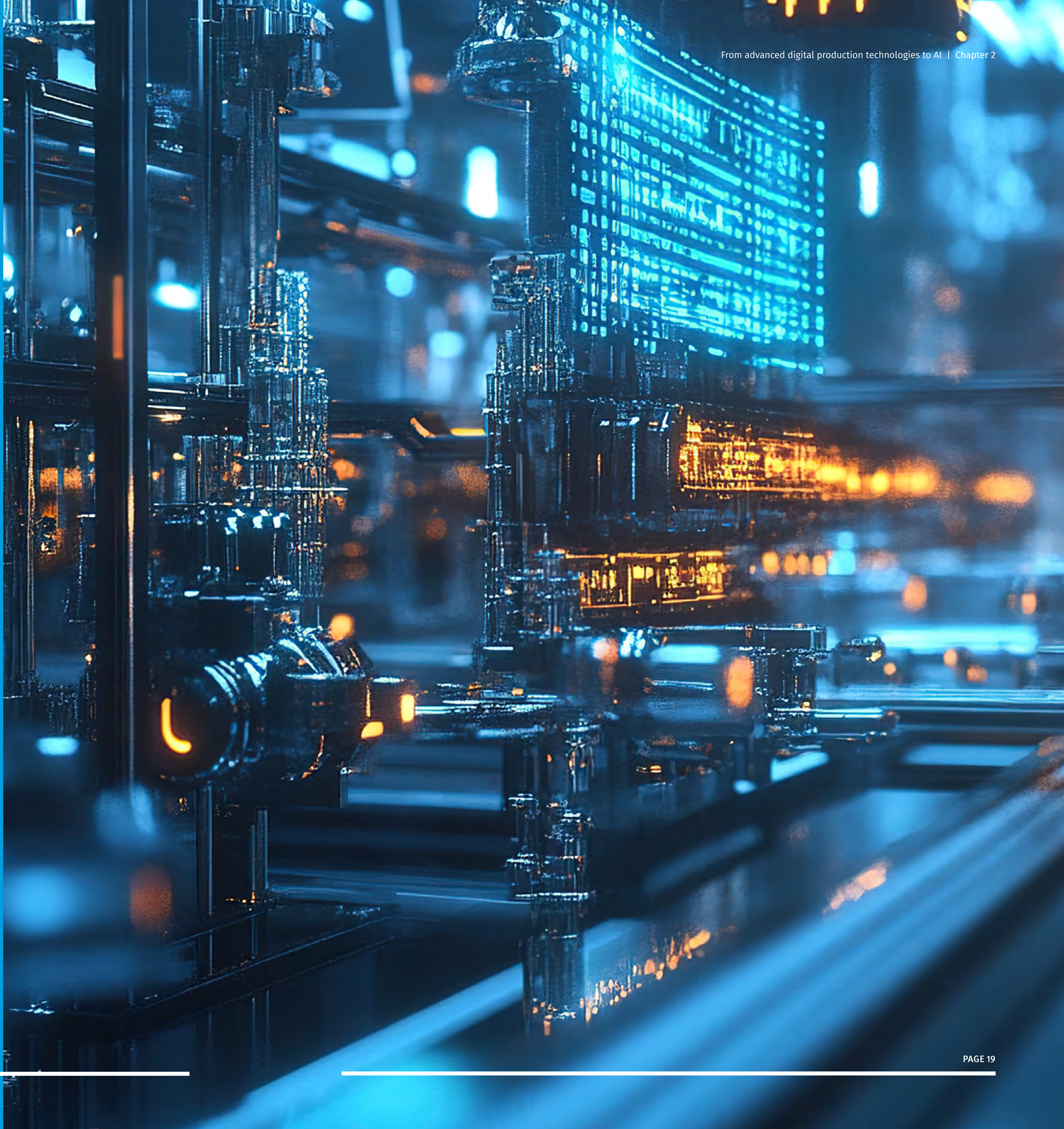
Section 5 explores various national approaches to AI governance, the significance of different AI visions, and their practical implications, particularly in relation to sustainability.

Section 6 introduces policy implications for emerging economies.

Section 7 concludes.

2

From advanced digital production technologies to AI



Artificial intelligence represents the final step in advanced digital production technologies. The ability to make machines "intelligent" in the sense of making them able to decide, make predictions, and infer output from a given input is the last step in the evolving digitalization process. AI is understandably attracting much attention, beyond digitalization and the fourth industrial revolution. Recent developments, for example, GenAI (generative AI) – e.g. large-language models (LLMs) and foundation models such as ChatGPT and Dall-E – have shown the potential of AI applications to profoundly reshape the economic and social spheres of our society. Some examples of LLM applications coming from manufacturing include predictive maintenance (where LLM can analyze maintenance logs, operational data and sensor inputs to predict equipment failures before they occur) and supply chain optimization (where LLM can assist in managing complex supply chains by analyzing historical data, inventory reports and external factors). There are some similarities and some differences between so-called digital production technologies and AI, which are worth considering before moving onto the analysis of AI.

Advanced Digital Production Technologies (ADPT) are characterized by an ongoing evolutionary process of technological innovations in hardware, software and connectivity. They encompass three types of different yet complementary sets of technologies, which are required to be deployed simultaneously in order to offer firms and users the full potential of productivity increases. Firstly, there are hardware components, which include tooling and complementary equipment necessary for the operation of modern industrial robots and intelligent automated systems, as well as 3D printers; this category includes technologies that have been mostly built during previous waves of technological innovation (e.g. during the third industrial revolution). Secondly, the software component is critical since it is only through its development that the hardware components – once integrated and connected – can perform specific tasks and lead to the gains in efficiency and productivity promised by such technologies. There have been great advances in the software realm, for example, with computer-aided manufacturing and computer-aided design (CAM/CAD), and there are increasing advances towards the creation of cyber-physical systems. Thirdly, hardware and software components require a connection through both actuators and sensors which are placed into ADPT and which are increasingly able to "communicate" in the environment where they are set to operate (Andreoni and Anzolin 2020).

ADPTs are often associated with the broader term fourth industrial revolution, and there have been two main contrasting narratives to consider this process of technological change. The first narrative emphasizes the key and unprecedented opportunities which new digital technologies would bring to production systems and to society, for example, in terms of productivity increases, product and process upgrading, job upgrading and upskilling (Pedota et al. 2023; Sorbe et al. 2019; Sturgeon 2021). A second narrative, which has become more prominent in recent years, points to the challenges and the risk that these technologies and their potential – so far unrealized – interconnection can bring. Two risks are particularly relevant in the manufacturing realm; firstly, there is the risk of widening the gap between big firms and SMEs (Radicic and Petković 2023), especially in terms of the benefits accruing from the adoption of these technologies. This is the case in both advanced and emerging countries; existing evidence in the UK, Germany and South Korea confirms that there is an existing challenge in small and medium firms adopting ADPTs (Sommer 2015; Yu 2018). In emerging economies, some of these risks are increased by production capabilities not being fully developed and by the presence of foreign companies which, by controlling the rate of adoption and deployment of ADPTs, could increase the power imbalance across the existing global value chain. In particular there is already evidence that multinational companies (MNCs) using ADPTs are in the position of having higher control over the supply chain and squeezing out local suppliers who do not comply with technology/standards (Mosch et al. 2021). The second risk, which is also where a great deal of the general anxiety over this topic lies, concerns the effects of digital technologies on jobs (Fana et al. 2024; Fernández-Macías and Bisello 2022). While it is certainly true that historically the adoption of new technologies has made jobs less strenuous and dangerous (for example, certain types of press machines, welding robots, handling machines and robots, which contributed to relieving physical stress from workers), often freeing workers from repetitive tasks, it is also true that this has often happened through a process of restructuring where some jobs disappeared, and others were created – for example when semi-automatic machines replaced manual operation and the number of workers required in that specific application decreased. While in the past, overall, the net result has been positive, there are concerns that this time things could be different (Marengo 2022), both in terms of technologies potentially increasing control over workers and substituting mechanisms between capital (technologies) and labour (Cirillo et al. 2021; Krzywdzinski et al. 2018).

These challenges, among others, are more pronounced in emerging economies. While some authors have argued that digital technologies may offer emerging economies opportunities to leapfrog certain steps of the development process, and in particular industrialization, here we argue that the building-up and accumulation of foundational capabilities is critical for long-term development (Andreoni et al. 2021). These capabilities include infrastructure, technological and productive capabilities; it is very hard to discuss AI or Industry 4.0 before solving issues around basic and digital infrastructures (e.g. roads, electricity, Wi-Fi connection) which often are a precondition for engaging with more sophisticated technologies. In addition to this, and particularly relevant for the aim of designing policies that would lead to positive spillovers to the broader economy, it is key to consider that emerging economies are mostly (excluding mainland China) importers of digital production technologies, which are produced in the Global North; this is a critical aspect not only because of the deepening of some countries' trade deficit if they keep on exporting low value-adding goods and services and importing high value-adding goods and services, such as ADPTs, but also because it is likely to widen the existing gap in terms of technological capabilities, leaving developing countries as users (at best) of ADPTs, while preventing learning and innovation around new technologies.

This brief summary of opportunities and challenges related to digital production technologies leads us to consider whether there are similar, and more or less critical issues in the case of AI. As commentators have argued, there seems to be a high potential for disruptive changes, especially in the labour market, yet the consequences of AI adoption in socio-economic terms are hard to foresee, both because it has not been widely adopted and also because there are very few empirical sources and data available to inform an assessment of AI impact. Section 4 below will review existing arguments and debates on the impact of AI on labour. It is likely that AI-enabled technologies present a potentially higher risk of substitution than ADPT, given that they are thought to work in a similar way to humans and to create and emulate human-type intelligence. In addition, and probably as one of the most critical elements of AI, which is not new when compared with ADPT yet remains highly emphasized, is the collection of data and the reliance of AI technologies on the increasing amount of data available. Crucially, as a result of the working principles behind generative AI and the latest AI advancements, the availability and quality of datasets are as important as these technologies. Therefore, data are a critical point when discussing AI. The types of data which are used to feed machine learning systems are collected in a variety of ways, and there is little discussion about the quality and potential bias of such data. This aspect

raises questions in terms of data availability, data storage and ethics around the data that are then used to make decisions in a more automatic way.

Different perceptions about AI highly depend on how it is conceptualized. Recent literature has reviewed three ways of understanding AI (Hötte et al. 2023b). Firstly, long-range perspectives consider AI as an outcome of the long-term co-evolution of hardware and software technologies and would be the last step towards automation. Secondly, mid-range views associate AI with modern forms of computing to perform tasks previously associated with human-like intelligence. Thirdly, short-range perspectives associate AI with the latest developments in machine learning, and mainly with recent innovations in deep learning.

In the rest of the report, we will expand on the existing evidence on AI and manufacturing, particularly providing literature and data analysis on two spheres of interest:

- **The manufacturing of AI technologies**, by looking at countries and, where available, companies which are at the forefront of production and innovation in AI technologies.
- **The sectors** – with a specific focus on manufacturing sectors – where AI is most commonly used, and references to different stages of the value chain where it can be used/is already used.

3

AI beyond the hype: definitions, production and innovation dynamics

3.1 DEFINITIONS AND KEY TECHNOLOGIES

In recent years there has been mounting hype around AI improvements and the present and future opportunities which AI may bring. Such hype has been characterized by forceful statements such as "AI could take 80% of our jobs"[1] or images of robots kicking human workers off the shop floor and out of the office. Again, hundreds of webinars, workshops, and articles ask similar questions along the lines of: will AI take our job?

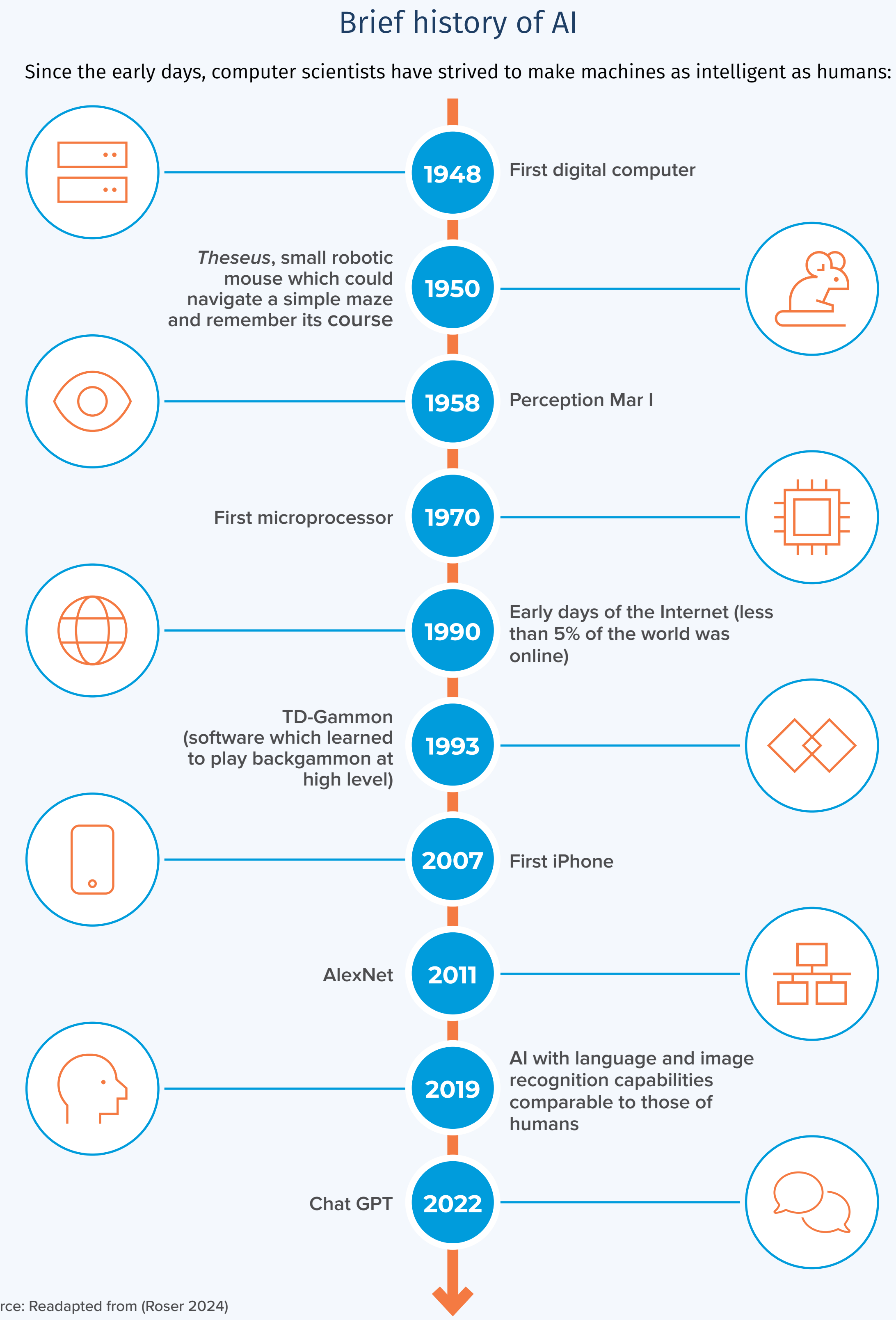
In this section of the report, we will unpack the concept of AI and delve into the technologies underpinning new tasks and the abilities of machines. Furthermore, we aim to understand the key dimensions for a robust and comprehensive policy analysis.

AI is a branch of computer science focused on creating machines capable of intelligent behaviour; it aims to develop algorithms and technologies which allow computers to perform tasks typically requiring human intelligence, and to acquire capabilities such as learning, reasoning, problem-solving, perception and also decision making. Machine learning has emerged as a key concept for AI, since most of the successful AI applications which we experience today are based on the premise that computers can learn from data given to them with algorithms using statistics-based techniques to enable their learning and predictions. All AI systems rely on machine learning which needs to be trained, and training computation is one of the three fundamental factors which drive the capabilities of the system, together with algorithms and input data (Roser 2023).

Before getting into a comprehensive definition, and unpacking the key elements of AI systems, we provide a brief overview of AI's historical trajectory (see also the box below). One of the most interesting aspects of AI is that although it was born in the 1950s, it has received few resources until the last decade, when it experienced a strong surge in private investment. It is documented that for the first six decades (after the 1940s), training computation increased in line with Moore's law, doubling roughly every 20 months, but that since 2010 the doubling time has decreased to just about six months (Duan et al. 2019; Roser 2023). As we will see below, this increase in investment has resulted in the doubling of AI scientific publications in a decade, in large and widely attended AI conferences, and in new PhD programs, along with an increasing number of job opportunities requiring AI skills.

1) https://economictimes.indiatimes.com/tech/technology/ai-could-replace-80-of-jobs-in-next-few-years-expert/articleshow/100088990.cms?from=mdr

FIGURE 1: Key dates for AI



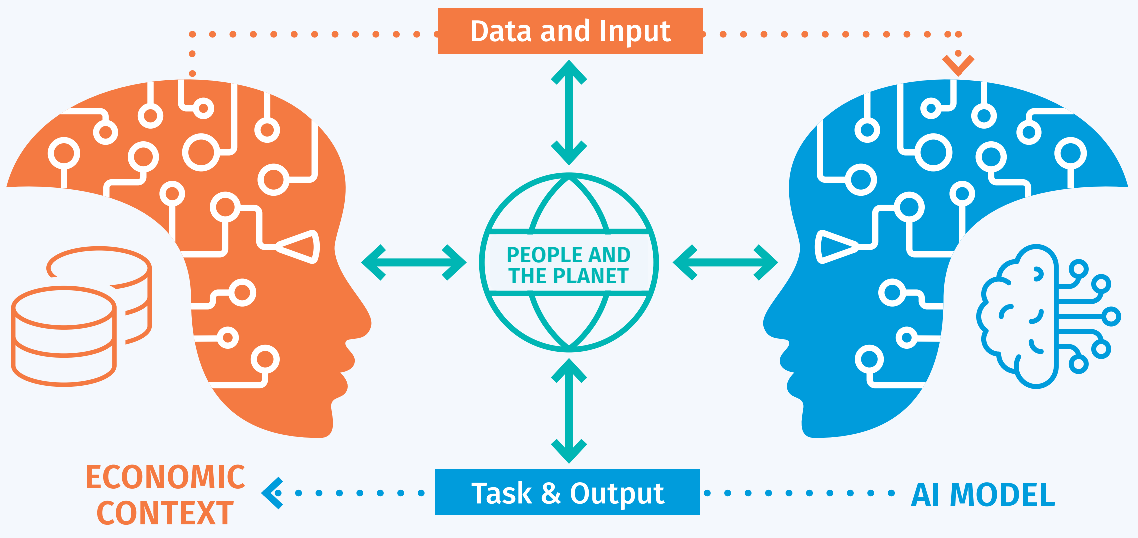
Source: Readapted from (Roser 2024)

We now get into the technological specifications of AI systems. These are the results from the combination of new hardware and software components (the former has made it possible to reach significantly larger computational capacity and enabled stronger interconnection among multiple devices), and new software development. The latter, software, is mainly based on machine learning statistical methods, which are revolutionizing the way computers work. AI is often referred to as a General-Purpose Technology (Crafts 2021) and its complexity stems from the numerous technological developments which are increasingly embedded in multiple technologies; the fact that AI is neither purely a hardware tool nor purely a matter of software development makes its development, examination and regulation very challenging (see section 5 for a focus on regulation). Such peculiarities make it also complicated to measure, since it is hard to collect and discuss data – at the national and especially international level – given that AI is such a cross-cutting technology not captured within the existing classification of products and economic activities (Righi et al. 2022).

Therefore, defining AI is a complex task because of the multiple technologies involved and the complexity of the overall system. In this report, we adopt the OECD definition, which has been accepted by all OECD member states. OECD's definition of an AI system is given below. Such a broader and comprehensive definition is graphically represented in Figure 2.

A machine-based system that can, for a given set of human-defined explicit or implicit objectives, infer, from the input it receives, how to generate outputs such as predictions, content, recommendations or decisions which can influence real or virtual environments. Different AI systems are designed to operate with varying levels of autonomy and adaptiveness after deployment.[2,3]

FIGURE 2: Key dimensions of the OECD Framework for the Classification of AI Systems



Source: Authors' replication based on (OECD 2022).

2) In addition to the revised "AI System" definition, the OECD is working on an Explanatory Memorandum to complement the definition and provide further technical background. While the definition is necessarily short and concise, its application in practice would depend on a range of complex and technical considerations. https://oecd.ai/en/ai-principles

3) The definition is also combined with the OECD AI Principles, which are the first intergovernmental standard on AI, adopted by OECD countries in May 2019.

Here, to better understand AI technologies, we can disaggregate further the different components:

1. **INPUTS**
As already mentioned, inputs – including rules and data – play a very important role and can be provided by humans or machines in operating AI systems. The AI system infers how to generate outputs after receiving them from the environment, and it processes the input through one or more models and their underlying authorisms. For example, "visual object recognition system implemented by a deep neural network performs "inference", i.e., infers how to generate its output (in this case, a classification of the object in the image) by passing its input (the pixels of the image) through the deep network (a parameterized algebraic expression composed of addition, multiplication, and certain nonlinear operations)"[4].

2. **OUTPUT**
The output has a specification of the word "content", which clarifies that the definition refers to GenAI systems, which produce "content", such as text, video or images.

3. **ENVIRONMENT**
The environment is referred as not "physical" in the sense that it is virtual, with actions from the AI system, and generates real sensory inputs to the AI system.

4. **ADAPTIVENESS**
Some AI systems can continue to evolve after their design and deployment, and this underlies the additional characterization of an important group of AI systems.

5. **EXPLICIT OR IMPLICIT**
Objectives are defined as explicitly, when they are directly programmed into the system by a human developer, or implicit, when the system is capable of learning new objectives.

4) https://oecd.ai/en/wonk/ai-system-definition-update

In essence, what enables the AI system to function is a combination of technologies. Specifically, each system has an infrastructure layer and an algorithmic layer from bottom to top. The infrastructure layer constitutes the basic hardware of critical technologies including graphical processing units (GPUs), dedicated AI chips and high-speed networks. Among the special chips developed for artificial intelligence are Google's TPU and NVIDIA's A100 Tensor Core GPU. The algorithmic layer is characterized by machine learning algorithms, including deep learning.

The recent global wave of attention towards AI has been catalyzed by the release of remarkable advancements in the field of GenAI. Owing to its ability to produce outputs which mimic existing patterns, and thereby pave the way to the creation of entirely new ones (including text, codes, images, speech and music) based on learned data, GenAI has taken the world by storm. Several companies have released chatbots powered by GenAI – e.g. OpenAI ChatGPT, Google Gemini, Microsoft Copilot, etc., thus igniting global competition for dominance in this sector. The technological advancements enabling such successes are two-fold: on the hardware side, the conversion of graphical processing units (GPU), powerful processors developed for computer gaming graphics, to non-graphical computing tasks has unlocked powerful computing resources; on the software side, the success of GenAI and large-language models has been built primarily on advancements in Transformer-based architectures, which are central to modern large-language models and generative tasks. These architectures are distinct from earlier approaches like convolutional neural networks (CNNs) and Generative Adversarial Networks (GANs).

3.2 WHO IS PRODUCING (AND INNOVATING) WHAT?

Who is producing the technologies at the core of the infrastructure and algorithmic layer? The use, regulation, and diffusion of a specific technology cannot be separated from the main actors – both individual firms and countries – who produce, innovate, trade and invest around the key production segments of that specific technology. This section of the report will dig into existing data sources; despite being patchy and with a prevalence of data focused on advanced economies, it is possible to present an overview of production and innovation around the main AI technologies. Beginning with the production of AI systems, one of the key technologies in the infrastructure layer is the logic chip, for example CPU and GPUs, which are the fundamental information processing units of computers and other electronic devices. Despite improvements and the introduction of more tailored chips, for instance, featuring mixed-precision computing (to speed up computing by reducing the precision of numerical formats) and tensor cores (to handle specific computational patterns found in neural networks), there is no such thing as an AI chip at the moment. Therefore, NPU, GPU and TPU constitute the basis of current AI systems. Figure 3 presents an overview of the market share for logic chip production by manufacturing stage.

FIGURE 3: Overview of the market share for logic chip production by manufacturing stage

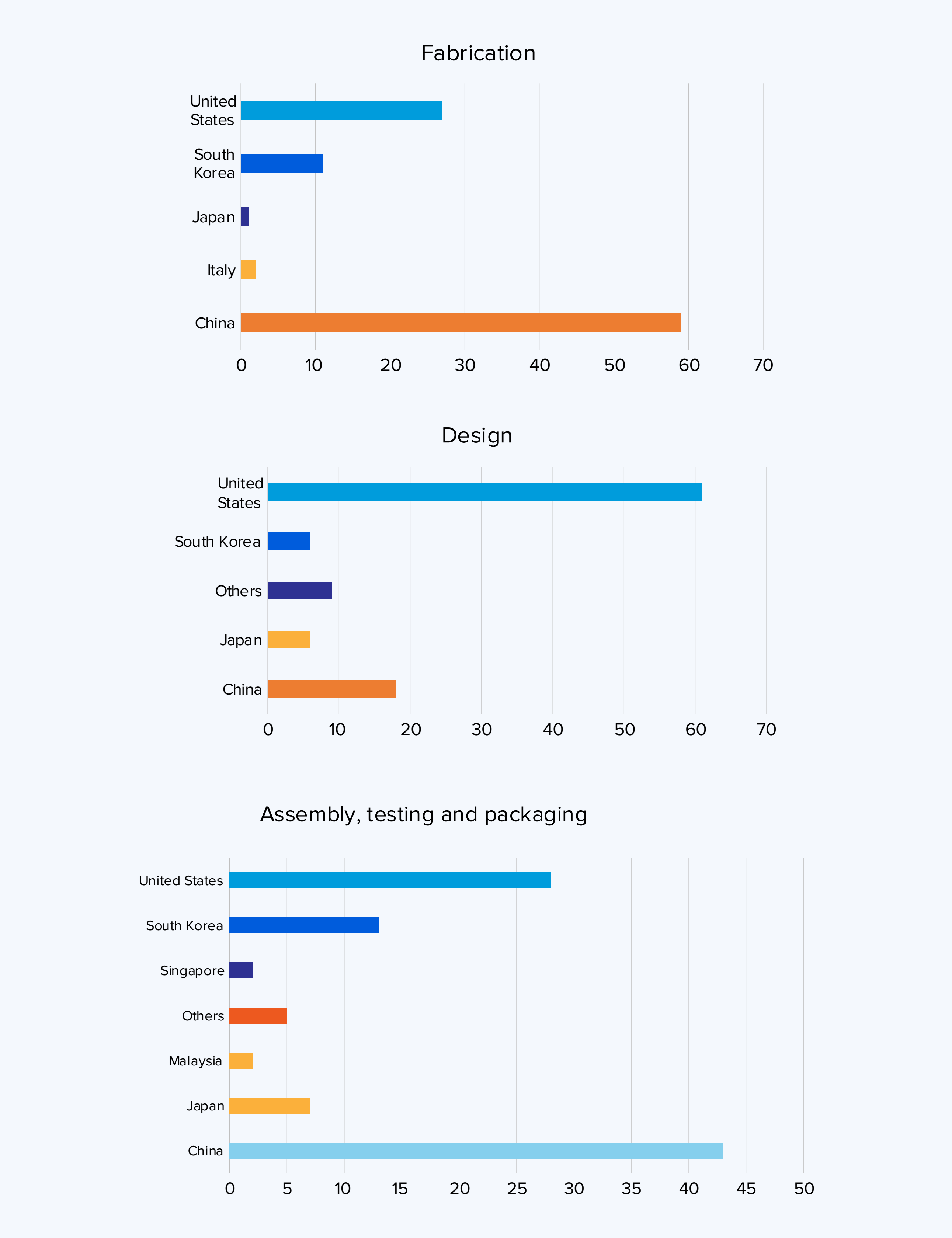
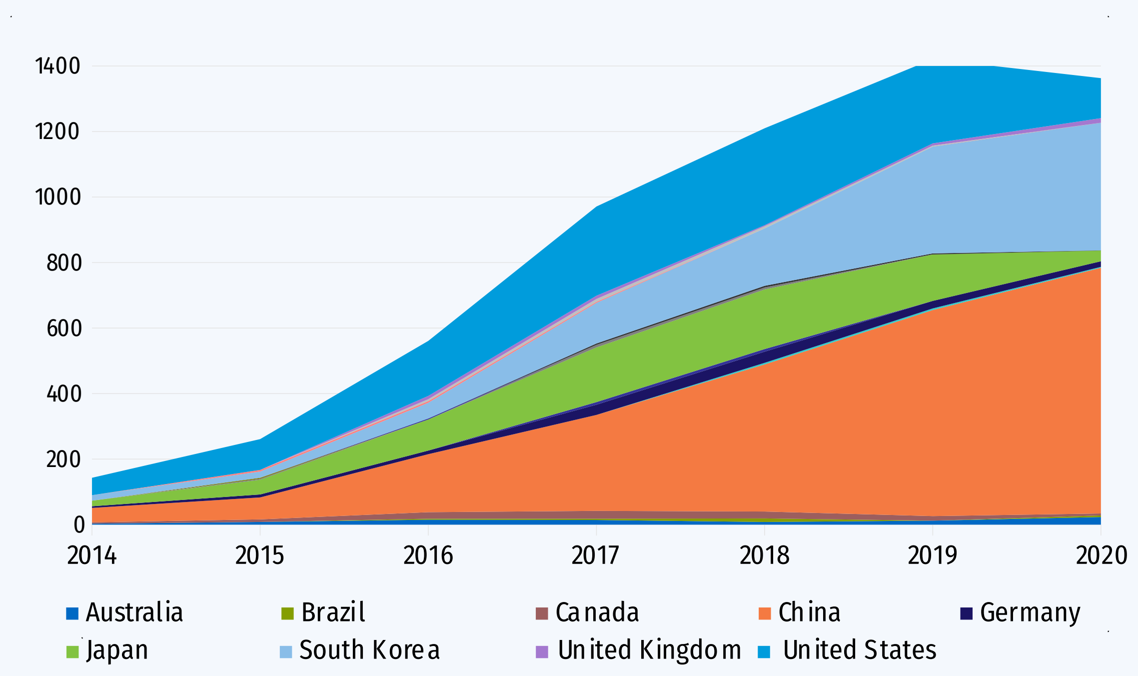


Figure 3 indicates US dominance in the two higher value-adding phases of logic chip production, namely design and fabrication. China and South Korea also have a good position, and the former especially has become a key player in assembly, testing and packaging. Beyond China, Malaysia is the only other emerging economy to play a significant role in one of the main segments of chip production (i.e. assembly, testing and packaging) with 2% of global market share. The design and fabrication segments of production are both highly concentrated, with a dominant position for the US in both the former and the latter. It is relevant to mention that the production of chips is extremely expensive, and characterized by high sunk costs at the beginning of the investment phase, not only because of the complexity of the production process, but also due to the sophisticated capital equipment and related capabilities required (e.g. cleanrooms).

Manufacturing of key AI technologies is closely related to innovation capabilities; in fact, especially in key semiconductor products, which are characterized by high levels of complexity, manufacturing and innovation capabilities are complementary, and characterized by strong feedback loops along the innovation process (Dibiaggio 2007). Similarly to the manufacturing of logic chips for AI, innovation in the field is also characterized by high concentration at the country level (Igna and Venturini 2023).

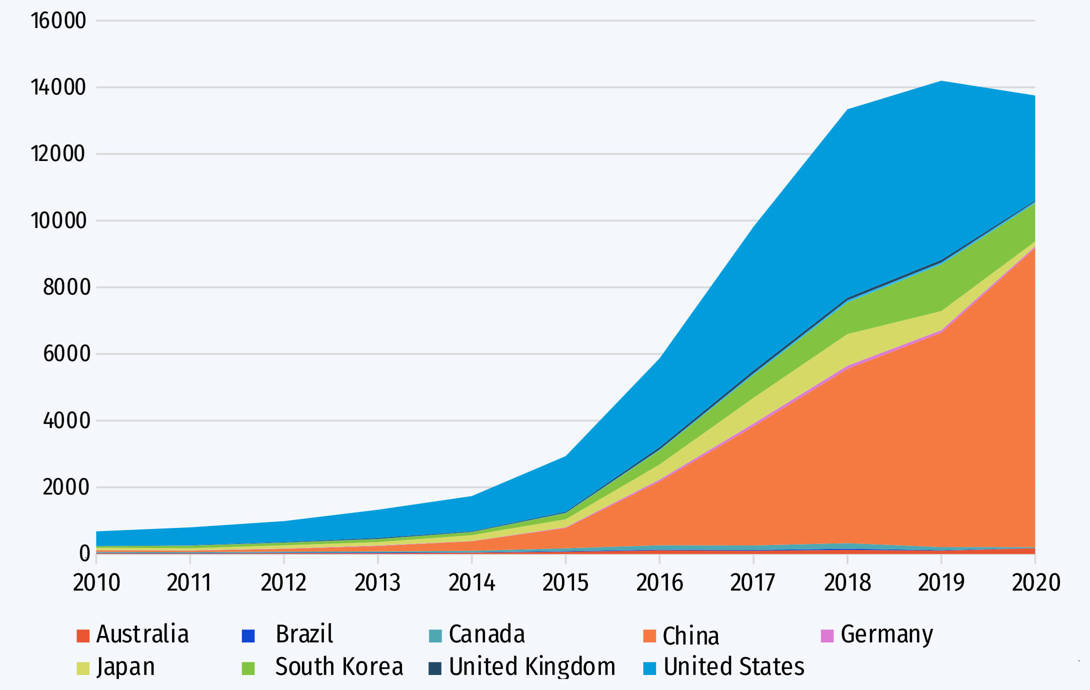
In the next four figures we present patent applications granted in industry and manufacturing (as the main fields of interest for this report) along with three other high value manufacturing sectors: physical sciences and engineering, telecommunications and personal devices and computing.

FIGURE 4: AI patent applications granted in industry and manufacturing



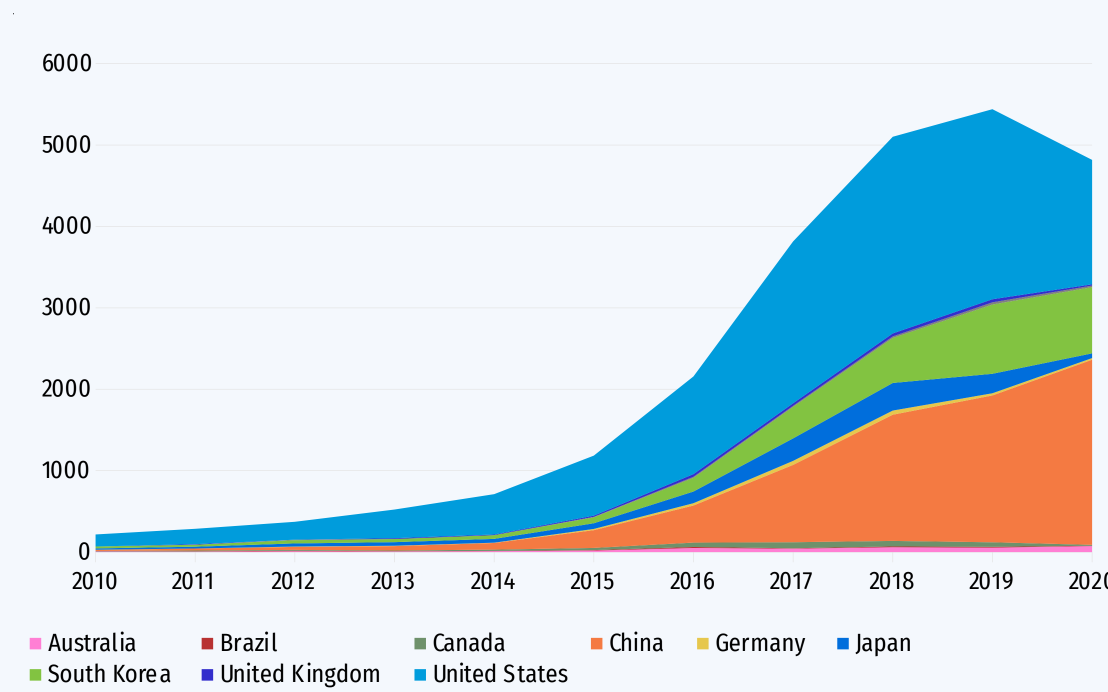
Source: Authors based on data from OurWorldinData.org

FIGURE 5: AI patent applications granted in computing



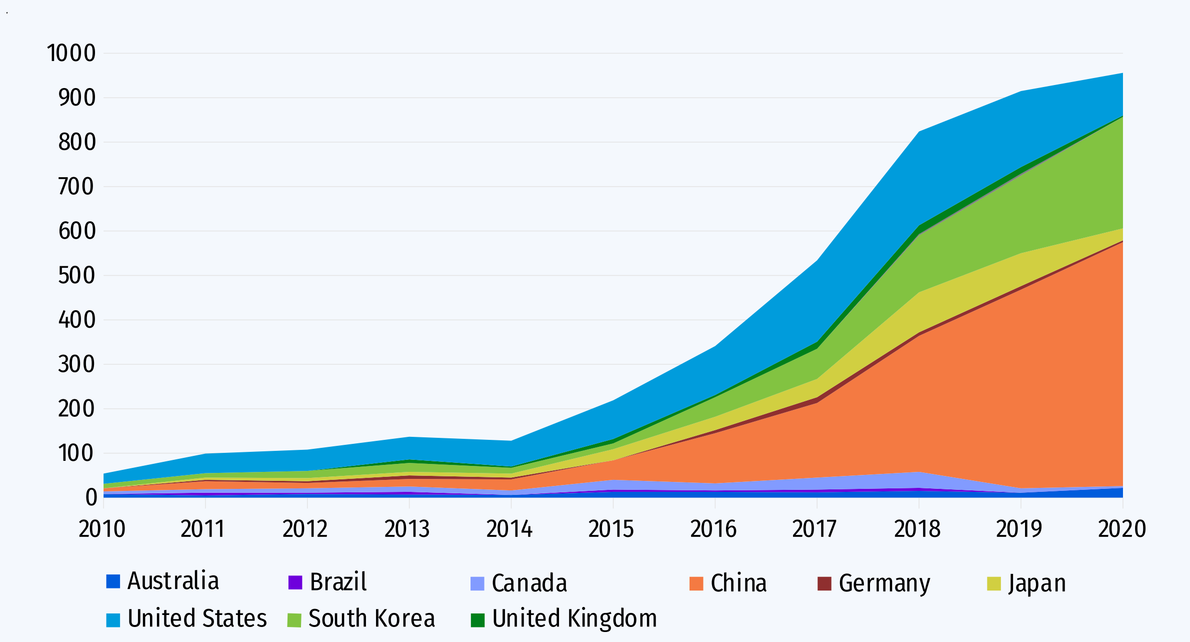
Source: Authors based on data from OurWorldinData.org

FIGURE 6: AI patent applications granted in telecommunications



Source: Authors based on data from OurWorldinData.org

FIGURE 7: Patent applications granted in physics and engineering



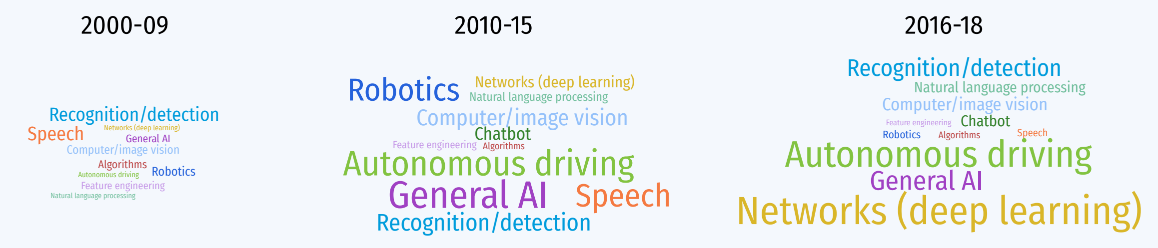
Source: Authors based on data from OurWorldinData.org

Figures 4, 5, 6 and 7 highlight two main trends. Firstly, China is the only developing country to have a significant share of AI applications in industry and manufacturing, computing, telecommunications, and engineering. While in industry and manufacturing there were innovation capabilities which grew over time, in telecommunications and computing, China had almost no AI patenting activities in the early 2000s and has managed to expand innovation activities in this field very effectively. Secondly, innovation activities in AI are very much limited to a handful of advanced economies, mainly the US, South Korea and Japan – whose activities in AI patenting have been shrinking in all fields.

Patents are widely used as a proxy for innovation and especially as a metric for R&D, and are critical for the production, adoption and learning dynamics around AI technologies. Within R&D, patents remain an important way to assess and measure AI-related technologies, since they contribute to the provision of solutions to the challenges facing AI systems. Recent studies show that core AI patents have become more original, (i.e. patents involving a broader range of technological fields) and more general (i.e. cited by patents belonging to a wider range of fields). In addition, it has become critical to recognize (and study) topics which are consistently at the core of AI innovation, such as robotics, computer/image vision and recognition or detection (Calvino et al. 2023).

When unpacking the type of innovation which has been occurring in AI systems, we note that most innovations have been clustering in certain areas/sectors/technologies. Figure 8 reports AI main topics (top 1% cited) in core AI patents' abstract by sub-period. The size of the words reflects the frequency with which each main topic appears in the sample which refers to the top 1% of cited patent applications filed at the USPTO (patents issued and pre-grant publications) referring to AI technologies. The sample relies on a sub-sample of core AI patents (463 patents), for which an AI main topic was directly available or imputed (Calvino et al. 2023). As can be seen from the Figure below, certain topics have become more important, and innovation efforts have been focusing here, for example autonomous driving, general AI, speech (recognition), and deep learning.

FIGURE 8: Word clouds of AI main topics, 2000-18

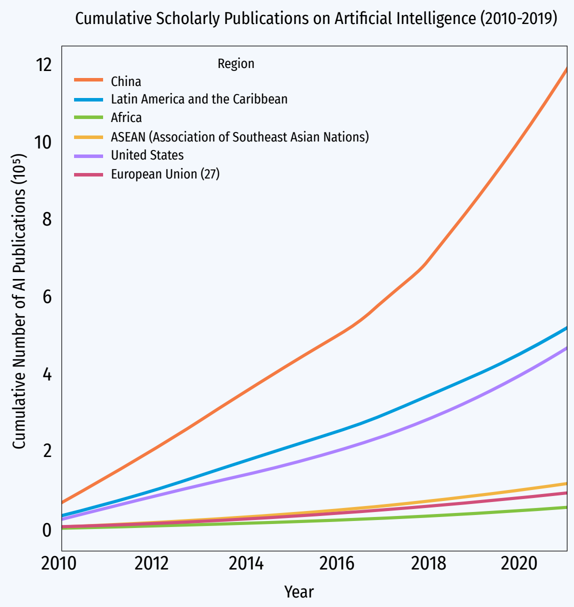


Source: OECD, STI Micro-data Lab: Intellectual Property Database, http://oe.cd/ipstats, June 2023.

Such thematic areas have also been analyzed by the AI watch at the European level; it studied the comparative advantage of countries around the world revealed through a topic model which identified nine areas/technological sub-domains. The areas are: i) audio and natural language processing; ii) computer and vision applications; iii) machine learning fundamentals; iv) machine learning for image processing; v) Internet of everything; vi) automation; vii) autonomous robotics; viii) connected and automated vehicles; ix) AI services. Interestingly for our focus on emerging economies, the study found that China has RCA in sub-domain ii, iii, iv, v, vi, while India has RCA in sub-domain ix.

Despite the critical role of patents in understanding AI system innovation trends, patents capture only one part of the technological development. A further useful way to evaluate R&D in AI is by considering the number of scientific publications which directly measure current research in the field; some argue that this provides a more comprehensive method of measurement. In fact, while a large proportion of the research undertaken on the hardware component is patentable (it is on a physical medium enabling increasingly faster and more widely distributed computation), the situation is different for software. Software innovations are typically non-patentable, and this makes scientific publications more appropriate than patents as a measure of techno-scientific progress (Noel and Schankerman 2013).

FIGURE 9: Scholarly publications on AI (2010-2019) in selected regions of the world (cumulative values)

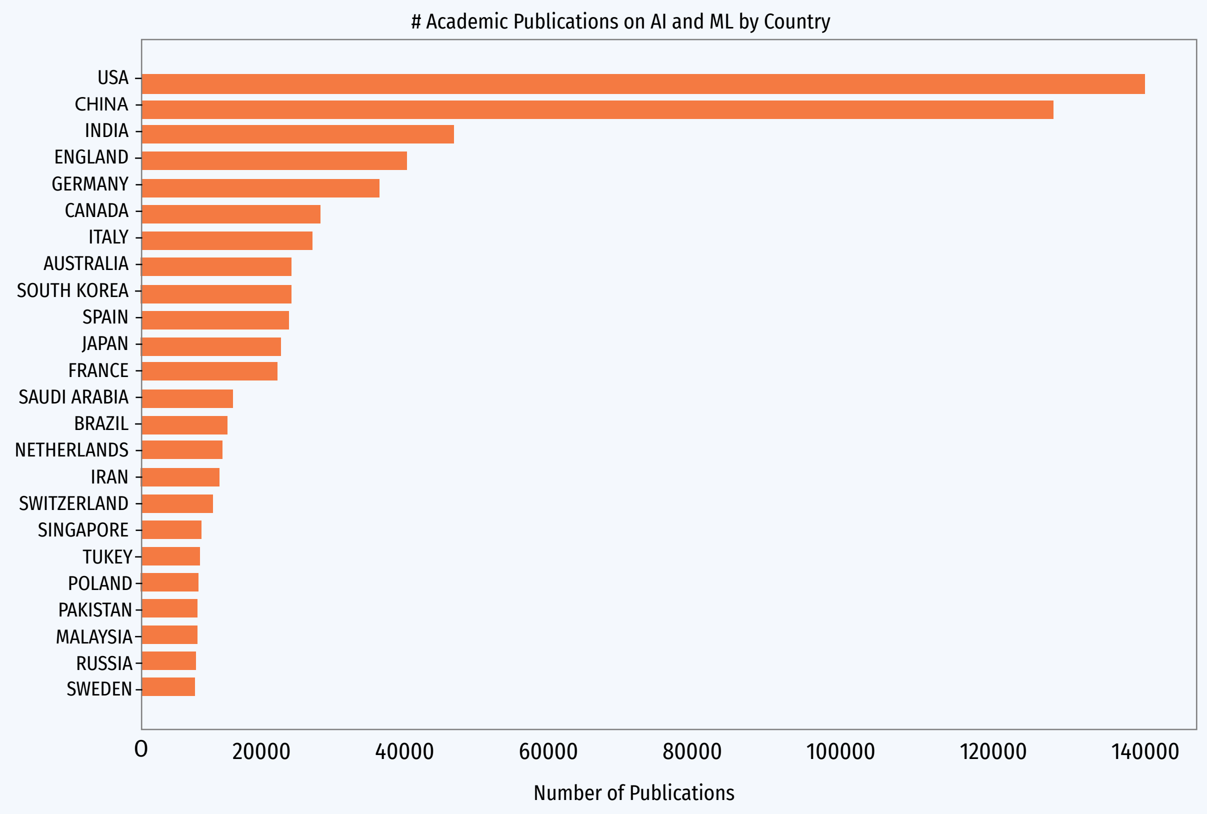


Source: Authors based on Ourworldindata

In the rest of this section, we present data on scientific publications in AI across different regions of the world, zooming into areas of interest such as Africa and Latin America. Figure 9 shows that China, the European Union and the United States have a much higher levels of publications in the AI field; China particularly presents sustained high growth since the early 2010s.

Unpacking the aggregate figures, we can observe (Figure 10) the number of publications on AI/ML by country; despite patents being created/introduced mostly in rich countries, there is high potential for development: for example, India, Brazil, Iran, Pakistan and Malaysia are among the top 15 countries for AI/ML publications.

FIGURE 10: Academic publications on AI and ML by country



Source: Authors based on Ourworldindata

The rest of this section presents insights into the regions of interest, i.e. Africa and Latin America. Despite these countries still being far from the forefront of innovation, both Africa and Latin America present increasing trends. Looking at Africa, it is interesting to note that Morocco is the country which (at least before the Covid pandemic hit) was doing particularly well, signalling also that the development of industrial capabilities and of economic indicators has been advancing in parallel to scientific publications. Despite Morocco doing reasonably well until 2020, the other best performers in Africa have been decreasing their levels of scientific publications; Egypt has seen a resurgence from 2016 however and it seems not to have been impacted by the pandemic crisis.

FIGURE 11: Scholarly Publications on AI (2010-2019): cumulative share of total Africa on selected African countries

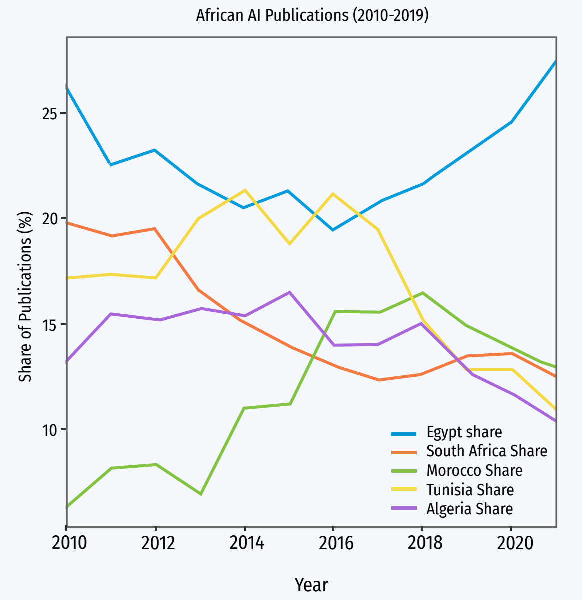
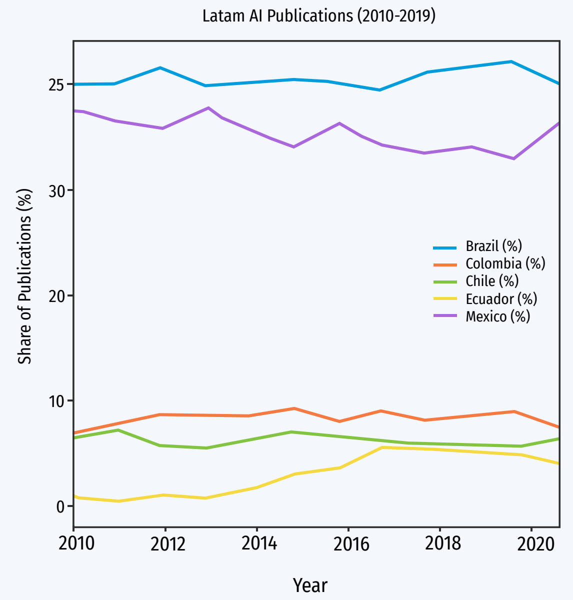


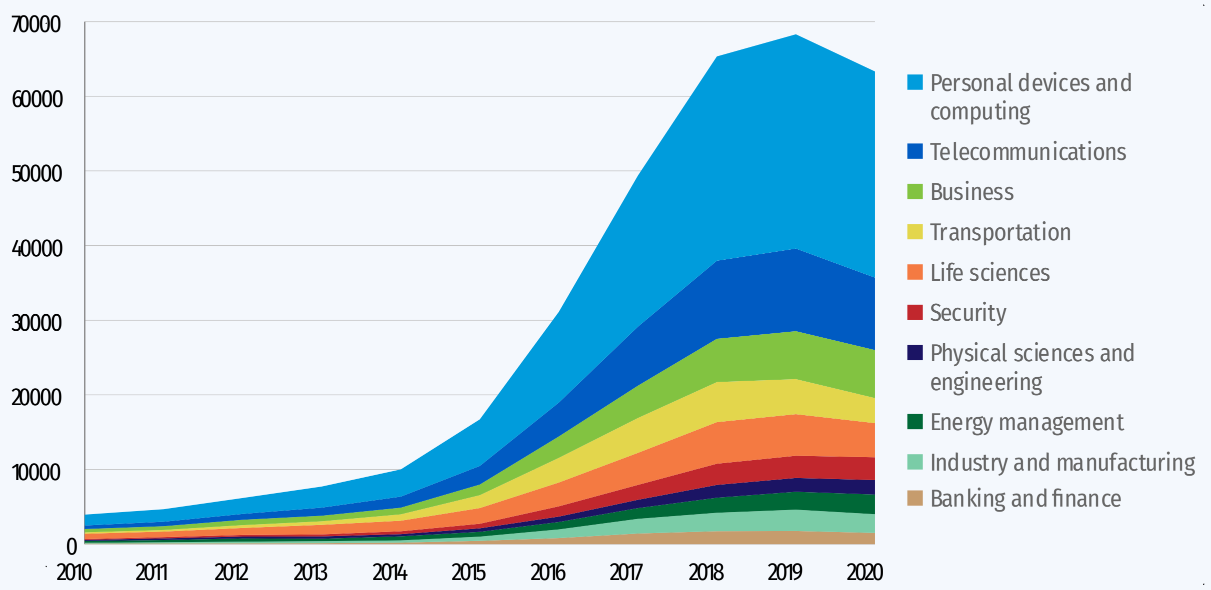
FIGURE 12: Scholarly Publications on AI (2010-2019): share of total Latin America in selected Latin American countries



3.3 AI ACROSS MANUFACTURING SECTORS AND ITS APPLICATIONS

The elements discussed in the previous section point to a very strong concentration both in terms of AI technologies production and innovation capabilities. One of the cornerstones of industrial policy, which highlights the importance of investing in certain sectors to raise the level of regions' and countries' capabilities, is that certain sectors are "better" than others in favouring the process of capabilities accumulation (Bell and Pavitt 1995). This is strongly related to certain sectors being technology-intensive and/or favouring a trajectory of learning opportunities. This argument is of high importance for the technology embedded in AI systems. As indicated in Figure 13 below, which shows AI patents granted by industry, there is a high concentration in terms of sectors where AI innovations proliferate; among the sectors with the most AI innovation, are personal devices and computing (which underwent massive growth from the early 2010s to 2019), telecommunications, transportation and business. Kim et al. (2022) find that AI applications vary across sectors also depending on product or process AI applications; AI applications for product enhancement are occurring more frequently in sectors such as autonomous vehicles, batteries, robotics and energy sectors, while AI for manufacturing process enhancement has happened more in the steel and semiconductor sectors. Evidence of sectoral heterogeneity is also addressed in a recent study by the UK Department for Science and Technology, which assessed that AI use is small in absolute numbers in the manufacturing sector; nonetheless the study has identified higher proportions of wider AI activity in the following sectors: automotive, industrial automation and machinery, energy, utilities, and renewables, health, wellbeing and medical practice, and agricultural technology.[5] A recent report, which considers the potential of AI in the Indian economy, reports that the major impact in the manufacturing sector will be higher efficiency and a simpler production process through the mechanization of previously human-based tasks (Jujjavarapu et al., 2018).

FIGURE 13: Artificial intelligence granted patents by industry

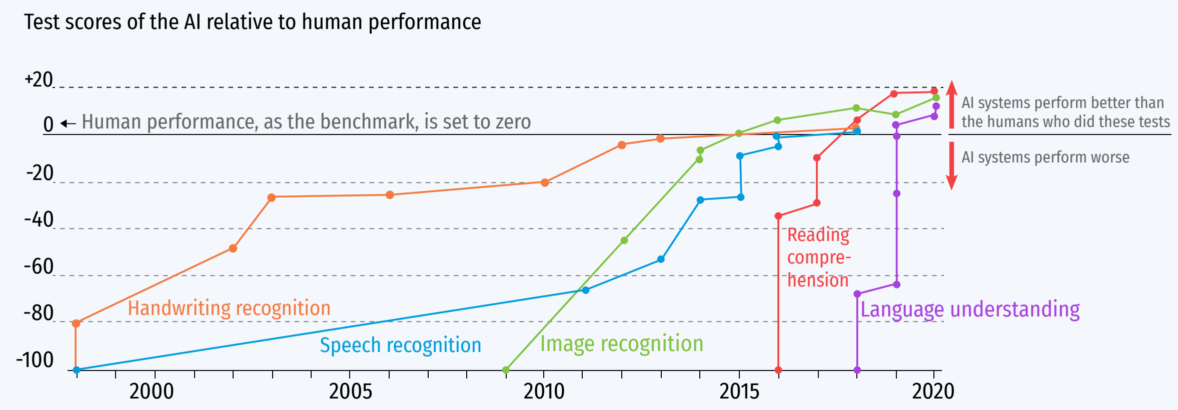


Source: Authors based on Ourworldindata

Sectors are also unequal both because of different levels of innovation intensity and because different AI applications tend to be more applicable to certain sectors, depending on the "abilities" and uses developed for specific sectors. The latter may include industries which benefit more (or less) from some capabilities/fields developed within the AI technology. For example, Figure 14 reports on the language and image recognition capabilities of AI systems; it can be observed that reading comprehension, image recognition and language understanding are the fields where AI systems perform better than the humans who took the test. Sectors such as retail, healthcare, automotive, and agriculture are among those where image recognition has wide adoption potential for tasks such as inventory management and visual research.

5) Sectors with higher use are financial services, ICT and R&D and scientific companies.

FIGURE 14: Language and image recognition capabilities of AI systems



Source: Kiela et al. (2021), DynabenchL Rethinking Benchmarking in NLP. See also OurWorldInData.org
Note: The capability of each AI system is normalized to an initial performance of -100

AI finds application in various sectors of manufacturing. At the organizational level, deep learning emerges as a prominent area of exploration, gradually supplanting conventional data analysis methods. Deep learning excels in discerning intricate patterns within trained datasets, demonstrating proficiency in recognizing diverse forms of unstructured data. Its efficacy spans across domains like object detection, natural language processing, and speech recognition, achieving notable success rates. However, challenges persist, notably in interpretability and extrapolation, alongside performance issues intricately linked to factors such as dataset size and quality, and the intricacies of its design and architecture. (Kim et al. 2022).

While GenAI has been thrust into the limelight, its impact on the economic context mainly focuses on education, the creative arts, media and journalism, healthcare, and marketing/design. Nevertheless, advancements in enabling technologies (such as GPUs and neural networks) for GenAI are expected to spill over to other types of AI applications. For example, if we consider the manufacturing sector, GenAI has promising applications across different realms, from design to training, from process control to predictive quality control. Generative design and prototyping can generate multiple design variations based on specific parameters and constraints, helping engineers explore innovative product designs. For example, in the automotive or aerospace sectors, GenAI can suggest lighter, optimized shapes while maintaining the strength required. Another example is intelligent process control where GenAI can help to control the parameters for complex processes like injection moulding, 3D printing or welding, while ensuring precision and reducing material waste.

Crucially, different types of AI, such as predictive AI and diagnostic AI, are expected to have a much greater impact on advanced manufacturing. Diagnostic AI is employed extensively for fault detection and quality control. On the other hand, predictive AI plays a crucial role in industrial maintenance and operations, where it predicts failures and optimizes maintenance schedules. This technology processes the continuous data streams generated by IoT sensors embedded in industrial equipment. It is important to note that both predictive and diagnostic AI applications run on similar GPU platforms and use CNNs and recurrent neural networks (RNNs), thus benefitting from recent advancements in GenAI.

4

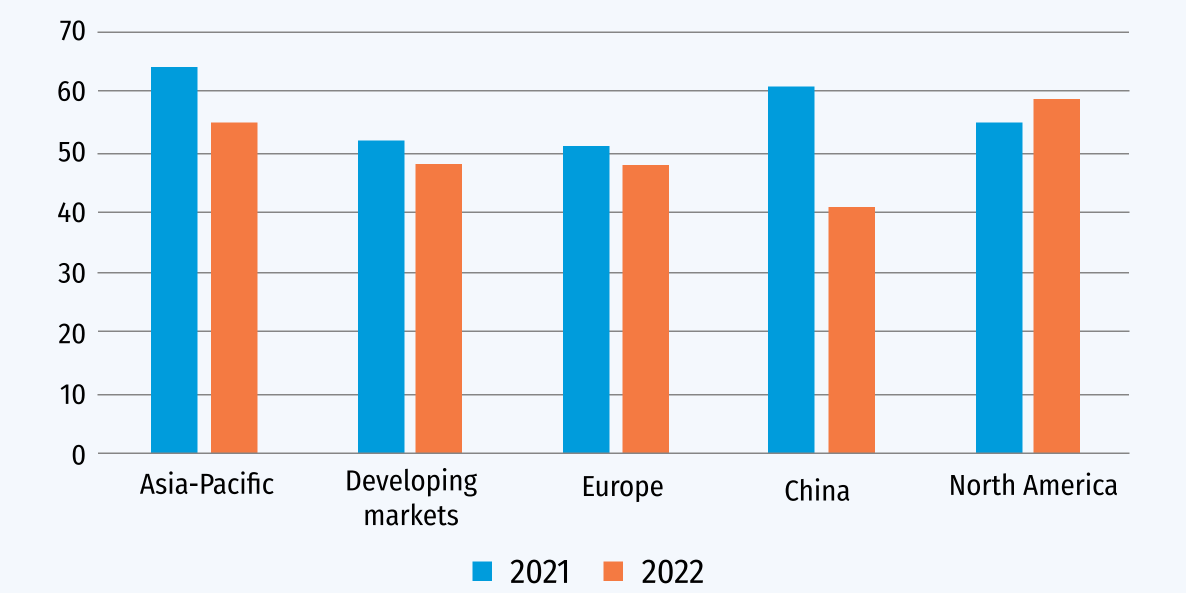
AI diffusion and its impacts on the economy and jobs

4.1 DIFFUSION AND IMPACT ON THE ECONOMY

In order to address the economic impact of a technology, it is relevant to understand firstly whether the technology has been widely adopted and used; in other words, and to borrow the expression from the economist Nathan Rosenberg, we shall have to study diffusion dynamics in order to analyze the economic relevance of new technologies. Data limitation to assess the adoption of digital technologies, and especially of AI, is a pervasive challenge when assessing its diffusion. Yet, the challenges in the adoption of more basic types of technologies point in the direction of a slow diffusion and the relevance of structural bottlenecks to AI adoption and implementation.

Starting from a more aggregated dataset, Figure 15 presents an overview of organizations which reported using any type of AI system by geographical areas. Two interesting elements emerge: on the one hand, developing markets are in the aggregate performing in a similar way to Europe, while Asia-Pacific and China are the greatest adopters of AI. On the other hand, all regions present an inflection between 2021 and 2022, except for North America, which could be a sign of the strong digitalization and reindustrialization effort happening in the United States with the use and implementation of different policy measures.

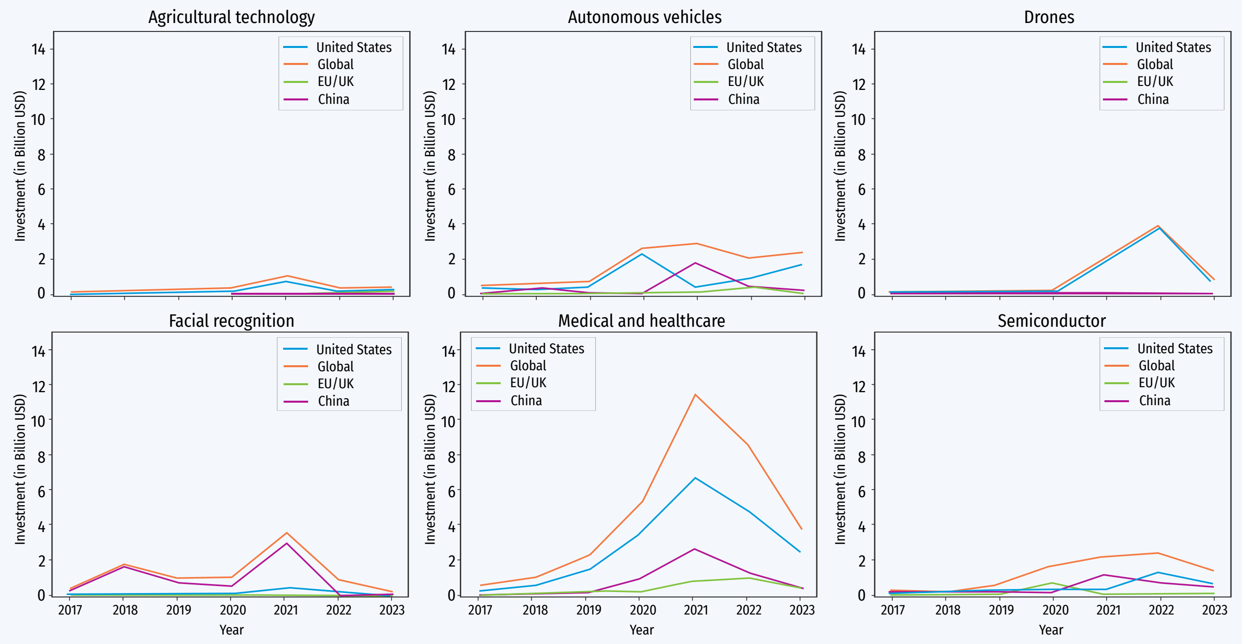
FIGURE 15: Organizations reporting AI adoption



Source: Authors based on AI

Shifting to a more micro level, data on annual private investment in AI by focus area are also available. Figure 16 shows the trends in the six main areas, where medical and health care and data management are the two areas receiving the most attention from private investors; in all areas, US investors are leading.

FIGURE 16: Annual private investment in AI, by focus area



Source: Authors based on Ourworldindata

It is worth mentioning that in terms of private investment directly related to AI, there are three types of firms: firstly, firms whose core business is AI and which do not patent; secondly, firms which only file AI-related patent applications; and thirdly, firms whose core business is AI and which do file patents. The latter type are generally the most high-tech companies, and the largest number are located in the US and China. Combining all types of firms, the AI index (JRC) evaluated that there are 13,000 AI firms in the US, 10,000 in China, 5,500 in Europe and 3,000 in the UK (Righi et al., 2022).

Coming to the adoption of AI at a more granular level, it is firstly important to stress that the intrinsic properties of emerging digital and general-purpose technologies make it hard to estimate their adoption at the firm level, and thus to grasp determinants/drivers for technology adoption. This is especially the case given the absence of data at the micro-level. Nonetheless determinants are critical both at the policy making level (i.e. to focus policy makers' attention on gaps and bottlenecks which hinder adoption) and for the future diffusion of technologies, given that early-stage adoption establishes path-dependency for later diffusion mechanisms (Dahlke et al. 2024). In other words, the adoption of (or the failure to adopt) a technology such as AI can lead to technological lock-in/lock-out and contribute to alleviating (or exacerbating) divergent economic development across regions.

In theory, AI has the potential to increase productivity based on continuous technological improvements and a higher rate of innovation (Barro and Davenport 2019); such developments are likely to have significant impacts on knowledge production and organizational decision making (Paschen et al. 2020). For example intelligent manufacturing would improve production processes and enhance the possibilities to control, recognize, learn, and compare in the production system (Zhang et al. 2019).

At the practical level, the adoption/diffusion scenario appears more complex. Existing studies provide an initial empirical base for consideration and provide insights to policymakers. Looking at AI adoption across both the manufacturing and service sectors and building on a study that covers more than 380,000 firms in Germany, Switzerland and Austria, it was found that AI adoption is based on three main criteria: (i) co-location in industrial and regional AI hotspots; (ii) direct exposure to services transmitting deep AI knowledge; and (iii) relational embeddedness in AI knowledge network (Dahlke et al. 2024). This pioneering study interestingly aligns with existing elements in the evolutionary and innovation economic literature, which stress the importance of co-value creation, tacit knowledge in the development and adoption of a given technology, and proximity. A negative note reported in the paper is the identification of a strong pattern of clustering, and the fact that the relation of proximity identified in the adoption of AI is likely to hinder the broader diffusion of the technologies; this points to an important element to consider for policymakers. There is increasing literature which expresses concerns about the fact that the deployment of AI technologies could create dependencies on a small number of economic actors (Rikap and Lundvall 2022).

Another study focusing specifically on the manufacturing industry and covering surveys across 655 firms (being a representative sample across the manufacturing industries) focuses on the three aspects that have the greatest impact for AI adoption in manufacturing, namely digital skills, company size and R&D intensity (Kinkel et al. 2022). This study is also one of the first to address the question of adoption between domestic and foreign establishments, which is particularly relevant in the case of subsidiaries of MNCs in emerging economies and the way in which their actions can play out for AI adoption in emerging countries. They report that research-intensive, knowledge-based, and service-oriented companies tend to roll out AI technologies not only at their domestic but also at their foreign production sites.

There is also existing literature on the barriers faced by firms to the adoption of AI technologies. Some barriers are technology-related, such as data protection, data quality issues, compatibility barriers and standards, and lack of customized solutions (see for example (Dukino et al. 2020)). Meanwhile others are company-related, for example the size and type of industry and structural prerequisites at the firm level, for example in terms of infrastructure to support AI.

Overall, existing studies confirm that the adoption of AI is still patchy, and that it is hard to implement. Recent studies found that 16% of companies adopted AI (survey on German companies in 2020) (Dukino et al. 2019), and another survey found a figure of 23% (survey of 3000 companies) (Ransbotham et al. 2017). Among those who adopted AI, it was found that only 30% of companies implemented the technology in their production facilities, thus pointing to structural difficulties in retrofitting this technology into existing production systems.

4.2 IMPACT ON JOBS

The discussion about the impact of technology on jobs is a long-standing one. Fears of job substitution and of a world dominated by robotics and AI go in parallel with more nuanced assessment. Although some argue that this time things are different (Goller et al. 2023), there is still a lack of evidence to support what will happen. Interestingly, despite technology having historically contributed to an increase in the number of jobs, the job destruction narrative has been highly central in debates about new technologies (Hötte et al. 2023a). Taking a step back, in the recent past, analysis of the relationship between automation and jobs has been mainly based on skilled-biased technological change and routine-biased technological change frameworks (Anzolin 2021). Despite taking a different approach, the former focusing more on skills (imposing too narrow a one-to-one relation between technology and jobs) and the latter focusing more on tasks (pointing to the effect of technologies on tasks rather than on the whole job) they both foresee demand shifting from less skilled, routine-intensive jobs to higher-skilled non-repetitive tasks (Autor et al., 2003). Most authors agree that in the past automation and digitalization processes were first and foremost skill-biased. Recent evidence about AI suggests a different pattern; the use of GenAI leads to increased productivity in more complex and less ambiguous tasks with a greater impact on high-skilled workers. Yet not in the same way; for example, GenAI has improved in literacy and reading more than in math skills, which potentially would impact communication and writing-based jobs more than scientific ones.

As is the case for AI adoption at the firm level, in the case of AI impact on jobs, it is still hard to assess what will the near occupational future will look like. Overall, positive assessment seems to suggest a strong link between AI and higher productivity gains as well as total

income boost, suggesting that – as happened for previous technological waves – higher labour demand would more than compensate for the partial replacement of labour tasks. A recent study also looked at labour productivity by exploring a sample of 5257 companies which filed AI patents between 2000 and 2016; it found that, controlling for other variables, AI patents application have an extra-positive effect on companies' labour productivity. Interestingly, the effect holds mainly for SMEs and service industries, suggesting also that the manner in which the AI application is integrated into the production process changes the outcome (Damioli et al. 2021).

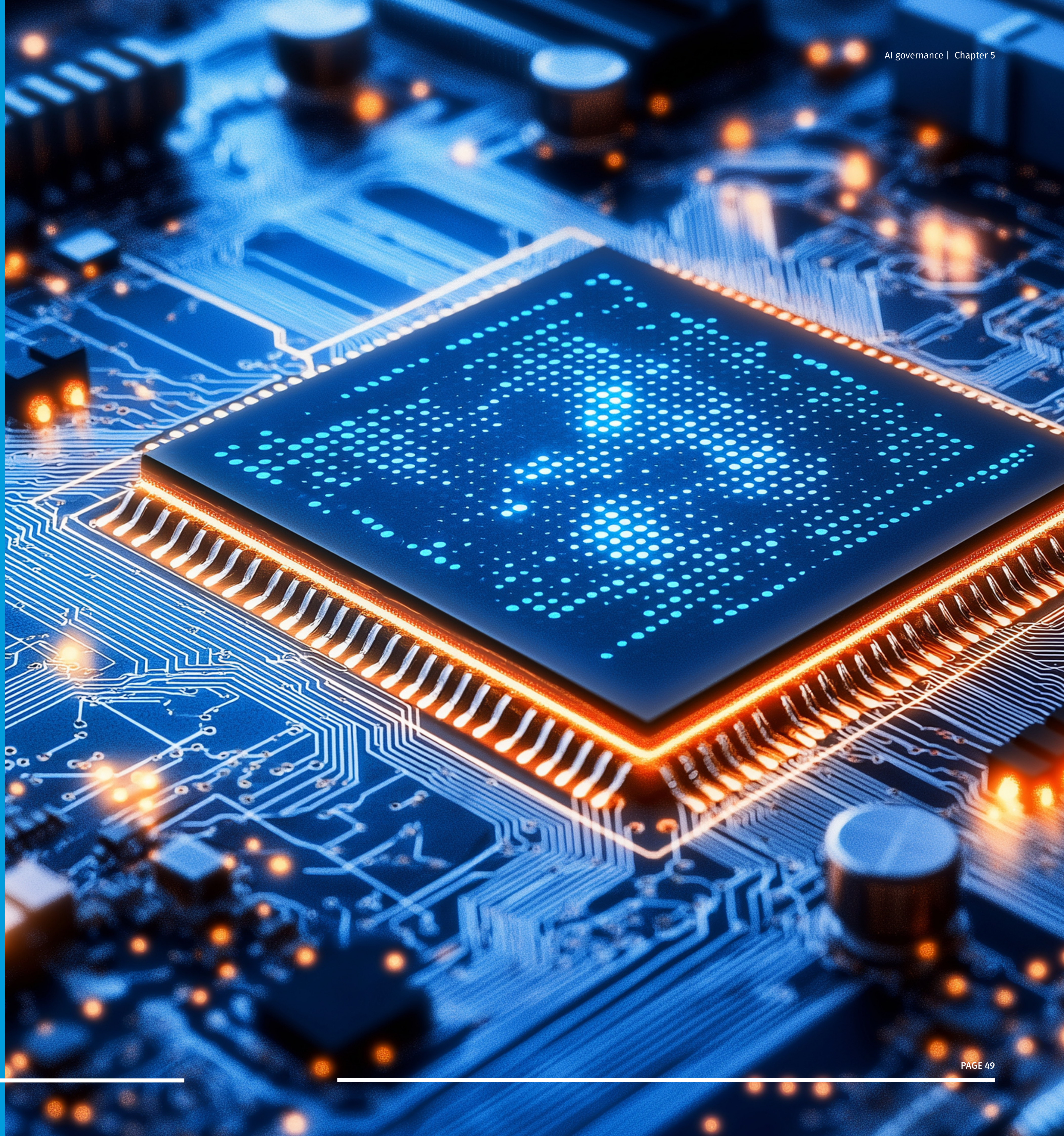
In terms of the impact on labour, existing evidence suggests mixed, and in some cases contrasting, results. This results in high uncertainty about the direction of change, especially concerning whether AI will display a labour-substituting or a labour-enhancing property (Shaoham et al., 2018). One strand of the existing evidence suggests that AI is likely to decrease the high-skill premium, given that AI is more likely to impact high-skilled/white collar workers who are more susceptible to substitution (Chelliah 2017). A recent report from the IMF assesses that almost 40% of global employment is exposed to AI, with developed countries being more at risk (60% of jobs are exposed to AI due to higher presence of cognitive task-oriented jobs), yet also in a better position to benefit from it. The same report suggests that about half of these 60% could be negatively impacted, while the rest are more likely to benefit. The IMF estimates 40% exposure in emerging markets and 26% in low-income countries, yet lower shares also correspond to lower capabilities to take advantage of AI opportunities, with consequences for the digital divide and for inequality at the international level (Cazzaniga et al. 2024). A second strand of the literature refers to a negative impact of AI by occupation, especially for low-skilled and production workers; on the other hand it would turn out to have a positive effect for workers in a higher position in the wage distribution. This perspective, which sees the skill premium widening, tends to consider AI as the continuation of the automation of jobs on a higher scale, a prospect that would disadvantage low-skilled workers (Bonfiglioli et al. 2023). Interestingly this last study indicates that the negative impact of AI on jobs refers mostly to services. Another study finds that AI widens the skill premium since it substitutes low-skilled labour with industrial robots.

Overall, it is hard to assess whether AI in manufacturing is showing more substituting or more augmenting/complementing effects. Agrawal et al. (2023) find that AI using a human-task template with the goal of automation would tend to augment more than to substitute. The mechanism is also hard to assess at an aggregated level because "one person's automation can be another's augmentation", and the two are not mutually exclusive. The distributional effects, and the impact on inequality levels, depend more on who the workers are who perform tasks which are automated, rather than on automation per se (Agrawal et al., 2023). In a recent study, which takes an occupational approach regarding the technical potential of AI, Tolan et al., (2021) show that AI progress could affect the way in which specific skills are rewarded; they find that labour market tasks require high levels of people (social/cognitive) skills as well as ideas (analytical skills), with AI exposure occurring more in the area of ideas abilities only. Many other factors can influence AI diffusion and its effect, for example, complementary conditions and the restructuring of business processes seem to be a necessary condition to enable the adoption and deployment of AI across different workplaces (Brynjolfsson et al., 2018)

A final methodological consideration. The methods utilized for analyzing AI's impact on employment relations often lack comprehensive data regarding job dynamics within organizations adopting this technology. Such studies tend to rely on predictive models infused with subjective assessments or to draw conclusions from organization-level data using proxy measures which fail to distinguish between AI and non-AI technologies. While these studies offer valuable insights it would be critical to use other methodologies to better understand what is happening at the firm, sectoral and country level. Using a wide survey across the UK, a recent contribution reveals that organizations adopting AI experience higher rates of both job creation and destruction compared to those implementing non-AI technologies. Moreover, it suggests that job creation is as likely as job destruction. This study does not claim causality, emphasizing that AI adoption is an endogenous process shaped by organizational dynamics and that more data is required to infer causal mechanisms (Hunt et al. 2022).

5

AI governance



AI governance refers to the frameworks, policies, and practices which guide the development and deployment of artificial intelligence technologies. It encompasses the ethical, legal, and technical standards required to ensure that AI systems are safe, fair, transparent, and accountable. Different countries are adopting varied approaches to AI governance (Galindo et al. 2021). Some are focusing on strict regulation to safeguard against risks, while others are incentivizing AI innovation to boost economic growth. Meanwhile, a few are leaving governance largely to private entities, trusting market forces to direct responsible AI development. These diverse strategies reflect each country's vision of a good AI society (Roberts et al. 2021).

Implementing an AI governance framework based on the vision of a good AI society comes with significant challenges. The rapid pace and disruptive potential of AI require strategic considerations at both national and international levels. Domestically, countries must balance the need for innovation against, among others, ethical concerns, data privacy, and job displacement (Mazzi et al. 2023). The fast-evolving nature of AI technology complicates the creation of comprehensive and adaptable regulatory frameworks. Internationally, differing AI governance approaches can lead to disparities in technological advancement and economic power, potentially disrupting global balances (Khan et al. 2022). This divergence complicates international cooperation on AI standards, trade, and ethical guidelines, creating a fragmented global AI landscape(Roberts et al. 2023).

Against this background, AI governance is also intrinsically linked to industrial development. At a national level, effective governance frameworks can foster a conducive environment for AI innovation, attracting investments and driving technological advancements. Conversely, overly restrictive regulations can stifle innovation. Other countries' approaches to AI governance also significantly impact a nation's industrial development because they shape the competitive landscape in which industries operate. For example, if a country adopts a more lenient regulatory framework, it might attract more AI investment and foster faster innovation, potentially giving its industries a competitive edge. Countries with stringent regulations may find their industries at a disadvantage from an economic standpoint, as they might face higher compliance costs and slower innovation cycles. At the same time, a more regulated approach to AI governance might also shape the adoption of AI according to the vision of a good AI society, safeguarding other relevant aspects for industrial development, especially in developing countries, such as quality job creation and widespread adoption and benefits in the local production system.

Additionally, differences in AI governance can lead to challenges in international collaboration, standardization, and market access, affecting how industries develop and compete globally (Vermesan et al. 2022). To sum up, AI governance influences how industries integrate AI, shaping their operational efficiencies, product development, and market dynamics. Thus, understanding the overall AI governance context is crucial for evaluating its impact on industrial development. The rest of section 5 presents an overview.

5.1 APPROACHES TO AI GOVERNANCE

5.1.1 The United Kingdom: Pro-Innovation Approach

The United Kingdom embraces a pro-innovation approach to AI governance, characterized by a flexible regulatory framework designed to foster responsible innovation ("A Pro-Innovation Approach to AI Regulation: Government Response", n.d.). The UK government is implementing a new framework to clarify and unify the AI regulatory landscape, aiming to solidify the UK's position as a global AI leader, drive growth, and enhance public trust.

Acknowledging the rapid evolution of AI, the UK's framework focuses on agility and iteration, allowing for continuous adaptation. Industry stakeholders praise this pragmatic and proportionate approach.

Underpinned by five guiding principles—safety, transparency, fairness, accountability, and contestability—the framework initially relies on non-statutory measures implemented by existing regulators using their domain expertise. This avoids rigid legislative requirements, and creates room for flexibility in response to technological advancements.

After an initial period, the government may introduce a statutory duty for adherence to these principles, monitored by central support functions. Emphasizing international collaboration, the UK aims for interoperability with global regulatory frameworks, enhancing its competitiveness in the global AI market.

5.1.2 The United States: the Executive Order on AI

In the United States, at a federal level the Executive Order on AI reflects a strategic effort to harness AI's benefits while mitigating associated risks (House 2023). Signed by President Biden, the Order acknowledges the rapid development of AI technologies and underscores the need for governance to balance promise and risk.

The Order adopts a whole-of-government approach, tasking various federal agencies with responsibilities ranging from workforce development to safeguarding national security. The order also focuses on equity and fairness, ensuring that AI systems do not reinforce biases or discrimination, while mandating transparency and accountability in AI development and deployment.

The establishment of ethical guidelines for federal AI procurement and the creation of AI safety standards reflects a commitment to responsible innovation.

Key policy goals outlined in the order include promoting competition and innovation in the AI industry, upholding civil and labour rights, protecting consumers' privacy, establishing federal policies for AI procurement and use, developing watermarking systems for AI-generated content, and maintaining the US's global leadership in AI. The box below presents a deep dive into the state of California's experience of regulating AI.

At a state level, it is relevant to mention the debate around the Safe and Secure Innovation for Frontier Artificial Intelligence Models Act (SB 1047), in California, which focuses on regulating AI systems rather than their specific applications, and aims to ensure the responsible development and deployment of advanced AI models. The bill defines a "covered model" based on the amount of computational power and financial resources needed for its development. The focus is on high-capacity AI systems which can pose significant risks, such as enabling the creation of weapons of mass destruction or cyberattacks on critical infrastructure. Developers of these models are required to implement comprehensive safety and security protocols. These protocols must include provisions for full shutdown capabilities, cybersecurity protections, and testing procedures to assess whether the model poses a risk of causing critical harm.

This bill is an example of regulating AI systems, focusing on their underlying development and training processes. It follows a preventive approach to managing risks which could arise from the development of powerful AI models, aiming to balance innovation with public safety concerns. This touches on a crucial distinction raised by opponents of the bill: the regulation of AI technology itself versus applications of it. Opponents argue that technology, in its raw form, is neutral and should not be regulated, since it does not inherently cause harm. Instead, it is the applications of that technology — how it is used — which can create risks and should be the focus of regulatory efforts. For example, AI models like large language models or image generators can be used for beneficial purposes (e.g. medical advancements, accessibility tools) or for harmful activities (e.g. deepfakes, misinformation). Critics of broad AI regulation fear that regulating the underlying technology stifles innovation, limits development, and creates unnecessary barriers for benign or positive uses of AI. Instead, they advocate for regulating specific uses of AI which lead to harmful outcomes, in much the same way that a rocket engine could be used to launch satellites into space or to deliver nuclear warheads; the engine itself is not the problem, but the application of that engine is.

This argument has precedents in other domains. For instance, in the regulation of dual-use technologies, governments often regulate the applications (e.g. nuclear arms) rather than the underlying technologies (e.g. nuclear energy) to allow for peaceful and innovative use while at the same time preventing harm. However, for example, the dual-use nature of nuclear technology both complicates non-proliferation efforts but can also facilitate compliance, by providing states with plausible deniability (Pauly, 2021). Similarly, tools like encryption can secure data but could also be used by criminals; regulatory frameworks in cybersecurity largely focus on the contexts where such technologies are abused, rather than banning encryption itself. During the Obama administration, discussion of reforms for export controls for dual-use technologies, including encryption, were aimed at balancing security goals with scientific collaboration and innovation (Burke, 2012). These precedents suggest that California's debate is part of a broader regulatory question: should we focus on controlling tools or on how those tools are wielded?

While regulation of AI applications could prevent misuse without stifling innovation, it also leaves open questions about the speed of response to emerging threats and whether certain capabilities of AI models themselves could be inherently risky regardless of context. As AI continues to evolve, this tension between technology and application in regulatory frameworks will remain central to policy discussions.

This approach aims to incentivize a competitive and innovative AI landscape while safeguarding public interests and national security. By prioritizing public-private partnerships and collaboration with international allies, the US aims to strengthen its global leadership in AI while ensuring that innovation is aligned with ethical standards and public trust.

5.1.3 The European Union: The AI Act

The European Union leads with the AI Act, the first comprehensive regulation on AI by a major regulator worldwide (Proposal for a Regulation of the European Parliament and of the Council Laying Down Harmonized Rules on Artificial Intelligence (Artificial Intelligence Act) and Amending Certain Union Legislative Acts 2021). The AI Act categorizes AI applications into three risk levels: unacceptable risk, high risk, and low or minimal risk. Applications posing an unacceptable risk, such as government-run social scoring, are banned. High-risk applications, like CV-scanning tools, are subject to stringent legal requirements. Applications not classified as high-risk face minimal regulation. This tiered approach aims to mitigate the most severe risks associated with AI while allowing for innovation in less risky applications. The AI Act sets a precedent for global AI regulation, balancing safety, ethical standards, and innovation.

5.1.4 Canada

The proposed Artificial Intelligence and Data Act (AIDA), part of the Digital Charter Implementation Act, 2022, aims to ensure responsible AI development in Canada ("The Artificial Intelligence and Data Act (AIDA) – Companion Document" 2023). It mandates businesses to implement governance mechanisms addressing risks, to provide transparency, and to ensure ongoing monitoring of AI systems. The Act adopts a flexible approach, tailoring safety obligations to AI systems' risk levels, with detailed regulations developed through consultation. Additionally, the Voluntary Code of Conduct on the Responsible Development and Management of Advanced Generative AI Systems was announced in September 2023. This code offers interim standards for Canadian companies, fostering responsible AI practices and strengthening public confidence until formal regulations are established. It highlights AI's transformative economic impact and its role in addressing critical challenges, based on feedback from a consultation process.

5.1.5 Brazil

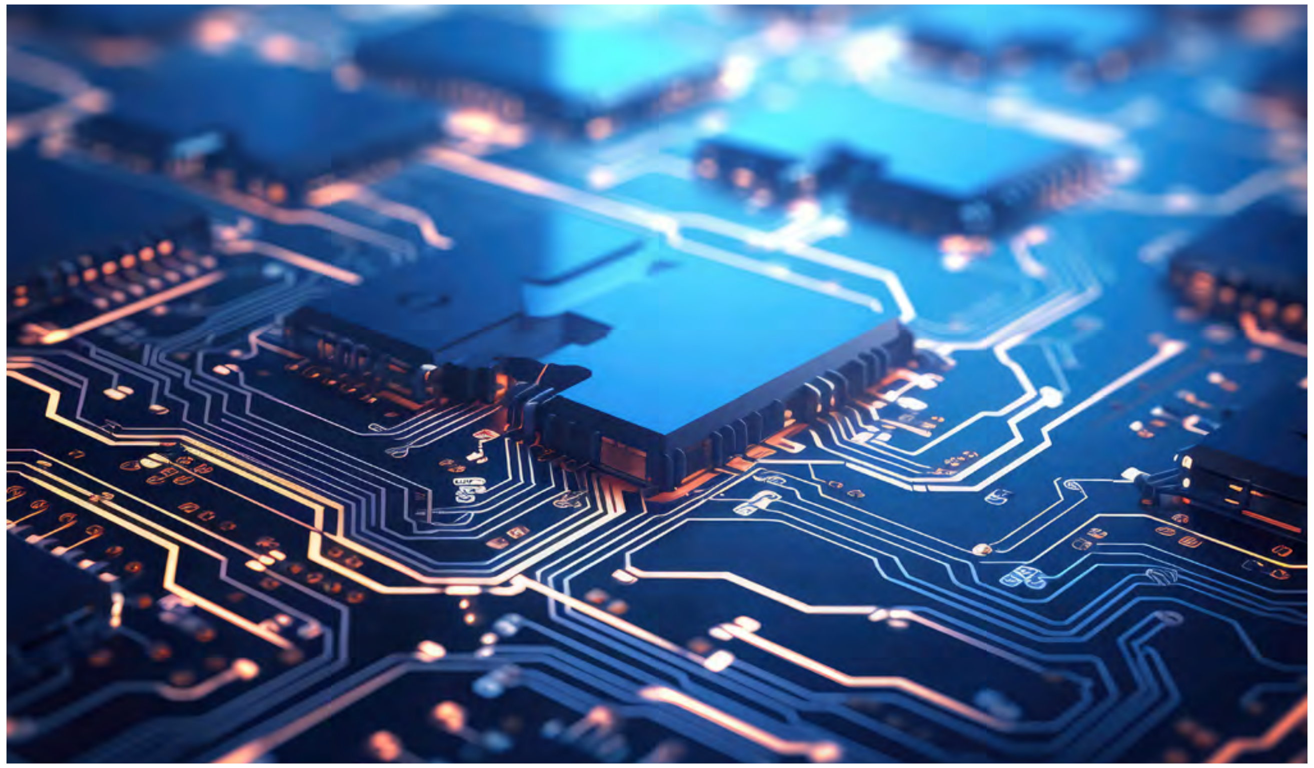
The Brazilian AI Strategy aims to promote trustworthy and ethical AI. Brazil has emerged as a leader in AI regulation in South America, proposing new instruments to govern the development and use of artificial intelligence. Although none of the three AI bills introduced since 2019 in Brazil have made it through Congress, a new bill, 2338/2023, was introduced in May 2023 to replace the previous attempted drafts. Brazil's proposals coincide with global efforts to codify responsible AI practices into law, particularly seen in Western jurisdictions like Europe and Canada. The country's approach involves a risk-based methodology, categorizing AI systems into compliance obligations based on perceived risks to core values such as privacy, non-discrimination, transparency, and security (Belli et al., 2023). Brazil's legislative intents mirror the principles outlined in the EU AI Act, emphasizing human rights, ethics, and democratic values. The proposed bills mandate transparency, mitigate biases, and ensure public impact assessments, with penalties for non-compliance including fines and suspension of AI system development or supply. This aligns with global trends towards responsible AI governance, as nations seek to balance innovation with safety and ethical considerations.

5.1.6 People's Republic of China

Chinese regulators adopt a supportive yet prudential stance towards AI, balancing the promotion of AI with safeguards against potential harms. Oversight has increased, focusing on specific AI technologies rather than the entire industry to avoid stifling innovation. Regulatory efforts have progressed through three stages: the first was Strategic Planning and Industry Self-Discipline (2017-2020), the initial strategic focus with industry self-regulation and key planning documents such as the 2017 Plan of Next Generation AI Development. The second was Voluntary Standards and Regulatory Oversight (2020-2022): Development of national standards and guidelines with increased government participation. The third is Direct Supervision (2022-present); it introduces mandatory regulations for specific AI technologies, such as recommendation algorithms, deep synthesis, and generative AI services. Provincial-level regulations and local governance experiments are also growing. Key regulations include the 2021 Recommendation Algorithm Provisions, 2022 Deep Synthesis Provisions, and 2023 Generative AI Measures, focusing on content moderation, data protection, and algorithmic governance. Future laws will enhance these foundations, ensuring AI security, ethicality, and transparency, aligned with data protection laws like the 2021 Personal Information Protection Law (PIPL)("AI Governance in China: Strategies, Initiatives, and Key Considerations | Practical Law", n.d.)

5.1.7 South Korea

South Korea, one of the most digitally connected and tech-savvy nations globally, is making significant strides towards becoming a leader in artificial intelligence (AI). On 14 February 2023, the Science, ICT, Broadcasting and Communications Committee of the Korean National Assembly proposed legislation to enact the “Act on Promotion of AI Industry and Framework for Establishing Trustworthy AI” (the “AI Act”). The AI Act is still not approved as of August 2024. The draft of the comprehensive legislation consolidates seven previously fragmented AI laws into a unified framework, aiming to support the AI industry and protect users by ensuring the trustworthiness of AI systems. It differs from the AI Act, which distinguishes between AI applications and mandates requirements depending on the level of risk; the Korean AI Act adopts an approach which aims to facilitate the adoption of the technology. Key provisions of the AI Act include allowing the development of new AI technologies without government pre-approval, setting standards for "high-risk AI" related to human life and safety, supporting innovative AI businesses, establishing ethical guidelines for AI, and creating a "Basic Plan for AI" and an "AI Committee" overseen by the Prime Minister.[6]



6) https://law.asia/ai-regulatory-frameworks-south-korea

FIGURE 17: National approaches to AI Governance

Jurisdiction	Approach to AI Governance	Key Features	Regulatory Framework	Developments (2024)
 United Kingdom	Pro-Innovation Approach	Flexible, adaptive regulation to foster responsible innovation, relying initially on non-statutory measures with five guiding principles: safety, transparency, fairness, accountability, and contestability.	New framework focusing on agility and avoiding rigid legislative requirements. Statutory measures may be introduced after a review period.	Emphasis on international collaboration and ensuring interoperability with global frameworks.
 United States	Executive Order on AI (2023)	Whole-of-government approach focusing on equity, transparency, AI safety standards, and public-private partnerships. Promotes innovation while safeguarding privacy, civil rights, and national security.	Federal agencies tasked with developing and implementing AI governance. Establishes ethical guidelines for federal AI use and content watermarking.	Strengthening of AI safety standards and partnerships with international allies to maintain global leadership in AI.
 European Union	The AI Act	Tiered risk-based regulation: Unacceptable risk applications banned; high-risk applications regulated, and minimal regulation for low-risk. Focus on ethics, transparency, and innovation.	Comprehensive regulation categorizing AI by risk level (e.g. social scoring banned). Strong legal requirements for high-risk applications.	First major comprehensive AI regulation globally; sets a precedent for ethical AI governance while allowing innovation in less risky areas.
 Canada	Artificial Intelligence and Data Act (AIDA)	Risk-based regulation, with voluntary standards for AI system governance. Focus on transparency, monitoring, and public confidence.	AIDA proposes safety obligations based on risk levels, with detailed regulations developed through consultation. Voluntary Code of Conduct implemented in 2023.	The Voluntary Code of Conduct strengthens interim AI governance until formal regulations are in place, emphasizing responsible development of generative AI.
 Brazil	Brazilian AI Strategy	Risk-based methodology which categorizes AI systems based on privacy, non-discrimination, transparency, and security risks. Focus on aligning with international standards.	Proposed bill (2338/2023) emphasizes transparency, public impact assessments, and penalties for non-compliance, including fines and suspension of AI system development.	New bill introduced in 2023 to replace earlier drafts, mirroring principles from the EU AI Act.
 People's Republic of China	Supportive yet Prudential Stance	Focus on promoting innovation while regulating specific technologies like recommendation algorithms and generative AI. Regulations introduced in phases, increasing direct oversight over time.	Key regulations include the 2021 Recommendation Algorithm Provisions, 2022 Deep Synthesis Provisions, and 2023 Generative AI Measures.	Enhanced mandatory regulations on content moderation, algorithm governance, and AI security. Future laws will build on these foundations.
 South Korea	AI Act (Proposed 2023)	Consolidates fragmented AI laws into a unified framework aimed at promoting innovation and ensuring trustworthiness of AI. No pre-approval for new technologies, but risk-based standards for high-risk AI.	AI Committee to oversee the Basic Plan for AI. Standards set for "high-risk" AI applications concerning human life and safety.	Legislation still pending as of 2024, aiming to streamline AI regulation and foster innovation through risk-based approaches.

5.2 AI ETHICS AND THE ROLE OF INTERNATIONAL ORGANIZATIONS

AI ethics has emerged as a critical component in the development and deployment of AI technologies, and it is relevant also in the context of industrial development.

As AI becomes increasingly integrated into industrial processes and products, ethical considerations become paramount in shaping the development and deployment of these technologies. Ethical concerns such as fairness, transparency, accountability, privacy, and bias are particularly relevant in industrial settings where AI systems may influence critical decisions, affect workforce dynamics, and impact societal well-being. Adhering to ethical principles ensures that AI technologies are designed and used in a way which aligns with societal values and norms, fosters trust among stakeholders, and promotes sustainable industrial development (Floridi et al. 2020). Moreover, ethical AI practices can stimulate innovation, drive competitiveness, and mitigate risks, thereby contributing to the long-term viability and success of industrial ventures. By addressing ethical considerations in the development and deployment of AI technologies, industrial stakeholders can mitigate potential harms and increase the potential of AI to drive positive economic and social outcomes.

Many countries have developed and published ethical frameworks for AI, both neutral and sector-specific, to address the growing integration of AI technologies in various fields. Countries like Canada and Singapore have developed ethical frameworks for AI. Canada's Pan-Canadian AI Strategy promotes ethical AI development across various industries, while Singapore's Model AI Governance Framework provides comprehensive guidelines in order to ensure AI that is implemented responsibly and transparently in different sectors (Taeihagh, 2021). In 2021, Russia adopted a national AI Ethics Code, which now serves as the foundation for subsequent sector-specific AI ethics recommendations and frameworks. Other countries have also developed sectorial principles. For instance, the European Union and the United States have established comprehensive guidelines for AI in healthcare in order to ensure ethical practices, emphasizing principles such as transparency, accountability, and fairness (Pesapane et al., 2018; Morley et al., 2022; Morley & Floridi, 2020). Estonian public service organizations have implemented ethical principles for AI through the Value Sensitive Design framework. This approach involves semi-structured interviews with public servants and developers to ensure that ethical considerations are embedded into AI applications (Hinton, 2023). Japan has made significant investments in digital health technologies, including AI, through programs like the Cross-Ministerial Strategic Innovation Promotion Program for an "Innovative AI Hospital System". The country has developed ethical considerations based on the World Health Organization's 2021 Guidance on the Ethics and Governance of AI for Health, focusing on principles such as patient benefits and responsive AI (Katirai, 2023).

Other stakeholders, such as various international organizations, among others the Organization for Economic Co-operation and Development (OECD) ("OECD Legal Instruments", n.d.) and the United Nations (UN), (Nations, n.d.) have released documents outlining principles and/or frameworks for AI ethics (Prem 2023). The role of international organizations, as well as universities and other non-governmental stakeholders, in promoting AI ethics is not secondary. These initiatives aim to provide guidance and promote best practice in AI development and deployment, fostering international cooperation by establishing common standards and norms, such as the Unified Framework identified by Floridi and Cowls (2022). However, the effectiveness of such soft legal instruments is subject to criticism, since they are often non-binding and lack enforceability. While they offer flexibility and encourage voluntary compliance, their non-granular nature may pose challenges in achieving meaningful oversight and accountability in the rapidly evolving AI landscape (Morley et al. 2021). Nonetheless, international organizations play a crucial role in facilitating dialogue, knowledge-sharing, and collaboration among stakeholders to address ethical concerns and promote responsible AI innovation on a global scale.

One example is the Global Digital Compact (GDC), A UN initiative to advance UN goals for an "open, free, and secure digital future for all" (UN, GDC, 2022). It was adopted at the Summit of the Future in September 2024; it is aimed at creating a shared framework for digital governance, including AI. The GDC seeks to establish minimum global standards on critical issues such as AI ethics, data privacy, and digital inclusion. However, the process of building this global consensus has revealed key fault lines between countries, particularly around issues like surveillance, data sovereignty, and the regulation of AI technologies. There are significant challenges posed by the actions of state actors such as Russia, China, and the US. These nations have differing doctrines regarding Internet governance, with Russia and China favouring state sovereignty and control over digital spaces, while the US and EU advocate for a more open, free, and multilateral approach (Wylde, 2023).

Trust is identified as a crucial component for the successful implementation of GDC goals. Without building trust between states and within the broader international community, achieving a "free, open, and secure Internet" will remain challenging. However, the practical steps for building trust remain underexplored in current frameworks (Wylde, 2023).

The GDC's success hinges on its ability to balance diverse geopolitical interests while crafting a minimum consensus which aligns with both innovation and ethical standards. By taking inspiration from existing frameworks like the OECD AI Principles and other multilateral agreements, the GDC hopes to set a global baseline for ethical AI use which can be adapted across different regions and economies.

At the same time, the global digital governance landscape is highly fragmented, with no single multilateral body overseeing all aspects of digital governance (the Final Report of the UN High-Level Advisory Body on AI outlines the current challenges and provides seven recommendations to address them, including the establishment of an AI office within the UN Secretariat (Nations, n.d.)). Different forums, such as the WTO for e-commerce and WHO for digital health, each address specific aspects of the digital world; the result is a lack of coordinated regulation. Developing countries often struggle to participate meaningfully in these fragmented systems due to capacity constraints and power imbalances (Correa et al., 2023). Concerns have been raised about global digital market power being concentrated in a few countries and companies, which exacerbates inequalities and limits developing countries' ability to participate in digital value chains (Correa et al., 2023).

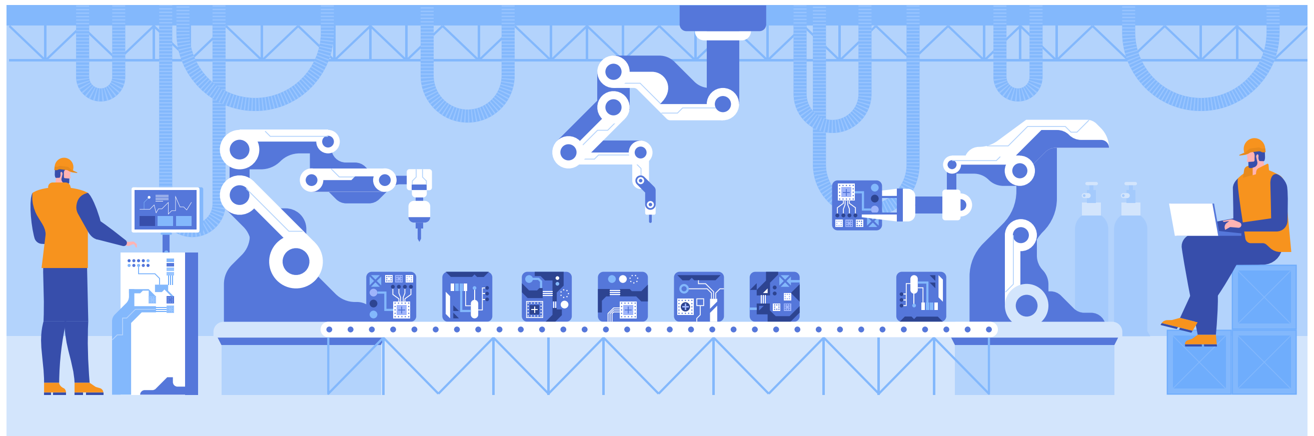
There is an acknowledgment of the innovation divide between countries, particularly in AI and digital technologies. The GDC must address the need for technology transfer, intellectual property rights, and access to innovation for developing countries in order to bridge this gap and foster inclusive digital growth. Ultimately, the GDC represents a significant step towards harmonizing AI governance globally, although its ability to achieve widespread adherence and address the concerns of both developed and developing nations remains to be seen.

5.3 SIGNIFICANCE OF AI VISIONS AND PRACTICAL IMPLICATIONS

The significance of different AI visions and their practical implications extends beyond national borders, influencing both the AI governance landscape and decision-making processes from a national to a global scale. Countries may adopt varying approaches to AI governance, ranging from regulatory frameworks to non-binding white papers, and the international context also plays a crucial role in shaping AI innovation. This complex interplay of national and international regulations creates a multifaceted governance landscape which impacts industrial development across sectors. Additionally, AI development is not governed in isolation but is subject to a web of sectorial legislation and policies, such as data protection laws and industry-specific compliance regulations. Furthermore, extraterritorial legislation, such as the General Data Protection Regulation (GDPR), extends regulatory reach beyond national boundaries, impacting businesses worldwide (Gunst and Ville 2021). Such legislation aims to protect EU citizens' privacy rights, independently of whether or not the controller or processor are physically present in the EU, and imposes compliance obligations on businesses operating globally who process EU citizens' personal data, therefore necessitating consideration of legal and ethical implications in AI development and deployment strategies.

The alignment between the macro vision of AI at the national level and the micro texture of applicable legal and governance frameworks is essential for fostering legitimate AI development and deployment. This complex regulatory landscape might prove challenging for industrial development. Compliance with diverse and sometimes conflicting regulations can be burdensome for industries, leading to regulatory uncertainty and potential barriers to innovation.

Potentially, harmonization efforts at both national and international levels can streamline regulatory requirements, reduce compliance costs, and promote interoperability, thereby facilitating the adoption of AI technologies and fostering cross-border collaboration. However, harmonization of AI governance is complex as a result of the divergent AI visions and regulatory approaches adopted by countries worldwide. While countries may agree on overarching principles for AI development and deployment at a high level of abstraction, differences in implementation strategies hinder harmonization efforts. For instance, some countries may prioritize promoting innovation and economic growth without imposing stringent regulatory requirements, while others opt for a more precautionary



approach which emphasizes risk-based categorization of AI systems, as exemplified by the EU AI Act (Roberts et al. 2021). These contrasting approaches reflect differing perspectives on balancing innovation with risk prevention and societal protection.

The lack of harmonization in AI governance can impact industrial development in relation to businesses operating across borders. Inconsistencies in regulatory requirements across jurisdictions may lead to increased compliance costs, for example in relation to non-EU AI deployers operating in the EU (Walters et al. 2024), along with barriers to market access, particularly for small and medium-sized enterprises (SMEs) with limited resources. Moreover, divergent regulatory standards can hinder interoperability and compatibility of AI technologies, impeding collaboration and innovation on a global scale. Additionally, compliance with multiple and potentially conflicting policies may stifle innovation and slow down the adoption of AI technologies, particularly in highly regulated sectors such as healthcare and finance (Mohammad Amini et al. 2023).

The inclusion of developing countries in AI standardization is also very important. The international development of AI standards within ITU, ISO, IEEE, and IEC provide a foundation for global cooperation in both production and services sectors. Developing countries can benefit from this cooperation through more efficient inclusion in Global Value Chains (GVCs).

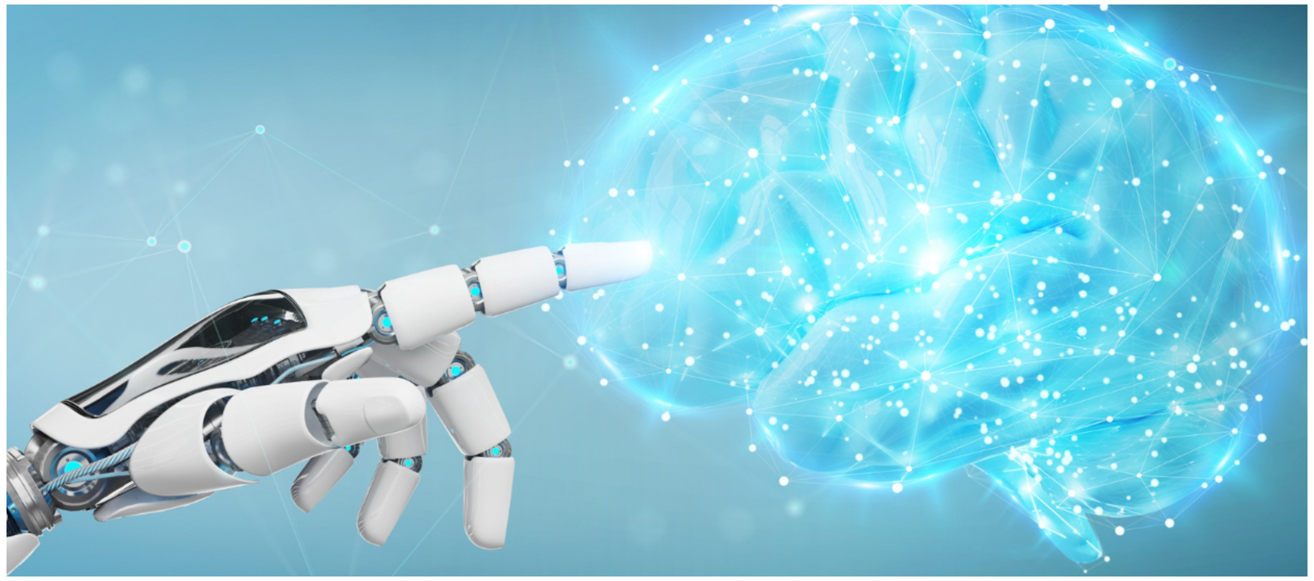
Overall, the complex regulatory landscape requires a holistic approach which balances regulatory compliance with innovation, ensuring that AI technologies contribute positively to industrial development while upholding ethical and legal standards.

5.4 AI AND SUSTAINABILITY

The intersection of AI and sustainability has emerged as a critical topic amidst the world's pressing challenges, such as climate change (Floridi et al. 2020). AI presents immense potential for addressing sustainability issues by providing innovative solutions for monitoring, predicting, and mitigating environmental impacts ("The AI Gambit: Leveraging Artificial Intelligence to Combat Climate Change—Opportunities, Challenges, and Recommendations | AI & SOCIETY", n.d.). However, there is growing concern about AI's sustainability challenges, particularly its substantial energy consumption and computing power requirements (Kindylidi and Cabral 2021). This is a point of concern because even very simple tasks which would not require AI, for example, making a simple mathematical calculation, could increasingly become part of the operations that are conducted through programs such as ChatGPT, with an unnecessary use of energy.

The concept of "AI for sustainability, and the sustainability of AI", encapsulates distinct yet interrelated dimensions of using AI to address sustainability challenges while ensuring the responsible and environmentally sound development of AI technologies.[7]

7) AI for sustainability" refers to the use of AI tools and techniques to support and advance sustainability objectives, such as monitoring environmental changes, predicting climate patterns, and optimizing resource management (van Wynsberghe 2021). This aspect emphasizes the potential of AI to contribute to global sustainability efforts, including the achievement of Sustainable Development Goals (SDGs), by offering innovative solutions to complex environmental problems (Cowls et al. 2021). Conversely, "sustainability of AI" pertains to the ecological and ethical considerations surrounding the development, deployment, and governance of AI technologies themselves. This involves minimizing the environmental footprint of AI systems, for example by reducing energy consumption and carbon emissions associated with AI operations, along with ensuring equitable access to AI benefits and mitigating potential societal risks (Vinuesa et al. 2020). The distinction shows the need not only to harness AI for sustainability goals but also to foster a holistic approach which integrates principles of sustainable development throughout the entire lifecycle of AI products and systems. This includes promoting ecological integrity, social justice, and responsible governance practices to achieve a harmonious relationship between AI innovation and environmental stewardship.



This dynamic interaction between AI and sustainability significantly impacts industrial development, influencing both national and international levels. While the integration of AI can enhance industrial processes and resource management, it also poses challenges in terms of environmental sustainability and energy efficiency. Addressing these challenges and leveraging the opportunities presented by AI in the context of sustainability is essential for fostering sustainable industrial development both domestically and globally.

The relationship between AI for sustainability, and the sustainability of AI, is tied to AI governance. Internally, countries face the challenge of establishing robust governance frameworks which promote the development of AI for sustainability purposes while mitigating its potential negative impacts. This includes addressing issues such as data privacy, transparency, accountability, and bias in AI systems deployed for sustainability purposes. Additionally, countries must grapple with the environmental footprint of AI technologies, particularly their energy consumption and carbon emissions, and implement measures to promote energy-efficient AI solutions.

However, given the global dimension of AI and its implications for sustainability, AI governance also necessitates international cooperation and, potentially, harmonization, despite the challenges discussed in the previous session. As AI technologies and sustainability challenges such as climate change transcend national borders, harmonized approaches or cooperative efforts would ensure consistency, interoperability, and ethical standards across different jurisdictions. This poses challenges around collaboration among governments, industry stakeholders, academia, and civil society to develop common frameworks and standards for AI governance.

Furthermore, the geopolitical relevance of AI adds another layer of complexity to international cooperation on AI governance. Issues such as data sovereignty, intellectual property rights, and national security concerns intersect with efforts to promote sustainability and ethical AI practices.

However, harmonizing AI governance and sustainability efforts on a global scale is exceptionally challenging due to the diverse and often conflicting interests of countries, particularly among advanced economies. These nations are heavily invested in protecting their technological advantages and economic interests, which makes them less likely to collaborate on technology sharing, even if potentially needed to address environmental issues. For example, recent international climate negotiations, such as the COP conferences, have highlighted the difficulties in achieving consensus on environmental action, as countries prioritize their national interests over global commitments (Feijóo et al., 2020) (Bodin, 2017). This fragmentation poses significant barriers to the development of a cohesive and effective global AI governance framework which can adequately address sustainability challenges.

These challenges are exacerbated by the fact that AI and sustainability are complex, interconnected issues which require coordinated efforts across various sectors and jurisdictions. However, the competitive nature of international relations, especially among technologically advanced nations, often leads to a lack of willingness to engage in the necessary collaboration, further complicating the implementation of global solutions (Nishant et al., 2020).

This lack of cooperation not only hinders the sharing of AI technologies which could be beneficial for global sustainability, but also results in fragmented and often contradictory regulatory approaches which undermine collective efforts to address pressing environmental concerns. However, AI policies and regulations often refer to the same sustainability goals and principles. Mostly, they focus on social sustainability rather than expressly mentioning environmental sustainability. The risk-based approach, particularly the detailed one included in the AI Act, shows a clear prioritization of achieving sustainable AI. At the same time, international convergence is mostly at a high level of abstraction, with less consensus at a more granular level, and there is a dimension of lack of enforceability in policy papers and guidelines, compared to a legal instrument such as the forthcoming AI Act. Therefore, fostering nuanced solutions of collaboration and harmonization, for example through international organizations, would be desirable to ensure that AI technologies contribute to global sustainability goals while upholding ethical principles and human rights.

5.5 DRAWING CONCLUSIONS FOR WAYS FORWARD

The analysis of various jurisdictions has revealed a diverse spectrum of approaches to AI governance, each tailored to the unique socio-economic and cultural contexts of their respective countries. At the national level, the EU is pioneering more stringent regulation aimed at fostering AI development in line with its values, such as privacy, security, and ethical considerations. The AI Act aims to stimulate innovation while ensuring robust protections for individuals. In contrast, the UK has opted for a more flexible approach, limiting the legislative activity in relation to AI in favour of guidelines. This strategy is intended to spur innovation by reducing regulatory barriers, potentially accelerating the integration of AI technologies across industries. However, this approach may raise concerns about insufficient safeguards against the potential risks of AI.

Countries like Canada and Brazil are taking cues from the EU's risk-based framework, embracing the importance of protecting individuals from AI-related harms. By prioritizing safety and responsibility, these nations aim to direct AI innovation towards safer and more ethical applications. This alignment indicates that despite varying socio-economic conditions, the fundamental principles of a risk-based approach resonate globally, suggesting a universal recognition of the need for responsible AI governance. This is also in line with the proliferation of ethical frameworks which have characterized the past few years.

On the other hand, a laissez-faire approach, as seen in the UK, might facilitate the rapid adoption of AI technologies, enhancing competitiveness and industrial growth. However, the risks associated with this rapid integration are not uniform across countries. In less industrialized nations, there is a heightened risk of exacerbating existing inequalities and creating new forms of socio-economic disparity.

Identifying the optimal approach to AI governance in less industrialized countries requires a nuanced consideration of multiple factors. These include the current level of technological infrastructure, the regulatory capacity of institutions, the socio-economic impact of AI deployment, and the potential for exacerbating existing inequalities. For instance, robust infrastructure and regulatory frameworks are crucial for managing AI's risks and benefits effectively. Additionally, assessing the socio-economic impact involves understanding how AI might affect job markets, access to services, and data privacy within different socio-economic strata. In conclusion, while high-level principles of AI governance such as risk-based regulation and fostering innovation are universally acknowledged, their implementation must be adapted to the specific needs and contexts of each country. This adaptability ensures that AI policies not only promote technological advancement but also safeguard public welfare and mitigate risks. The following chapter will explore these aspects, considering the relevant factors which come into play in relation to AI governance in less industrialized nations.

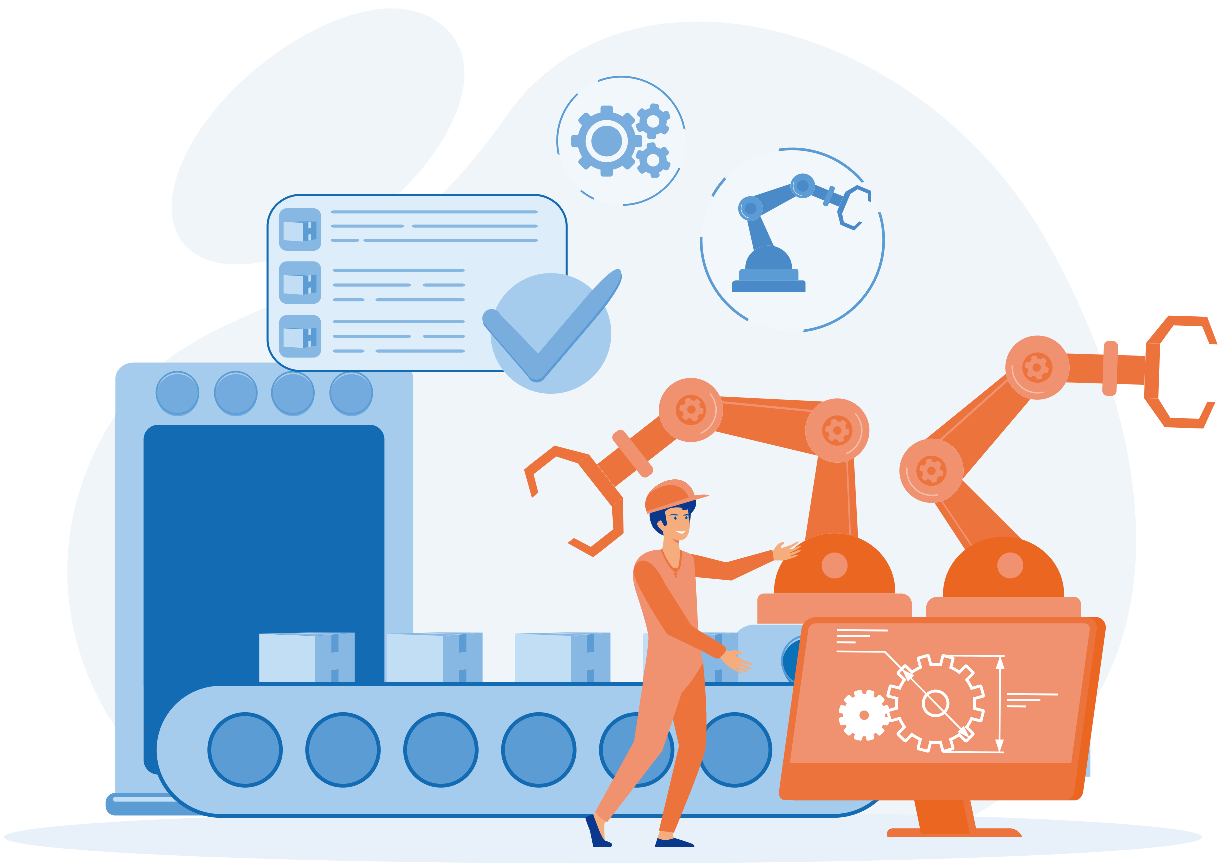
The international community responded recently with the Pact for the Future and its Global Digital Compact, which draws attention to the needs of developing countries, and tries to provide guidance on the use of advanced technologies. The key premise of the compact is to realise an open, safe and secure digital space for all. Open source is another avenue that becomes increasingly important for development, and to realise the Sustainable Development Goals in particular. The use of open-source solutions is relevant in a manufacturing environment, and one of the avenues to provide access to technology for developing countries. Despite access, it is not automatic, since expertise to use and apply such technologies is still required. The Global Digital Compact and the UN Secretary General's roadmap for Digital Cooperation do, however, highlight the importance of open source, open data, and open standards to spread the benefits of digital technologies, and AI. In general, more emphasis on (digital) public goods need to be placed to realise the promises of current technological trends.

6

Implications and recommendations for emerging economies

AI in manufacturing is likely to have a disruptive impact in terms of transforming both the productive structure and employment dynamics; as with all disruptions, the use of AI in manufacturing creates opportunities and challenges. However, these are not equally distributed among countries. Developing countries are already facing significant challenges regarding AI adoption, production and regulation. As discussed in Chapter 2, challenges related to advanced digital production technologies will likely be even greater with AI. In fact, as AI is a complex system with multiple layers of interrelated technologies, the capability to produce and innovate around it is critical in order to avoid reliance on advanced economic technologies in the future. Yet, as shown in Chapter 3, the distribution of AI is extremely concentrated, both in terms of the capabilities to produce and innovate around AI technologies, and in terms of the sectors and the uses where AI has more applications (chapter 4). Such concentration could enlarge existing gaps in the absence of targeted policies and investments to fill these gaps in developing countries. In addition, chapter 5 has highlighted the relevance of an AI vision and a coherent approach to AI governance in order to foster sustainable AI development.

Although some uses and applications of AI are in the early stages of development, there is increasing discussion about the risks posed by such technology and how both international institutions and governments in developing countries can act to reduce existing gaps and to decrease the level of technological dependence on advanced economies, while fostering the adoption of new technologies. We have identified five key areas where action from developing countries' governments is needed.



1 INVESTMENT IN INFRASTRUCTURE AND PRODUCTIVE CAPABILITIES

Adopting critical technologies which result in AI systems relies on infrastructure availability and reliability. For example, without a source of stable electricity, which can, in turn, sustain ethernet and WiFi connection, there is no possibility of effective deployment of advanced digital production technologies – and even more so of AI. Some islands of productivity could be present, as already happens with large MNCs which rely on their own energy provision, but without stable electricity, it is very hard to deploy more sophisticated technologies on a broad scale in a national or regional economy. Developing pre-existing conditions which enable the full use of technologies is key.

Action points

- Achieving sustainable development can only be ensured by energy coverage and reliability across all regions of the country. This requires implementing strategies that include digitalization and AI adoption, ensuring that electricity and the establishment of fast connectivity are set as pre-conditions for further development.
- The UNIDO digitalization tool, EQuIP, provides a valuable framework to measure the country's position on key infrastructure indicators, such as energy availability, energy reliability, and access and quality of digital connectivity. Developing country-level measures based on such tools can deliver an accurate picture of the existing infrastructure, providing guidance for targeted actions needed to establish the enabling conditions necessary for growth.[8]

2 ACCESS TO AI TECHNOLOGIES AND THE ROLE OF GOVERNMENT IN FOSTERING ENGAGEMENT WITH AI TECHNOLOGIES: SOME SECTORS MATTER MORE THAN OTHERS

Digital Public Goods that share knowledge, expertise, and technology ensure that digital technologies benefit all. Open Data and Open Source are important mechanisms to democratize access to technology. The report highlights a massive concentration in two aspects: AI applications are concentrated in a few sectors, and AI-related technologies are extremely concentrated both in terms of their production and innovation aspects. Developing countries require key investments into sectors which are characterized by high productivity dynamics and economies of scale, where the adoption of digital technologies and AI, in particular, is more diffused. AI is used in different segments of the production process, from research and development to detection to logistics; tapping into some of these applications would open up learning opportunities which are critical to trigger/unlock learning by adopting and by using mechanisms. The government's role is thus twofold.

Action points

- Designing opportunities for the population to engage with advanced technologies is essential for fostering innovation and inclusivity. This can be achieved by developing programs at schools, universities, and through collaborations with third-sector actors to reach individuals outside the school age population.
- Additionally, mapping the sectoral capabilities and identifying the competitive advantages of each country or region is vital to understand the specific segments with the greatest potential for investment.

8) These four indicators were defined as the enabling infrastructure for digital production technologies. Reference to EQuIP.

3 PUBLIC-PRIVATE PARTNERSHIP TO LEVERAGE RESOURCES IN A MISSION-ORIENTED APPROACH

The first two implications require both strong organizational capabilities at the government level and fiscal space for investment. The goal of technology adoption in order to increase productivity and create jobs could be defined as a societal mission which requires collaboration between the public and the private sector.

Action points

- Mapping key private sector actors within the country is crucial, as they can provide both technological expertise and financial resources to support effective public-private collaboration.
- Simultaneously, strengthening government capabilities through targeted training programs and courses for senior officials is essential to ensure informed decision-making.

4 ROLE OF GOVERNMENT IN ENSURING AI ADOPTION AND JOB CREATION

We are in a very early stage of AI adoption, so it is hard to make predictions in terms of job substitutions. Despite the peculiar characteristics of AI – i.e. being a technology, the aim of which is to act/behave and think as a human – there are not enough data to argue that applications of AI in manufacturing will disrupt employment. As happened with the adoption of previous technologies, from robotics to CAD/CAM or PLC systems, the automation of certain processes will impact (both in terms of substitution and of heavy changes) certain tasks and occupations.

Action points

- The government should focus on developing educational programs that prioritize the use of AI, starting from schools and including also bachelor, master and PhD programs. In addition, it is important to invest in capacity building including education and training programs to develop a skilled workforce capable of leveraging AI's potential. For example, AI Literacy Programs can be introduced to provide a foundational understanding of AI among the general workforce, ensuring these programs are accessible to those interested in exploring them.
- Another critical measure is empowering local businesses, with special focus on SMEs, to foster the adoption of AI tools. This can be achieved through targeted policy measures that offer incentives and training to facilitate the integration of digital and AI technologies.
- Engaging both civil society and labor unions is crucial to overcome the resistance of new technologies adoption, particularly in an era of high unemployment and low labor shares. Involving diverse stakeholders beyond the government will be essential for the successful implementation of these policies.

5 AI GOVERNANCE

AI governance significantly influences how AI is developed and adopted across both the public and private sectors, particularly shaping its integration into manufacturing industries within emerging countries. The governance approach can determine the speed, scale, and ethical considerations of AI adoption, impacting everything from innovation to economic development. By examining existing examples of AI governance, emerging countries can identify best practices and lessons learned, enabling them to adopt strategies which align with their specific needs and contexts while promoting sustainable and responsible AI integration.

Therefore, emerging countries should consider which approach to adopt in relation to AI governance both based on the vision for AI in society and in relation to short-, medium- and long-term objectives, including investment in new technologies and sustainability goals.

Action points

- It is essential to define a clear vision for integrating AI into society, considering ethical implications and its potential to address societal challenges and drive positive social impact. In addition, AI governance should be aligned with societal values and cultural contexts, ensuring that its development and deployment foster inclusivity, fairness, and public trust.
- In the short term, implementing pilot projects in key sectors such as healthcare, agriculture, and manufacturing will allow for the testing of AI applications with a focus on delivering immediate benefits.
- Over the medium term, AI adoption should be expanded across multiple sectors, guided by the lessons learned from initial implementations, while ensuring scalability and sustainability. Strengthening partnerships with international organizations, the private sector, and academic institutions will stimulate innovation and foster knowledge exchange.
- In the long term, AI should be embedded into the broader national strategy for sustainable development, ensuring alignment with long-term sustainability goals, including environmental protection and resource management.

Conclusions

This report has analyzed AI technologies on the structural level (i.e. understanding where innovation and production capabilities lie) and in relation to governance, which is key for regulation and application. The application of AI in manufacturing is still in its early stages both in advanced economies and developing countries. The latter would need to design policies which promote a gradual and steady structural transformation of their economy in order to build the preconditions to engage with more sophisticated technologies.

The successful adoption of AI technologies hinges on the availability and reliability of infrastructure, particularly stable electricity and digital connectivity. Without these, the deployment of advanced digital production technologies is limited, especially on a broad scale. To support AI adoption, it is crucial to prioritize energy coverage and connectivity across all regions, with tools such as UNIDO's digitalization metrics providing valuable insights into infrastructure readiness. Additionally, AI technologies are highly concentrated in specific sectors, making targeted investments in high-productivity areas essential for developing countries. The government plays a dual role in fostering AI engagement by facilitating access to advanced technologies through education, and through industrial policies targeting key sectors. Public-private partnerships are vital in order to leverage resources and drive a mission-oriented approach to technology adoption, requiring strong organizational capabilities and collaboration between the public and private sectors. Furthermore, governments must ensure that AI adoption does not lead to job losses but instead creates opportunities through education and training programs. Engaging civil society and labour unions is also critical to overcoming resistance and ensuring the successful implementation of AI-related policies.

AI governance plays a critical role in industrial development by influencing the environment for AI innovation. Effective governance can attract investment and drive technological advancements, while overly restrictive regulation may hinder innovation. The approaches of other countries also impact a nation's industrial competitiveness, as lenient regulations can foster faster innovation and attract more investment, potentially giving those industries a competitive edge. However, stricter regulation can ensure that AI development aligns with societal goals, promoting benefits such as job creation and widespread adoption in the local production system, which is particularly important for developing countries.

Emerging countries should develop AI visions tailored to local needs in order to ensure a broad adoption of AI technologies. By closely monitoring the AI governance approaches of other nations, they can learn from global best practice and adopt frameworks that balance the need for regulation with attracting investment. This balance is fundamental for fostering innovation while maintaining social and environmental sustainability, particularly in sectors like manufacturing. Developing a governance framework which aligns with local priorities can help in shaping rules which not only encourage AI-driven growth but also safeguard against potential societal and environmental impacts. Additionally, engaging in dialogue with international organizations can provide emerging countries with valuable platforms for cooperation, enabling them to share experiences and collaborate on scalable AI solutions.

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