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HOW TO MEASURE AI: TRENDS, CHALLENGES AND IMPLICATIONS

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HOW TO MEASURE AI: TRENDS, CHALLENGES AND IMPLICATIONS

How do comparable and similar indicators to measure artificial intelligence (AI) look across countries? In answering this question, our study addresses two main aims. Firstly, the paper introduces a holistic approach as operational tool to measure AI development (supply side) and adoption (demand side), which covers AI definition, AI technologies taxonomy, and a set of indicators. Secondly, the suggested methodology combines several sources of information like survey, bibliometric, and patent analysis. Next, by analyzing the results of a pilot survey and calculations, the reliability of indicators and a tentative assessment the state of the art of AI development and adoption in Russia is provided. Taking into consideration the complex nature of AI, the study represents a number of baseline parameters that give an overview of AI progress on a country level. The next step will be an elaboration of detailed indicators that at capture AI characteristics to a greater extent in different economic sectors.

Keywords: artificial intelligence, AI definition, digital technologies, indicators, measurement.

JEL Classification: O33, O38.

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Introduction

In the new stage of global socioeconomic development, digitalization becomes a key transformative phenomenon. Recent developments in the field of AI made it a core digital technology [Brynjolfsson et al., 2017]. As the next generation of ICT, it is expected to become an important growth and innovation engine [Brynjolfsson, 1993; Bresnahan and Trajtenberg, 1996; Bresnahan et al., 2002; Cette et al., 2016; Syverson, 2017]. The International Telecommunication Union (ITU) estimates that AI's contribution to GDP growth may achieve 1.2% per year by 2030. This figure is three times higher than that of information and communication technologies in the 2000s [ITU, 2018]. Being a modern general-purpose technology [Bresnahan and Trajtenberg, 1995], AI fosters innovation and requires additional organizational changes, human training, and other additional resources [Higón et al., 2017]. More advanced techniques of predictive analytics, for example, are complemented with more sophisticated equipment with augmented reality or other modern industrial applications [Brynjolfsson et al., 2017].

At the same time, AI leads to drastic transformations on the labor market [Acemoglu and Restrepo, 2019; Bessen, 2019], competition field [Aghion et al., 2019], and overall economic structure [Goolsbee, 2019]. The OECD estimates that in developed economies around 14% of occupations may be automated and more than 30% may undergo changes in how the work process is organized [OECD, 2018b]. For developing countries, this is even more challenging due to the predominance of labor-intensive jobs [ILO, 2018].

To respond challenges and seize opportunities raised by technological advancements, there is a great need for AI governance and, thus, measurement [Cockburn et al., 2018; OECD, 2019]. This requires the definition and classification of AI technologies in an operational manner. Currently, no leading economy has implemented a comprehensive system to measure AI development and use. There are several reasons that explain this. Primarily, the relatively recent recognition of AI as a particular technology extracted from ICT results in vague definitions, unclear boundaries between artificial intelligence and other digital technologies, as well as difficulties in classification of digital technologies, products, and services [Gokhberg et al., 2020b].

Within the international scope there is still no accepted statistical standard that contains recommendations on how to provide a measurement exercise. However, Eurostat, the OECD, as well as national entities undertake efforts to set the boundaries of AI, the technologies that constitute it, principles, and metrics [European Commission, 2018; AI HLEG, 2019a; OECD, 2019]. On the Russian agenda, AI has garnered great attention as well since 2019 with the adoption of the national AI strategy.

There is a request from different stakeholders for quantitative data on the state of AI on a regular basis. Measurement exercises are at their initial stages and largely discussed by governments and international organizations [ITU, 2018; European Commission, 2020a]. Several pilot surveys examining adoption are conducted in EU countries, Canada, and South Korea [European Commission, 2020, Ministry of Science and ICT, 2020; Statistics Canada, 2019]. The number of indicators and its composition vary. Existing initiatives often use traditional publications and patent indicators to measure its research output and overall development [NSF, 2020; WIPO, 2019]. Due to the rapid dynamics of AI, there is a room for considering the extent to which AI's nature is captured by such techniques. Taking AI as a general-purpose technology with a wide range of applications, there are several conventional indicators that give insight into AI dissemination across economic sectors [Statistics Canada, 2019].

When designing a measurement system, key requirements should be considered. In particular, such metrics are expected to provide stable data over equal periods of time. These indicators should be updated and enlarged according to the pace of development of AI. The introduction of new indicators into the existing statistical system also takes time [Abdrakhmanova et al., 2018]. This generates a search for more flexible indicators with a shorter time for data presentation, as well as their combination with more traditional ones.

Taking into account such limitations and long-term goals in the field of AI, this research answers several questions related to AI deployment.

RQ1: Which indicators are frequently used by national institutions and international organizations?

RQ2: Which indicators provide a comprehensive, systemic and comparable view of AI development?

RQ3: How well do traditional statistics and new sources of information capture AI's features in supply and demand and quantify them?

In order to respond, we analyze and synthesize different methodologies at the national and international levels (the form of assessment, methods of data collection and processing, set of indicators, measurement challenges), study current statistic surveys in the field of digital technologies, and propose a set of metrics by discussing the advantages and limitations of existing approaches.

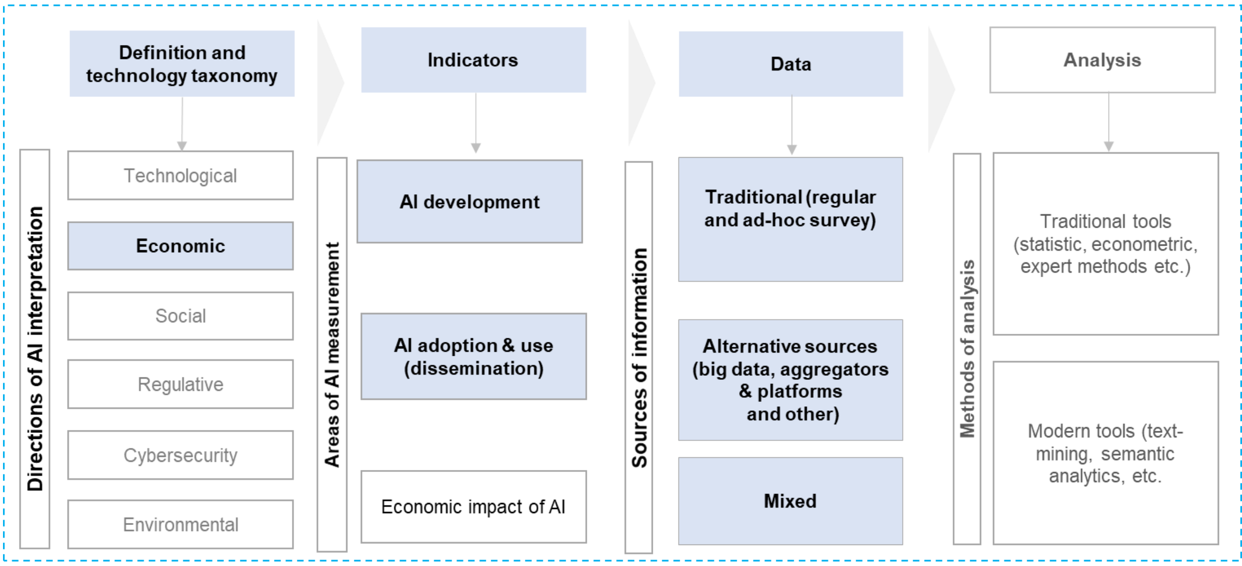
The paper is structured as follows. In Section 1, we explain the framework of the paper. Section 2 briefly overviews existing AI definitions used in national strategies and other documents, as well as international organizations. In Section 3 we define indicators to measure AI. Section 4 provides the results of the calculations and discusses them. Lastly, the conclusions of the study and recommendations for developing and implementing a system of indicators are presented.

1. Analytical Framework to Measure AI

The measurement of AI requires a set of preliminary steps, which includes a general understanding of AI as a phenomenon (scope and definition) and the boundaries of technologies to establish a basis for its further analysis [European Commission, 2018; JRC, 2020a; OECD, 2019].

Figure 1 provides a proposed concept of AI measurement in an economy. It includes definition and technology classification, the indicators themselves, data for indicator measurement and also methods of analysis. Last but not least, different approaches to investigate data are described as well as those outside the scope of the current study. Indicators as the main operating tool of measurement depend upon the directions of AI interpretation and sources of data.

Figure 1. Analytical Framework for AI Measurement



Note: The elements that not colored are outside the scope of this study.

Source: authors' elaboration based on [European Commission, 2018; OECD 2018a; JRC, 2020a; 2020b].

AI as a general-purpose technology may be defined from different angles. The most common perspectives include technological, economic, social, regulative, cybersecurity, and environmental. This paper focuses only on the economic one, which describes it as a source of value and collaborative activity [Cette et al., 2016; Syverson, 2017; Brynjolfsson et al., 2017].

In order to reveal the possible areas of AI measurement, we turn to academic research to find data sources and methods of analysis. Indicators related to AI might be integrated into two large groups — development and use. The first category refers to the issues of its creation and often includes bibliometric and patent analysis [Fujii and Managi, 2018; Zhang et al., 2019]. Along with this, it covers trends in AI [Oh et al., 2018; Zhang et al., 2019; Habibollahi and Pecht, 2020; van Beuzekom, et al., 2020], determinants of AI invention [Uhm, et al., 2020], level of technological development [Fujii and Managi, 2018; Park and Jun, 2020], sectoral trends in AI [Rodzalan et al., 2020].

The second array of papers refers to AI adoption and use (dissemination) across sectors. On the aggregate level, AI is identified by economic ecosystem evolution and investments in AI. Such an approach allows one to estimate stakeholders' interest in the AI field and their activities. These indicators encompass AI as a particular industry, the spread of technologies and range of applications, performance and AI efficiency, and correspond to the practical purposes of numerous participants.

Data for indicators might be collected in several ways, which are organized in three main groups: traditional sources like surveys, alternative sources, and those obtained through a mixed approach that combines the first two. Large-scale surveys remain one of the key channels through which to receive objective information from a wide sample of organizations [OECD, 2018a]. Along with this, there is a set of alternative approaches. Recently, there has been great interest in new sources, including government and other public data from information systems, big data from different thematic systems (for example, transactional financial data), aggregators and platforms (GitHub, Reddit blog posts), social media (LinkedIn), and similar [Gokhberg et al., 2020b; HAI, 2019; Tortoise, 2019; Oxford Insights and IDRC, 2020].

In general, there are two main groups of methods to analyze information. The first one represents more conventional tools widely used in academia and practice. Research output can be defined with bibliometric and patent analysis, more recent altmetrics indices, and clique analysis [Oh, et al., 2018; Zhang et al., 2019; Habibollahi Najaf Abadi and Pecht, 2020; Pantano and Pizzi, 2020]. Word cloud analysis, correlation analysis, Bayesian analysis, multivariable statistics analysis, content analysis, exploratory factor analysis, partial least squares path modeling, and numerical and graphical modeling are often used in papers to find relationships in data or assess its impact on research performance [Haseeb et al., 2019]. The group of econometric statistical analysis is largely applied to identify patterns of technology usage. Quantitative studies can be supplemented by case studies, SWOT analysis, or the like. For example, economic indicators, like the number of AI startups and the proportion of AI startups in an industry are paired with the analysis of startup profile, business models, and organizational practices [Soni, et al., 2020]. Expert interviews with Delphi technique are another popular tool frequently used for different tasks [Abdullah and Fakieh, 2020; Chen et al., 2020; Belanche et al., 2019].

Further, we discuss in detail the first three elements of the aforementioned framework from the empirical side. In order to do this, we collect information at the national and international levels. For the former, a range of countries was selected based on the following criteria. The idea of selection encompasses both the supply and demand side of digital technologies, as AI belongs to a broader field of ICT. They are following:

– business expenditure on R&D in ICT: shows how actively a country engages in the development of emerging digital technologies where AI is the leading one;

– ICT share in the country's value added: shows the performance of the ICT industry and its recognition on global markets

– industry value added: reflects sectoral capacity to adopt new technologies. It serves as indicator of the overall industrial development and highly depends upon novel technological solutions [Industrial Strategy Council, 2019].

These criteria are internationally comparable and often used for similar purposes. The first two serve as proxy for the ability to develop and deliver digital products and services [OECD, 2018a; OECD, 2019]. Across the sectors that employ ICT, traditional industry, which integrates manufacturing, electricity, construction, and mining, is the largest consumer of new technological developments in relation to GDP. Hence, it is important to understand scale of its potential adoption measured with industry value added (third criteria). Such an approach is used by WEF in constructing the Readiness for the Future of Production index as the mark of scale of technologies dissemination and might be relevant for the current study [WEF, 2018].

For the analysis, we chose those countries that are ranked in the top-20 in at least one indicator from both sets of supply and demand metrics (see Table 1). As countries vary across rankings, the first twenty positions give the countries variability and cover both large states with innovative ICT sectors (the US, Japan, the UK, South Korea) and at the same time those with strong manufacturing industry (Canada, China, France, Germany, and Japan).

Table 1. Country Selection for the AI Measurement Analysis

	Development				**Adoption**	
	Business expenditure on R&D in ICT 2017, mln euro		**Information, communication, % of value added, 2018**		**Industry (including construction) value added, 2018, bln 2010 constant US$**	
	Value	**Rank**	**Value**	**Rank**	**Value**	**Rank**
US	29411.4	1	6.9	7		
Japan	4758.4	2	4.9	17	1801.2	2
UK	3477.2	3	7.0	18	502.3	7
Germany	3345.5	4	4.8	18	1085.1	3
France	3312.7	5	5.3	12	484.7	8
South Korea	728.9	12	4.6	20	484.2	9
Canada					515.2	6
China					4941.8	1

Source: based on [Eurostat, 2020; World Bank, 2020; OECD, 2020].

In order to examine international initiatives in AI measurement, we examine international organizations (European Commission, ILO, ITU, OECD, UNESCO, WIPO) that have activities in digitalization and several AI indexes as composite metrics, which are currently not so numerous [European Commission, 2020a; OECD, 2019; ILO, 2018; ITU, 2018; UNESCO AHEG, 2019; WIPO, 2019]. There are indeed only two that cover large share of countries and focus predominantly on AI: the AI Index developed by Stanford's University Human-Centered AI Institute (HAI) and Global AI Index 2019 by Tortoise [HAI, 2019; Tortoise, 2019; Oxford Insights, IDRC, 2020]. The Government AI Readiness Index by Oxford Insights and the International Research Development Centre (IDRC) represents only the public administration field and does not capture AI development in other industries. This set of sources gives a systemic view on the state-of-the-art of AI measurement.

2. Defining AI for Measurement

To collect existing definitions and indicators, we turn to national strategies and similar documents like plans, reports of responsible authorities, methodological guidelines, roadmaps, acts, and laws that cover key tasks and purposes associated with their implementation in the field of AI. In most cases, AI-related indicators and targets are placed in various programs and strategies, which again proves AI's heterogeneous agenda and current status. Papers and reports of international organizations, like the European Commission and its entities such as the Joint Research Center, AI High-Level Expert Group on Artificial Intelligence (AI HLEG), OECD (AIGO), G20 Digital Economy Task Force, UNESCO, the International Labour Organization the International Telecommunication Union, World Intellectual Property Organization, and international standardization bodies are also in the scope of analysis [European Commission, 2018; JRC, 2018; JRC, 2020a; JRC, 2020b; AI HLEG, 2019; ITU, 2018; G20 DETF, 2018; UNESCO AHEG, 2019; WIPO, 2019; ILO, 2018; IEC, 2020]. For more detail, see Annex 1.

The main pool of national initiatives was adopted in 2017-2019 and set general goals, directions, and measures for the AI race. Diverse efforts are made at international organizations and involve definition, ethics principles, and standards development [Saran et al., 2018; European Commission, 2018; KAS, 2019]. In 2019, Russia adopted the National AI strategy as well. Providing strong support, governments need appropriate tools to monitor and assess its progress in economic and social life.

The differences in countries' approaches are induced by the distinct focus of national priorities on scientific, technological, and economic development. Taking into account the novelty of the agenda and the complexity of the object of measurement, separate studies and monitoring are conducted to measure the effectiveness of state support for AI, the development of research capacities, the commercialization of AI-based solutions, regulatory environment, and standardization [SNV, 2018; KAS, 2019; DIN, 2019; Zhang and Dafoe, 2019; Computing Community Consortium, 2019; Committee on Standards in Public Life, 2020]. However, they focus on particular issues instead of a systemic view.

The absence of a single definition that describes the nature of AI, and the technologies that constitute it, is one of the main limitations of measurement [Soni et al., 2016; Buiten, 2020; Thierer et al., 2017; Cockburn et al., 2019; Hager et al., 2017; Bostrom, 2014]. In order to respond this challenge, there is a number of initiatives at the international and national levels. The analyzed documents on AI focus on two main definitions — AI in general [Congress.gov, 2018; Government of Japan, 2016; GOV.UK, 2017; Australian Government, 2017] and the AI system [European Commission, 2018; AI HLEG, 2019; JRC, 2020a, 2020b]. The second is narrower and related to the specific embodiment of AI technologies.

In general, AI is viewed as the field of methods and techniques that allow one to perform functions requiring human intelligence [Raynor, 2020; Council of Europe, 2020]. AI meanings often differ from one document to another inside a country and depend upon the purposes of a particular strategy, which is usually a longstanding vision rather than operating tool. In Japan, the definition of AI is available in three documents: The Japan’s Plan for Dynamic Engagement of All Citizens (2016), The 5th Science and Technology Basic Plan (2016), and Draft AI R&D Guidelines for International Discussions (2017). The first attaches it with big data, the second one enlarges the scope of directions, adding internet of things and advanced communication. The last notion gives a more specific view of AI as a concept of software and AI systems

[Government of Japan, 2016; The Conference toward AI Network Society, 2017]. Several meanings of AI are set out in South Korean strategies. While in the I-Korea 4.0 AI R&D Strategy there are general outlines about human intelligence, such as cognition and learning performed by computers [Ministry of Science and ICT, 2018a], in 2020 the National Strategy for Artificial Intelligence AI represents the "science and technology that performs human intellectual functions with machines" [The Government of Republic of Korea, 2020].

AI terms are sometimes contradictory and plunged into one concept. However, almost all of them highlight AI as *a complex system that operates on intelligence similar to human intelligence and includes software, hardware, content, and other elements*. Sectoral terms are rare, except in France, which defines industrial AI as a system that executes part of human functions in the manufacturing process and raises its efficiency.

In AI discussions, there is a division between strong and weak AI, or general and narrow. "Strong" AI reflects AI systems with the same intellectual capacities as human, or even exceeding them for a wide range of tasks and fields, "Weak" AI is designed for the solution of specific tasks using methods and algorithms [The Federal Government, 2018]. To this end, aspects of human intelligence are mapped and formally described, and systems are designed to simulate and support human thinking. From this point, almost all definitions explain weak or narrow intelligence, which means that they perform a specific task or solve problems applying a set of methods and techniques and thus support human activity [BMWi, 2018].

From the selected countries, the Canadian and US terms represent an *operational* definition that enables AI quantification in economic activities. The operationalization of a definition means that a term reflects practical objectives and targets of an object and a set of categorized elements [European Commission, 2006]. Both definitions point to AI as simply a hard or software system, which is used in the functional fields of a firm. They are short, clear, precise, and appropriate for a wide range of applications. The Canadian one interprets AI as "systems that display intelligent behavior by analyzing their environment and taking actions - with some degree autonomy - to achieve specific goals. AI-based systems can be purely software-based or embedded in a device" [Statistics Canada, 2019]. The US definition is more expanded as it adds human-like functions, such as perception, cognition, planning, learning, communication, or physical action. Other approaches treat AI as single or multiple technologies [Government of Japan, 2016; GOV.UK, 2017; The Government of Republic of Korea, 2020] or intelligence [State Council, 2017; U.S.-China Economic and Security Review Commission, 2017].

We distinguish between definitions marked as such in the documents of international organizations or national governments and highlighted them as such. First, we list all elements that constitute a list of selected definitions. By examining them more closely, one may notice common characteristics (elements), which cover AI class as a socioeconomic phenomenon, its purposes and applications, the methods and technologies, effects of AI, sometimes stakeholders, and issues related to data [GAO, 2018; NIST, 2019; OECD, 2019; WIPO, 2019]. Among them we distinguished elements cited in three and more definitions and based on this, provided a closer analysis.

Almost all the selected definitions specify the nature of AI, which may be technology, a group of technologies, or a set of technological solutions (see Table 2 and Annex 2 and 3). Most often AI is considered as a system with an indication of its embeddedness in software, less frequently – hardware. Functions are also among the most often cited elements [US Security Commission, 2018; GOV.UK, 2017]. AI systems execute different operations related to perception, planning, learning, reasoning, communication, decision making, acting, and other cognitive functions [AIF, 2019; The Government of Republic of Korea, 2020]. A large part of the terms have a particular focus on the autonomy of such systems. AI techniques and technologies are elements that are not so widely mentioned and serve as an illustration of AI capacities and specific applications. It is noteworthy that machine learning is among the most popular AI techniques [US-China Economic and Security Review Commission, 2017; US Security Commission, 2018; MSIT, 2020]. Some terms also provide examples of the specific embodiment of AI technologies in products like personal assistants, self-driving cars, robotic cleaners, or automated translators [JRC EU, 2020].

Table 2. Main Structural Elements of AI Definition in National and International Documents

Document with AI definition	**Elements of the definition**				
	Nature	**Embeddedness**	**Functions**	**Technologies / Techniques**	**Examples of products/ services**
National level					
National U.S. Security Commission Artificial Intelligence Act, 2018	+	+	+	+	
The 5th Japan Science and Technology Basic Plan, 2016	+				+
The UK Industrial Strategy, 2017	+		+		
France Alliance Industrie du Futur, 2019	+		+	+	
National Strategy for Artificial Intelligence of South Korea, 2020	+		+	+	
Canada Survey of Digital Technology and Internet Use, 2019	+	+			
Report to Congress of the U.S.-China Economic and Security Review Commission, 2017	+	+			

Australia 2030 Prosperity through Innovation, 2017	+				
Russian National strategy development of artificial intelligence for the period up to 2030, 2019	+	+		+	
International level					
JRC AI Watch Methodology to Monitor the Evolution of AI Technologies, 2020	+		+		
European Commission Artificial Intelligence. A European Perspective, 2018	+				+
AI HLEG A definition of AI: Main capabilities and scientific disciplines, 2019	+		+	+	+
JRC Artificial Intelligence. A European Perspective, 2018	+		+		
European AI Strategy: EC Communication, Artificial Intelligence for Europe, 2018	+		+		
OECD Oslo Manual 2018	+				
ITU Assessing the Economic Impact of Artificial Intelligence, 2018	+				
JRC AI Watch Defining Artificial Intelligence, 2020	+		+	+	+
OECD Scoping the OECD AI Principles Deliberations of The Expert Group on Artificial Intelligence at the OECD (AIGO), 2019	+		+		

Source: authors elaboration based on [U.S. Security Commission, 2017; Prime Minister of Japan, 2016; GOV.UK, 2017; AIF, 2019; The Government of Republic of Korea, 2020; Australian Government Innovation and Science Australia, 2017; President of Russia, 2019; JRC, 2018, 2020a, 2020b; European Commission, 2018; AI HLEG, 2019; OECD, 2018a; ITU, 2018; OECD, 2019].

The term elaborated upon by the High-Level Expert Group on Artificial Intelligence (HLEG) of the European Commission may be considered a benchmark and argues that the AI component is often embedded as a part of larger systems [AI HLEG, 2019]. The Russian definition stated that at the national level, the AI strategy has similar structural elements as major international organizations and key players in this field (OECD, the USA, China etc.). It may be used as a reference point for an operational definition.

AI designation is important, but not enough to provide for a quantification of AI. The second component of the proposed analytic framework represents taxonomy, i.e., the classification of technologies that constitute the AI domain. There are still discussions on how to demarcate them, as most technologies are closely tied to each other. There are also different taxonomies of AI technologies based on the purpose of analysis (see Table 3). Despite the different classifications, there is a set of pure technologies that constitute the AI technological core that are mentioned in national documents. This includes computer vision, natural language processing, and speech recognition and synthesis. Other areas (robotics, connected and automated vehicles, AI applications and services) are not pure technologies, but complex products that contain AI components. Machine learning is a key technique of AI. The Russian approach along with three core directions also distinguish intelligent decision support technologies that are widely used in different application fields. Last but not least, these technologies relate to advanced artificial intelligence, so-called “strong AI”, and are connected with perspective methods but are at the initial stage of development.

Table 3. Most Frequently Mentioned AI Technologies in National and International Documents

Source	**Computer Vision (image recognition)**	**Natural Language Processing**	**Speech Recognition and Generation**	**Decision Support Technologies**	**Machine Learning**	**Robotics and Automation**	**Connected and Automated Vehicles**	**AI Applications and Services**	**Other**
JRC EU, 2020 The AI Techno-Economic Segment Analysis	+	+	+	+	+	+	+	+	
JRC, 2019 Technical Report AI Watch Defining Artificial Intelligence	+	+	+		+	+	+	+	
Canada Survey of Digital Technology and Internet Use, 2019	+	+	+	+	+			+	+
U.S. Whitehouse, 2019	+	+	+	+	+	+			
Artificial Intelligence Strategy, 2018	+	+	+	+	+	+			
Next Generation Artificial Intelligence Development Plan, 2017		+					+	+	+
Russian National strategy development of artificial intelligence for the period up to 2030, 2019	+	+	+	+					+

Source: authors’ elaboration.

Thus, based on the Russian official definition and existing international approaches, we propose an empirical term, which may be applied for a wide set of measurement tasks:

Artificial intelligence is a system of software and/or hardware tools that can, with a certain degree of autonomy, perceive information, learn, and make decisions based on analyzing large volumes of data, among other things by imitating human behavior. It includes the following technologies: speech recognition and generation, natural language processing, data mining, computer vision, recommendation systems and intelligent decision support systems, process automation, and data analysis technologies based on deep learning algorithms.

A major problem that arises when trying to specify AI is so-called nesting, which is why definition and technologies classification should be studied jointly. This translates into difficulties in splitting technologies of higher and lower levels and their intersection in a unified notion [WIPO, 2019]. For example, an AI system may comprise speech recognition technologies that are part of a more complex recommendation system. Another issue refers to distinction between techniques and methods that may be applied in different technologies and industries. Machine learning is the most prominent example in this context. Machine learning represents a sub-area of AI and might be part of different technologies (see [WIPO, 2019] for an illustration of the accurate distinction between AI elements). Such a riddle takes more time for stakeholders' approval from different domains that commonly participate in working and expert groups and develop AI principles, guidelines. and policy recommendations.

3. Defining Indicators to Measure AI

3.1. Description of the Process of Indicator Selection

From an empirical perspective, we consecutively provide an overview of existing metrics at the national and international levels, including global indices. Based on the analysis of the existing global practices, a list of indicators for Russia is then constructed. There are several steps in the indicator analysis process.

First, we gather all country metrics inside development and adoption blocks, which are two major modules to measure AI, as shown in Section 1. The former encompasses scientific publications activity (papers and conferences), patents activity, funding and investments in a technology, and human capital [Zhang et al., 2019; Pantano and Pizzi, 2020; van Beuzekom et al., 2020]. They are also widely accepted in innovative assessment [OECD, 2018a]. In addition, the AI field might be characterized with new metrics like ecosystem, as AI is mostly driven by startups and small firms [Liu et al., 2020; Haseeb et al., 2019; Soni et al., 2020; Aghion et al., 2019; Chen et al., 2020]. Quite often existing approaches address public acceptance of AI. For example, the survey of that asking firms about AI and robotics development and diffusion on the current and future employment [RIETI, 2017].

Next, all indicators are marked as core (basic) that describe the main features of a technology phenomenon and those that are additional. Core metrics generally have wide application and describe the most important trends of AI advancements in basic (number of AI publications) and applied research (number of AI patents or publications), as well as use at organizations (jobs or specialists, etc.). Following this logic, the second group provides additional information and refines basic indicators, giving extra information about scopes and dimensions of its development (international co-citation of publications, the number of AI specialists by particular technology, etc.). Core indicators have a methodological foundation, they may be quantified for different countries and scaled for different dimensions. Thus, a core indicator has two features: 1) frequency — mentioned in documents; 2) applicability for a large sample of countries. All indicators may also be “hard”, e.g. based on accepted methodology, regular and quantitative by nature, or “soft” — mostly qualitative and flexible [Dziallas, 2019].

Indicators related to AI are retrieved from several sources. They are found in annual statistical materials for France, the US, Canada, and South Korea [INSEE, 2019; NSF, 2020; Government of Canada, 2020; Ministry of Science and ICT, 2020], reports and messages of governmental institutions like the US Patent and Trademark Office (USPTO) [USPTO, 2020]. There is also a scope of more flexible or soft indicators obtained via ad-hoc surveys or other sources, like big data, online aggregators (Crunchbase, LinkedIn), and so on. Such indicators like the number of AI occupations are based on jobs aggregators or business social media (LinkedIn) that do not have a solid methodology base. They are presented in official materials of governmental organizations, for example by the Trade and Industry (RIETI) in Japan, Alliance Industrie du Futur in France, European Commission institutions, and others [Ministry of Science and ICT, 2018b; RIETI, 2019; AIF, 2019; European Commission, 2020a, 2020b]. One more category includes reports and analytics from research and consulting entities like China Institute for Science and Technology Policy at Tsinghua University and Canada’s CIRANO (Centre Interuniversitaire de Recherche en Analyse des Organisations) [CIRANO, 2018; China Institute for Science and Technology Policy at Tsinghua University, 2018; Future of Humanity Institute, 2018, 2019; Daxue Consulting, 2020]. The last category encompasses a variety of indicators.

3.2. Development of the System of AI Indicators

This section discusses the indicators used by countries and in the global indices. Firstly, we examine the metrics incorporated in the national documents. Table 4 contains main indicators that measure AI development indicators. The list of revealed indicators by country is presented in Annex 4.

Patent and publication scores are the most frequently used indicators that are internationally accepted as a proxy of research output [SNV, 2018]. These may be quantified in several ways and may give different results, but are based on internationally accepted approaches to measure it. Enhancement in semantic technologies enable new methods of analysis and, thus, indicators. The TES Approach (techno-economic segmentation) by the EU Joint Research Centre integrates trends, participants, and technologies by automating document processing. It combines micro-data from non-official heterogeneous sources to “hard” indicators by using an organization as a unit of analysis [JRC, 2019]. Such big data exercises are becoming increasingly popular and complement, but do not substitute traditional ways of scientific performance measurement.

In the absence of statistical data, alternative sources also may provide useful insights into market development. AI developer maps, platforms and hubs (in France, UK, Germany, for example) and other aggregators serve as a source for industry composition for corporate strategies and policy making [European Commission, 2020a].

There are challenges to measuring specialists in AI due to the absence of classifiers and international standards. Currently, professions like data scientist, data analyst, and data engineer are included in the classifications in only a few countries, but are very much in demand on the labor market [HAI, 2019]. In order to retrieve such information, data from jobs aggregators and business social media is used, but a methodological basis is needed in order to scale to countries and regions.

The adoption perspective of AI technologies in industries has includes less metrics. In spite of the complexity, several countries have already introduced pilot AI statistical surveys like Canada, European Union, and South Korea. Indicators and questionnaires are rather similar and focus on the different types of AI technologies used, its purposes, and plans in the medium term (from one to three years) [NSF, 2020; Statistic Canada, 2019; Ministry of Science and ICT, 2020].

Statistical indicators are often tied with high costs and compliance standards – only most important data is imposed by national statistic offices on respondents. To obtain additional information, one must turn to ad-hoc surveys, which are organized to collect particular types of information. It helps to assess the perception of AI by businesses taking into account the whole ecosystem (suppliers, consultants, etc.) [AIF, 2019].

Table 4. Core Indicators to Measure AI in the Selected Countries

Indicators by area	US	Japan	UK	Germany	France	South Korea	Canada	China	European Union
I. AI development									
1. Publications									
Number of AI publications	+	+	+	+	+	+	+	+	+
Citation impact of AI publications	+	+	+	+	+	+	+	+	+
Number of AI publications in international co-authorship	+	+	+	+	+	+	+	+	+
2. Conferences									
Number of conference/proceedings papers in the field of AI	+	+	+	+	+	+	+	+	+
Percentage of AAAI (the Association for the								+	

Indicators by area	US	Japan	UK	Germany	France	South Korea	Canada	China	European Union
Advancement of Artificial Intelligence) Conference Presentations									
3. Patents									
Number of patent applications for inventions in the field of AI filed by Russian applicants, units (share)	+	+	+	+	+	+	+	+	+
Number of patents for inventions in the field of AI, units	+	+	+	+	+	+	+	+	+
Relative Specialization Index (RSI)	+	+	+	+	+	+	+	+	+
4. Expenses									
Expenses for research and development in AI	+		+						+
Public funding AI		+						+	
Total investments in AI companies	+								
5. Human capital									
Number of researchers in AI								+	
Jobs in the field of AI	+								
6. Ecosystem									
Number of AI firms						+		+	+
Number of AI projects									+
Number of startups in the AI area, thousand units									
Venture capital investment in AI								+	
II. Adoption and use in industries									
Number or share of organizations that used AI technologies/	+	+			+		+		
Number or share of organizations that developed AI technologies	+				+				
Number or share of organizations that used AI technologies on purpose					+		+		
Number or share of organizations that not used AI technologies on purpose							+		
Other indicators							+		
Public (society) attitude toward AI			+				+	+	
Open data			+						
Service robot shipments			+					+	
Industrial robot shipments			+					+	

Source: based on [NSF, 2020; USPTO, 2020; Industrial Strategy Council, 2019; Government of Canada, 2020; AIF, 2019; INSEE, 2019; CIRANO, 2018; Ministry of Science and ICT, 2017, 2020; European Union, 2020a, 2020b; Statistic Canada, 2019; RIETI, 2019; Future of Humanity Institute, 2018; China Institute for Science and Technology Policy at Tsinghua University, 2018].

Considering the international scope of AI measurement, global AI indexes represent another way to conduct AI cross-country measurement (Annex 5). However, they do not substitute national level indicators due to several reasons. Such rankings are often based on the national level indicators and on the other hand represent metrics that are composite and aggregate. They are useful for comparative analysis between countries, but detailed investigation demanded by policymakers and corporate stakeholders requires more specific indicators with sectors, regions, technologies classifications, and types of firms.

Global AI index analysis shows several important trends. From year to year its methodological framework expands by integrating newer metrics. For example, the Government AI Readiness Index in 2020 include three times more indicators than the year before (overall 33) across 10 dimensions (four a year before) [Oxford Insights, IDRC, 2020]. The AI index evolves in a similar way: three times more information in 2019 than in 2018. This becomes possible due to consecutive designing of AI's economic role and initiatives across the globe for its governance [OECD, 2020].

The selected indexes give more a broad view on AI development and comprise a larger share of advanced, more detailed metrics (see Annex 5). We address only those indicators that have a direct mention of AI and do not account for the field of ICT (for example, the number of STEM graduates, speed of broadband, and similar infrastructure characteristics).

In general, indexes are more flexible in terms of data sources. For example, the Microsoft Academic Graph offered by the HAI Index may be used to measure publications. From the supply side, traditional indicators of patents and publications offer such metrics as "Number of Deep Learning" papers or number of papers per capita [HAI, 2019]. The Global AI Index 2019 by Tortoise comprises a richer set of relatively new metrics for patents: average days taken for approval by patent office, Patent Acceptance Rate for Applicants and Inventors based on Google Big Query [Tortoise, 2019].

Indices describe more detailed human capital like graduates in STEM, AI, mathematics, or AI specialists by the number of data scientists, engineers, as well as courses for their education like number of universities offering "Advanced AI" courses, number of universities in Top 100 for Computer Science [Tortoise, 2019]. The Coursera Percentile Rank of AI Skills integrated in the HAI Index shows the interesting scope of specialists with AI skills [HAI, 2019].

The state of the AI ecosystem covers venture capital, technical, and institutional metrics. The group of technical metrics is described by the number of Kaggle Grandmaster and Master contributors, GitHub "Commits" and "Stars", which are used in the AI global index [Tortoise, 2019]. They reflect most short-term changes in AI development and the positions of specialists from different countries. It also depends upon the availability of open data which may be calculated by the Open Data Barometer Score [Tortoise, 2019].

Our analysis shows that the adoption side is currently represented by the smaller number of indicators than development. Partly it is explained by earlier stages of adoption and a relatively low current level. Another point relates to the difficulties of the heterogeneous needs of AI technologies and their application fields [European Commission, 2020a]. Along with typical robot installations, it also comprises hiring metrics which implicitly indicate demand for AI in corporate sector [HAI, 2019].

Metrics from the indices enlarge the perception of detailed AI indicators and may be used as additional measurements. Its selection may be ground in two criteria — the quality of the information resource and its applicability to a wide number of measurement units.

Taking into account the aforementioned results, the system of indicators for Russia is based on several pillars (see Table 5). First, it is comprehensive, that is, it covers development and use indicators. It comprises the core metrics revealed in the national level analysis. The system also reflects the national digital economy goals embodied in the metrics. This system is open which means the possibility of further integration of new, advanced indicators according to AI development and its dissemination in economy.

Table 5. The System of Indicators to Measure AI at the National Level in Russia

Group of indicators	**Core indicator**	**Additional indicators**	**Source of data**
	1. Publications		
Development of AI	• Number of publications of Russian authors in the field of AI in publications indexed in Scopus/Web of Science • Russia's share in the global number of publications in the field of AI in publications indexed in Scopus/Web of Science • Share of publications with international co-authorship in the total number of publications by Russian authors in the field of artificial intelligence in publications indexed in Scopus/Web of Science, %	• Number of publications of Russian authors in the field of AI in journals of the first and second quartiles (Q1 and Q2) indexed in Scopus/Web of Science, units • Share of Russian publications in the global number of publications in the field of AI in journals of the first and second quartiles (Q1 and Q2) indexed in Scopus/Web of Science, % • Percentage of publications in journals of the first and second quartiles (Q1 and Q2) in the total number of publications by Russian authors in the field of AI indexed in Scopus/Web of Science • Ratio of the average citation of	Scopus, Web of Science

Group of indicators	Core indicator	Additional indicators	Source of data
		Russian authors' publications in the field of AI indexed in Scopus/Web of Science at the global level, times	
	2. Conferences		
	• Number of conference/proceedings papers in the field of AI with participation of Russian authors indexed in Scopus/WoS (per year), units	Number of conference/proceedings papers of Russian authors in the A* conferences (per year), units	Scopus, Web of Science, conferences web-sites
	3. Patents		
	• Number of patent applications for inventions in the field of AI filed by Russian applicants, units • Share of patent applications for inventions in the field of AI submitted by Russian applicants in the global number of patent applications in this field, % • Number of patents for inventions in the field of AI, units	• Number of patent applications for inventions in the field of AI filed by Russian applicants under the PCT procedure, units	PatStat Global
	4. Expenses		
	Expenditures on R&D in the field of AI, thousands of rubles	Share of R&D expenditures in the field of AI in the total volume of R&D expenditures in the field of digital technologies, %	Statistical survey
	5. Human capital		
	Number of graduates with higher education in bachelor's, specialist's, master's, and secondary professional education in the field of AI, thousands of people	Number of persons with secondary professional and higher education who completed further professional training or retraining programs in the field of AI, thousands of people	Statistical survey
	6. Ecosystem		
	Number of startups in the AI area, thousand units	Venture capital leveraged by AI startups, mln rubles	Crunchbase
Adoption and use in industries	• Share of organizations using AI technologies in the total number of organizations, % • Share of organizations using AI technologies on purpose in the total number of organizations, %	• Share of organizations that developed AI technologies, in the total number of organizations that developed advanced manufacturing technologies, technologies, % • Share of organizations that used AI technologies in the reporting year, in the total number of organizations that used advanced manufacturing technologies, %	Statistical survey

Source: authors' elaboration based on the results of the analysis.

The core indicators are based on the analysis of existing approaches. Taking into account HSE expertise in STI assessment, we introduced several additional indicators. As there are several government projects to intensify the presence of Russian authors in the world's top-cited academic journals [Gershman and Kitova, 2017]. The group of patent metrics includes those applied under PCT as an additional indicator. Currently, the presence of Russian inventors abroad is rather low and national initiatives provide support for PCT applications.

It is important to note that not all indicators are currently possible to calculate. For R&D investments, there is a need to modernize the classification and delineate a category of AI inside appropriate statistical forms. It is difficult to calculate the number of AI graduates and specialists due to vague borders across ICT professions and, further, there are educational and professional standards that enable such estimations. In some countries like the US, occupation taxonomy already has introduced new positions of data scientists, data engineers, and others[4].

Due to the holistic nature of the designed system, sources of information for indicators vary. For development indicators, international databases are used. The statistical survey remains a feasible way of collecting regular and comparable data on adoption. One of the main innovations in this perspective is the pilot survey conducted on behalf of the ISSEK in the first half of 2020, which tests the proposed statistical indicators on AI adoption in different sectors. It was organized in the framework of activities to update the statistical measurement of the digital economy and included 616 organizations representing five Russian regions. The survey is based on the updated questionnaire of the existing national survey on ICT use and the production of computer equipment, software, and services areas. The sample of organizations is constructed proportionally according to the distribution of organizations across economic activities for the national survey in 2018. This makes the pilot sample representative. In selecting organizations, one important criterion is taken into account: a firm should have expenditures on digital technologies in the previous year, in 2018.

A special module on AI is introduced in the questionnaire. In addition to the main questionnaire, respondents were asked about the comprehensibility of the questions, as well as difficulties associated with gathering data. More than half of the firms answered that the questions were clear and understandable. However, in order to provide such data on a regular basis firms should modernize the internal management systems that gather information on AI in the mentioned areas. Hence, there is a room for the examination of AI measurement at the microlevel.

There is no "ideal" indicator, each of them has its limitations. However, they make a contribution to a systemic view of AI dissemination. The lack of methodology to highlight AI is one of the main constraints for many indicators. Based on existing guidelines for other technologies, it is important to understand which features require more detailed specification.

The group of metrics related to publications, conferences, and patent applications is the most widely used and accepted metrics at the international level. They are relatively easily calculated, comparable across large sample of countries, and provide a general view on the research output in AI. At the same time, they need further refinement for the AI field due its complexity and

[4] See in detail: https://www.onetcenter.org/taxonomy.html

cross-cutting nature. Obviously, they do not capture all AI developments. Typically, the number of patents and publications is calculated per year and thus cannot provide more operational insights. This set of indicators might be enlarged with more specific features like the *citation ratio and journals of the first and second quartiles (Q1 and Q2) indexed in Scopus/Web of Science, number of conference/proceedings papers of Russian authors in the CORE A* conferences (per year), and the number of applications under PCT.*

Indicators related to expenses are also among those most often used and agreed upon. They are a widely used and internationally accepted metric of research input, comparable across a large sample of countries, based on a standardized approach to calculation (OECD, 2018a) and provide long time-series. But they do not always result in causal relationships between costs and research output. As patent and bibliography metrics, they need a long period of calculation (annually). Another difficulty is tied with the delineation of the AI field from other digital technologies. From the policy perspective, it also does not fully reflect national goals in STI and digital policy. In order to highlight AI's role in digital technologies, we suggest including the *share of R&D expenditures in the field of AI in the total volume of R&D expenditures in digital technologies.*

Metrics for human capital are numerous, but not all of them allow for comparisons and stability through time. The number of graduates with higher and secondary professional education in AI reflect the sufficiency of talent in an economy to accomplish tasks for AI in different economic sectors. It also represents a basis to calculate the number of AI specialists. In addition, it provides for a long time-series. However, there are a set of limitations that hamper the current measurement. First, no adopted methodology exists due to the absence of classifications or guidelines that indicate AI-related courses and programs. Some indicators are already available, but they are not comparable across countries or are limited to a number of countries which have such data sources. Graduate indicators have a long period of time for the organization of data collection due to the annual periodicity of study programs. Along with the knowledge of actual number of students that finished the AI-related programs, it is important to monitor the transformation of graduates into professionals. Such information provides the *number of AI specialists.*

The ecosystem dimension describes startup development as they are the main drivers of the field. The number of startups in AI provides an illustration of AI business (industry) development and its dynamics and serves as a basis for further AI company calculation. It also implicitly indicates demand for AI technological solutions and is a widely accepted tool for cross-country comparisons. Nevertheless, currently no official methodology, guidelines or classifications for

AI field delineation exist. Therefore, different measurements may give different results. As an additional metric, *venture capital raised by AI startups* may show not only the scope of the industry, but its performance as well.

Finally, adoption represents a key issue for decision makers in most countries. Methodologically, the indicator of the number of companies is similar for different technologies and widely used across states. The approach for calculation and questions for the survey questionnaire of a qualitative nature is standardized (for example, use or not use), but needs agreement upon what to consider AI and the technologies that constitute it. In the case of regular measurement, the indicator may give long time-series. The second important metric refers to the purposes of AI use. Goals may be constructed in a functional (production, logistics, cybersecurity, marketing, etc.) or a business perspective (reduce costs, improve customer relationship, process optimization, etc.). However, to receive more feasible data, firms need to update their way of accounting for products and services based on AI in its activity. In doing so, guidelines that provide consistency of products and technologies classification across different sectors should be elaborated. No internationally accepted standards and guidelines are in place. In some cases, it is challenging to capture all solutions that integrate AI both in software and hardware. It is also important to account for the sectoral heterogeneity in AI demand and application. By responding this issue, one way is to look closer at the place of AI in manufacturing innovations. AI use and adoption inside advanced manufacturing technologies (*number of organizations that use AI*) diagnosis dissemination of AI across the most innovative production units, which still represent a significant part of the economy in developed and developing countries [UNIDO, 2020].

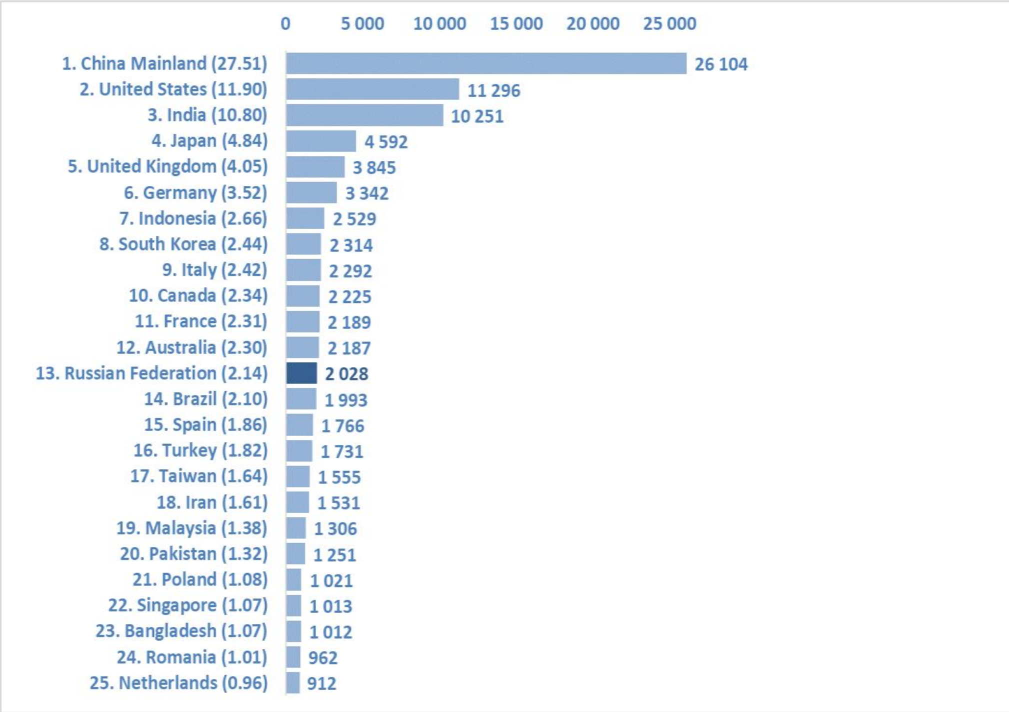
Such reasoning does not claim to be complete but rather gives a first general view on how to measure AI dissemination in the economy and obtain valuable conclusions from the data. It also provides ways and tools for further monitoring and estimation and may be applied for other digital technologies. AI indicators move STI measurement forward, but still need wide methodological discussion.

4. Calculating AI Indicators: Findings and Discussion

Here we provide the main results of the first experimental calculation of AI indicators and discuss them.

According to the HSE's earlier assessment of publication and patent activity, Russia's position in the field of AI is the strongest among all digital technologies [HSE, 2020]. In the country ranking by the number of AI publications indexed in Scopus, since 2010 Russian authors improved their position from 43rd place in 2010 to 13th place in 2019 (Figures 2 and 3). With the share of 2.14% in the global number of publications on AI in Scopus, Russia is comparable with Australia, France, and Canada (2.3-2.34%) and this value increased almost eight times over ten years.

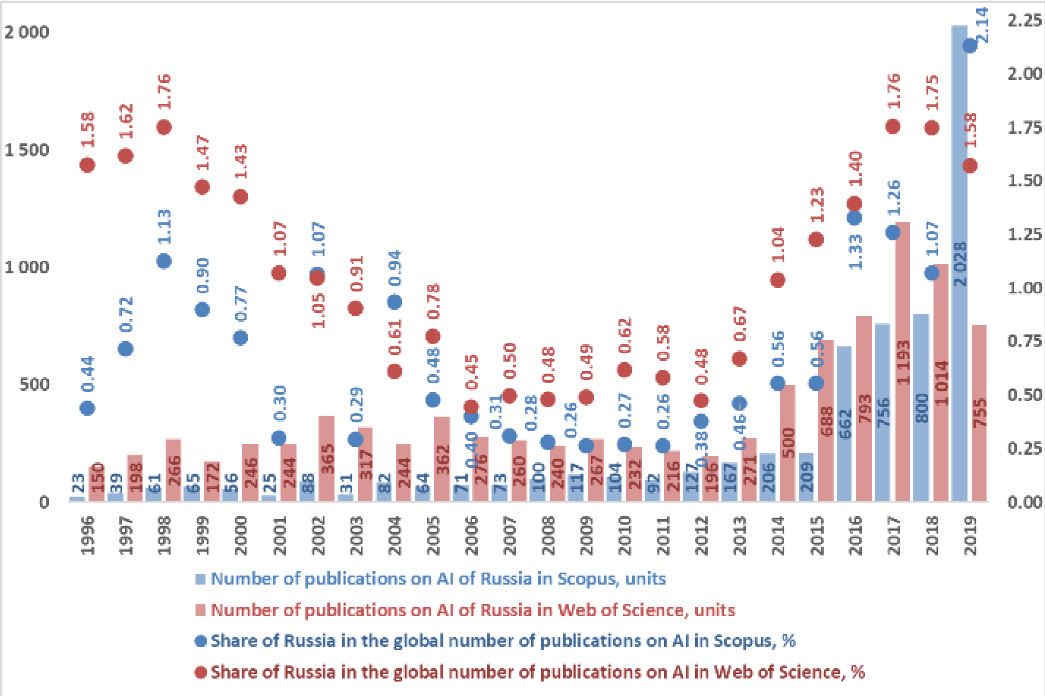
Figure 2. Number of Publications in the field of AI in Scopus by Top Countries



Source: HSE calculations based on the Scopus database.

An analysis of the WoS demonstrates similar trends, but at a lesser scale. At the same time, Russian researchers are not among actively cited authors across the globe. Citation Impact Relative to World shows a different and unstable dynamic (0.48 in 2019) over the last ten years. Another issue to be considered is percent of International Collaboration. It dropped from 40% in 2014 to 14.4% in 2019. This trend requires further detailed consideration of the internal facts that affect cooperation of Russian authors with foreign colleagues.

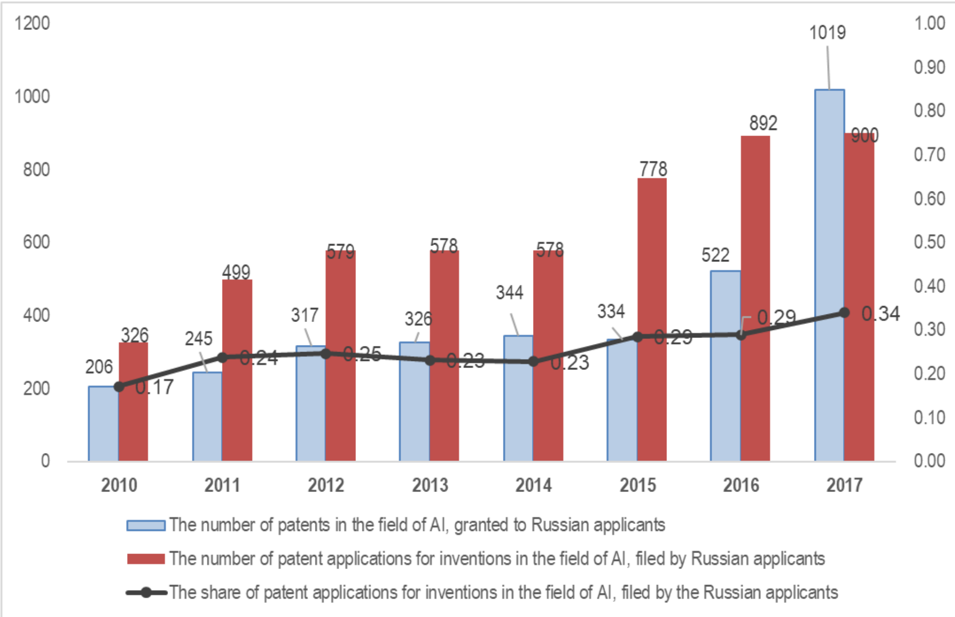
Figure 3. Main AI Publication Indicators in 1996-2019



Source: HSE calculations based on the Scopus database.

The share of patent applications for AI inventions filed by Russian applicants in the global number of patent applications in this field was 0.34% in 2017 (Figure 4). This is almost two times more than in 2010. This dynamic is positive, but insufficient for the development of domestic digital products and services. A drastic increase in interest in AI was noted in 2017 in comparison with the previous year, when almost two times more patents were granted (522 to 1,019 in 2017). However, applicants' activism in PCT documents was still low. Of the 900 patent applications for AI inventions filed by Russian applicants in 2017, only the small share was filed under the PCT procedure. The corporate sector is reluctant to engage in patent activities, which needs additional impetus from government to be presented globally. Overall, in recent years, there has been a positive trend in patent applications and academic papers, however, to achieve a meaningful improvement in global positions such efforts should be speed up both in terms of quality and quantity.

Figure 4. Number of Patents and Patent Applications Granted to Russian inventors in the field of AI



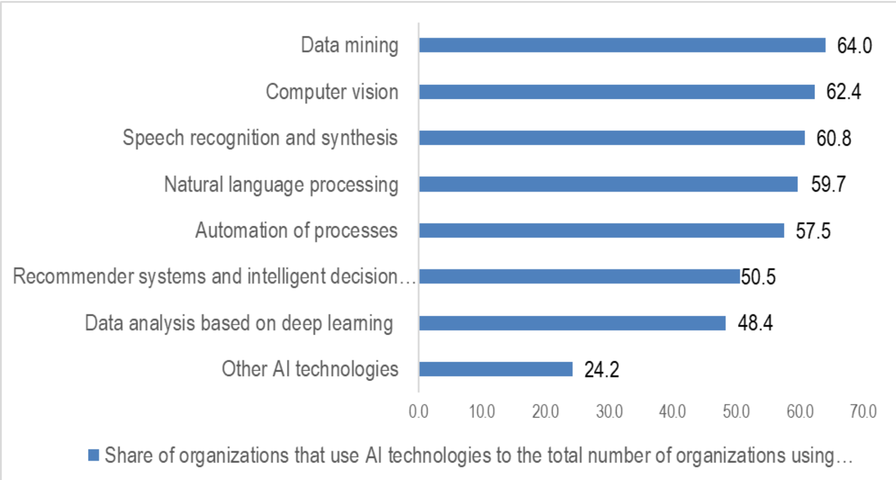
Source: HSE calculations based on the PatStat Global.

From demand side, Russian organizations are aware of AI and its effects for business. One third of the surveyed organizations use AI technologies — one among the eight provided by the questionnaire (Speech recognition and synthesis, Natural language processing, Data mining, Computer vision, Recommender systems and intelligent decision support systems, Automation of processes, Data analysis based on deep learning, and Other AI technologies). A similar study of the European Commission, realized in 2020 that covered almost ten thousand firms across the EU, states that an average rate of AI adoption is 42% for at least one of ten technologies [European Commission, 2020a]. Both in case of the Russian and European firms, in spite of slightly higher rates of the latter, the average level remains relatively low. But it is important to take into account, that the speed and rate of adoption depend upon the different technological features of sectors and characteristics of a particular AI technology.

Most Russian companies use technological solutions developed outside a firm. Roughly 20% develop AI in-house, ranging from 11.5% in Speech recognition and synthesis to 19.3% in Data mining (data analysis technologies based on machine learning algorithms). Inside the group of companies AI users, three AI technologies are the most in demand — Data mining, Computer vision, and Speech recognition/synthesis (Figure 5). They are adopted by approximately 19% of organizations from the overall sample of the surveyed organizations.

Sectoral decomposition shows that service sectors are among most intensive AI users. The ranking of the top-5 includes financial sector, ICT, public administration, wholesale and retail trade and education. These results slightly differ from the EU survey, where the ICT is the leading sector with large advantage from the second position represented by education. Human health, social work, as well as manufacturing, are also among most active users [European Commission, 2020b]. This reflects an important trend: currently Russian manufacturing industries fall behind in AI use in comparison with services. However, the greatest effects from AI adoption are expected to achieve in production industries [Higón et al., 2017].

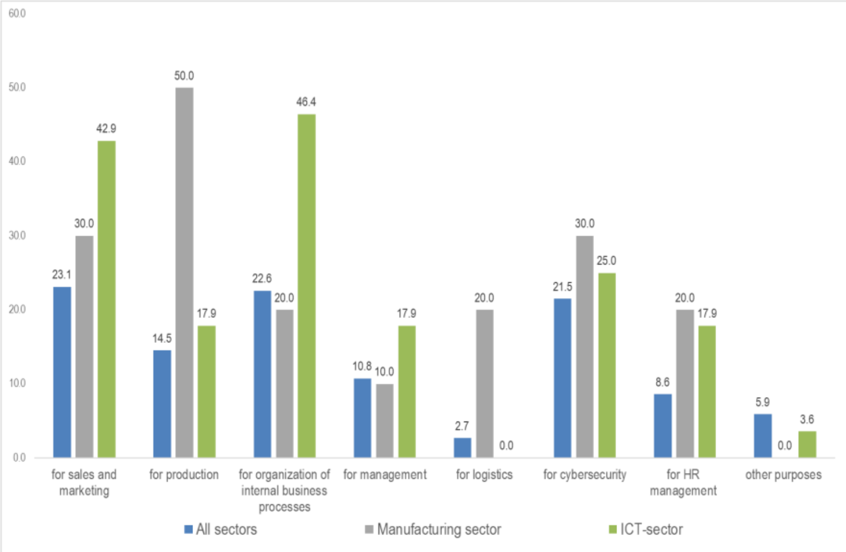
Figure 5. Share of Organizations that Use AI by Technology, %



Source: HSE calculations based on the results of the pilot survey.

The low maturity level of business in terms of AI adoption appears in the reasons for AI use, which are limited to three main functional areas — cybersecurity, internal business process organization, and marketing. Such results are robust across different sectors, both manufacturing and services. This evidences that AI is considered as a tool to improve communication with consumers and clients by processing large amount of data. As expected, AI for the production process is the largest in manufacturing comparing with other purposes, but still low in terms of the overall usage (Figure 6).

Figure 6. Share of Organizations that use AI by Purpose in the Number of Organizations using AI, %



Source: HSE calculations based on the results of the pilot survey.

Our results are largely supported by another study conducted by the ISSEK in 2019. Most industrial organizations have adopted digital technologies over the past several years. Almost half of the surveyed firms have plans to implement digital technologies in the future [ISSEK, 2020]. Firms are more optimistic about adopting digital technologies in the short (1-2 years) and medium terms (5 years). The number of those using industrial robotics is still low in comparison with the leading countries like China, the USA, South Korea, Japan, Germany [IFR, 2020]. Along with this, Russian business also demonstrates low willingness to widely adopt service robotics – only 13% over the next five years [ISSEK, 2020].

From the development side, many IT-companies focus on big data and cybersecurity technologies. Despite the fact that the plans for the next five years are quite modest, they are most often associated with the development of these among other artificial intelligence technologies. Both studies show that the gap exists between the development and use of AI. To overcome it, Russian has an actively the AI players, some companies are recognized as the leading developers globally.

Such results should not the attributed to mismeasurement. From a methodological perspective, the survey corresponds to those conducted by the EU, Canada, South Korea, and existing statistical standards. By developing the logic of the survey, the questions and technologies are designed in such a way as to provide the most precise and specific AI technological definitions and provide an unambiguous understanding, i.e. to become operationalized. The main goal of the experimental calculation is testing of the overall approach and identify the drawbacks. Taking into account the EU and other similar surveys, several additional indicators should be included in the framework. The first refers to the timing for AI adoption. As current usage remains low, it is expected that firms will implement their digitalization strategies over next five years. Factors or reasons not to use AI are another point to address [European Commission, 2020a].

The integration of the metrics describing AI talent is the next step for the system of indicator development, such as the Number of Data scientists, Data engineers, Machine Learning engineers, Artificial Intelligence engineers, and AI Researchers. In addition, there is a need to provide a basis for the measurement of AI Skill Penetration. In doing so, the relative classification and educational standards should be adopted.

Existing approaches to defining AI industry are mostly vague and do not give a clear understanding of how the numbers were obtained. Thus, the criteria of AI firms and activity should be stated in the industrial classifications, as well as other statistical guidelines. The number of AI startups or even unicorns are a plausible indicator, but do not reflect the dynamics of companies in AI field. Further methodological work should be continued in the AI discussion.

5. Conclusion and Policy Recommendations

AI has been one of the most in-demand topics on government and corporate agendas over the past several years and the shock of the pandemic solely reinforces interest in this technology. The current stage of AI presence in economic and social life requires tools for its governance and measurement. There is a range of initiatives by national stakeholders and international organizations to measure AI, but no country has already introduced a holistic system of indicators integrating the supply and demand sides.

The set of the key metrics to measure AI is rather similar across countries. It comprises publication and patent statistics, R&D investments in AI, human capital (number of specialists), and some characteristics of the industry like enumeration of startups. The business survey is a tool to receive data on adoption of particular AI technologies and the purposes of its application.

Together they represent a comprehensive, systemic and comparable indicators to measure main AI developments in a particular sector of activity or economy as a whole. Such design enables to cover AI development from basic and applied research to the ready to market technological solution. It also reveals main trends in technology dissemination and, thus, state of digital transformation in the firms. All the mentioned indicators may be presented on a regular base and introduced in large sample of countries, but needs some methodological activities on classification and standards for measurement.

Recent efforts of countries to survey AI usage evidence that statistics remain an appropriate source to define technology adoption levels in a methodologically adjusted and comparable way available for a long time span [Abdrakhmanova et al., 2016a; Abdrakhmanova et al., 2016b]. To measure development, existing metrics should be combined with new tools like big data, information from aggregators, and AI-related platforms (Reddit, GitHub). Along with new sources, advanced techniques like data mining and semantic analysis allow for new angles to investigate the role of technologies in the economy and the expected effects [Gokhberg et al., 2017; Gokhberg, 2020a]. AI complexity also fosters the development of new methods and metrics. Demand for new indicators is driven by developments in AI.

Based on the existing national practices, we offer a system of indicators to measure AI in Russia. The suggested approach offers a flexible tool to monitor and assess technology development taking into account national goals and global trends. It includes core metrics that provide essential information on state-of-the-art technologies, make it comprehensive, and may be applied for a large sample of countries. They are frequently used by national institutions and international organizations. All indicators describe the development and adoption side. The further refinement of the system should make it more balanced in terms of indicators that cover development and adoption perspectives and decompose by sectors of activity.

Due to rapid advancements in AI, the system is open for updates and new indicators. To date, not all suggested indicators are possible to calculate on the national level due to the absence of guidelines and classifications, which is the case of AI specialists. The selection of indicators requires several conditions to account for. First, it depends upon the level of existing statistical practices and introduction of digital technologies topic to it. Second, it requires synchronization with international approaches in definition and technology classification. Third, indicators should be designed in order to represent national policy and measures related to it. This requires the transformation of longstanding purposes in a set of clear and feasible set of metrics.

An experimental calculation to test indicators feasibility showed its relevance. A pilot survey is a tool to collect information on AI adoption and use at organizations from different sectors. The surveyed firms show a low level of adoption in 2019, as one third applied at least one AI-technology. Our results correlate with the trends in the European countries, where the wide usage of AI also remains limited. Along with acceleration of AI adoption, firms should be prepared to manage and properly account for AI in internal business environment.

It is important to remember that AI indicators are still at the initial stage of development and comparable studies are scant. We offer a basis and intuitively comprehensible framework for measuring AI in the economy and society. This is an important step in the development of the digital economy, the convergence of national practices, and its further improvement.

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Annex 1

Selected documents on AI from international organizations within the scope of the research

Organization	Document
European Commission	Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions on Artificial Intelligence for Europe, COM 237, 2018 European AI Strategy: EC Communication, Artificial Intelligence for Europe, 2018
European Commission Joint Research Center (JRC) of the European Commission	Artificial Intelligence. A European Perspective, 2018 AI Watch Defining Artificial Intelligence, 2020 AI Watch Methodology to Monitor the Evolution of AI Technologies, 2020
European Commission AI High-Level Expert Group on Artificial Intelligence (AI HLEG)	AI HLEG A definition of AI: Main capabilities and scientific disciplines, 2019
OECD	Oslo Manual, 2018
The AI Group of experts at the OECD (AIGO)	Scoping the OECD AI Principles Deliberations of The Expert Group on Artificial Intelligence at the OECD (AIGO), 2019
G20 Digital Economy Task Force	G20 DETF – Measurement of the Digital Economy
UNESCO the Ad Hoc Experts Group (AHEG)	First Draft of The Recommendation On The Ethics Of Artificial Intelligence UNESCO AHEG, 2019
WIPO	WIPO Technology Trends 2019 – Artificial Intelligence
ITU	Assessing the Economic Impact of Artificial Intelligence, 2018
ILO	The economics of artificial intelligence: Implications for the future of work, 2018
IEC	IEC White Paper: Artificial intelligence across industries, 2020

Source: based on [European Commission, 2018; JRC, 2018, 2020a, 2020b; AI HLEG, 2019; OECD, 2018a, 2019; G20 DETF, 2018; UNESCO AHEG, 2019; WIPO, 2019; ITU, 2018; ILO, 2018; IEC, 2020].

Annex 2

Selected national definitions of AI — countries perspective

Source	Definition
National U.S. Security Commission Artificial Intelligence Act, 2018	The term "**artificial intelligence**" includes each of the following: (1) Any artificial system that performs tasks under varying and unpredictable circumstances without significant human oversight, or that can learn from experience and improve performance when exposed to data sets. (2) An artificial system developed in computer software, physical hardware, or other context that solves tasks requiring human-like perception, cognition, planning, learning, communication, or physical action. (3) An artificial system designed to think or act like a human, including cognitive architectures and neural networks. (4) A set of techniques, including machine learning, that is designed to approximate a cognitive task. (5) An artificial system designed to act rationally, including an intelligent software agent or embodied robot that achieves goals using perception, planning, reasoning, learning, communicating, decision making, and acting.
The Japan's Plan for Dynamic Engagement of All Citizens, 2016	**Artificial intelligence (AI)** – technology that analyzes the big data gathered and accumulated as a result
The 5th Science and Technology Basic Plan, 2016	**Artificial intelligence (AI) –** technology that supports IoT, big data analytics, and advanced communication
Draft AI R&D GUIDELINES for International Discussions, 2017	**Artificial intelligence (AI**) – a concept that collectively refers to AI software and AI systems
Industrial Strategy: Building a Britain fit for the future, 2017	**Artificial intelligence —** technologies with the ability to perform tasks that would otherwise require human intelligence, such as visual perception, speech recognition, and language translation.
Germany Artificial Intelligence Strategy, 2018	**AI researchers** can be assigned to two groups: "strong" and "weak" AI. "Strong" AI means that AI systems have the same intellectual capabilities as humans, or even exceed them. "Weak" AI is focused on the solution of specific problems using methods from mathematics and computer science, whereby the systems developed are capable of self-optimization. To this end, aspects of human intelligence are mapped and formally described, and systems are designed to simulate and support human thinking.
Artificial Intelligence: «Making France a leader», 2018 Alliance Industrie du Futur, 2019	**Artificial intelligence** – not only a technological but also an economic, social, ethical, and political revolution. The **digitalization of industrial systems** makes it possible to delegate part of human intelligence to machines to increase the efficiency of industrial systems: their design, management, and control. The part of intelligence delegated under the artificial intelligence is learning intelligence from the analysis of data provided to AI (machine learning or deep learning for example) requiring data processing capabilities. The key technological elements of **industrial AI** are the collection, veracity, reliability, organization, security, and traceability of data and the construction of learning algorithms adapted to provide models for simulation, prediction, and control of industrial systems.
I-Korea 4.0 AI (Artificial Intelligence) R&D Strategy, 2018 National Strategy for Artificial Intelligence, 2020	**Artificial intelligence** – an intelligence that uses computers to implement some or all of human intelligence, such as cognition and learning. **Artificial Intelligence (AI)** is a science and technology that performs human intellectual functions with machines. AI can perform machine learning, have cognitive functions such as verbal, visual, and auditory senses, and understand and interpret the situation. It can create new added value through convergence.
Canada Survey of Digital Technology and Internet Use, 2019	**Artificial intelligence (AI)** refers to systems that display intelligent behavior by analyzing their environment and taking actions - with some degree of autonomy - to achieve specific goals. AI-based systems can be purely software-based or embedded in a device.
Report to Congress of The	**Artificial Intelligence (AI) —** machine programs that can teach themselves by

U.S.-China Economic And Security Review Commission. Chapter 4. China's High-Tech Development, 2017 State Council Notice of the 13th Five-Year National Science and Technology Innovation Plan, 2016	harnessing high-performance computing and big data and eventually mimicking how the human brain thinks **Artificial Intelligence —** human-like intelligence based on big data analysis, and the realization of humanoid vision, humanoid hearing, humanoid language, and humanoid thinking.
Australia 2030 Prosperity through Innovation, 2017	**Artificial intelligence —** computer systems that are able to perform tasks normally requiring human intelligence
Russian National strategy development of artificial intelligence for the period up to 2030, 2019	**Artificial intelligence** is a set of technological solutions that simulate human cognitive functions (including self-learning and search for solutions without a pre-set algorithm) and get results that are comparable with the results of human intellectual activity when performing specific tasks. A complex of technological solutions includes information and communication infrastructure, software, processes and services for data processing and solution search.

Source: based on [Government of Japan, 2016; Prime Minister of Japan, 2016; The Conference toward AI Network Society, 2017; GOV.UK, 2017; BMWi, 2018; The Federal Government, 2018; AIF, 2019; Ministry of Science and ICT, 2018a; The Government of Republic of Korea, 2020; KAS, 2019; Statistics Canada, 2019; U.S-China Economic and Security Review Commission, 2017; State Council, 2017; Australia Government Innovation and Science Australia, 2017; Russian Government, 2019].

Annex 3

Selected International Definitions of AI — international organizations perspective

Source	Definition
JRC, 2020 JRC Technical Report AI Watch Defining Artificial Intelligence	**Artificial intelligence (AI)** systems are software (and possibly also hardware) systems designed by humans that, given a complex goal, act in the physical or digital dimension by perceiving their environment through data acquisition, interpreting the collected structured or unstructured data, reasoning on the knowledge, or processing the information derived from this data and deciding the best action(s) to take to achieve the given goal. AI systems can either use symbolic rules or learn a numeric model, and they can also adapt their behavior by analyzing how the environment is affected by their previous actions
EU, 2018 Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions on Artificial Intelligence for Europe, Brussels, 25.4.2018 COM (2018) 237 final	**Artificial intelligence (AI)** refers to systems that display intelligent behavior by analyzing their environment and taking actions – with some degree of autonomy – to achieve specific goals. AI-based systems can be purely software-based, acting in the virtual world (e.g. voice assistants, image analysis software, search engines, speech and face recognition systems) or AI can be embedded in hardware devices (e.g. advanced robots, autonomous cars, drones or Internet of Things applications). AI system means any AI-based component, software and/or hardware. Indeed, usually AI systems are embedded as components of larger systems, rather than stand-alone systems.
High-Level Expert Group on Artificial Intelligence (AI HLEG) 2019	**Artificial intelligence** (AI) systems are software (and possibly also hardware) systems designed by humans that, given a complex goal, act in the physical or digital dimension by perceiving their environment through data acquisition, interpreting the collected structured or unstructured data, reasoning on the knowledge, or processing the information derived from this data and deciding the best action(s) to take to achieve the given goal. AI systems can either use symbolic rules or learn a numeric model, and they can also adapt their behavior by analyzing how the environment is affected by their previous actions. As a scientific discipline, AI includes several approaches and techniques, such as machine learning (of which deep learning and reinforcement learning are specific examples), machine reasoning (which includes planning, scheduling, knowledge representation and reasoning, search, and optimization), and robotics (which includes control, perception, sensors and actuators, as well as the integration of all other techniques into cyber-physical systems).
JRC, 2018 Artificial Intelligence. A European Perspective	**AI** refers to any machine or algorithm that is capable of observing its environment, learning, and based on the knowledge and experience gained, take intelligent actions or propose decisions. The autonomy of decision processes and interaction with other machines and humans are other dimensions that need to be considered.
European AI Strategy: EC Communication, Artificial Intelligence for Europe, 2018	**Artificial intelligence (AI)** refers to systems that display intelligent behavior by analyzing their environment and taking actions – with some degree of autonomy – to achieve specific goals.
Oslo Manual 2018 Guidelines For Collecting, Reporting and Using Data On Innovation	**Artificial intelligence (AI)** describes the activity and outcome of developing computer systems that mimic human thought processes, reasoning, and behavior.
ITU, 2018 Assessing the Economic Impact of Artificial Intelligence	**AI** can be considered an umbrella term covering a group of technologies that are capable of autonomously performing tasks that, if performed by a human being, would be considered to require intelligence.
JRC, 2020 AI Watch Methodology to Monitor the Evolution of AI	**AI system** — a computer system (e.g., algorithm, application, computational model, etc.) capable of performing tasks that involve perception, communication, reasoning, learning, planning and other

Technologies	perceptual or cognitive capabilities. AI systems are usually powered by machine learning, natural language processing, machine vision, deep learning, rule inference, etc. and applied to a wide range of applications such as personal assistants, self-driving cars, robotic cleaner, or automated translators.
Scoping the OECD AI Principles Deliberations of The Expert Group on Artificial Intelligence at the OECD (AIGO), 2019	**An AI** system is a machine-based system that is capable of influencing the environment by making recommendations, predictions or decisions for a given set of objectives. It does so by utilizing machine and/or human-based inputs/data to: i) perceive real and/or virtual environments; ii) abstract such perceptions into models manually or automatically; and iii) use model interpretations to formulate options for outcomes.

Source: based on [JRC, 2018, 2020a, 2020b; European Commission, 2018; AI HLEG, 2019; OECD, 2018a, 2019; ITU, 2018].

Annex 4

Indicators to Measure AI by Countries

Organization	Document	Indicators
NSF, 2020	The State of U.S. Science and Engineering 2020	R&D spending of seven AI-focused corporations AI scientific publications, by area or technology Citation impact of AI scientific papers by selected region or country AI scientific publications, by area or technology Adoption of AI capabilities, by industry Company adoption of AI technologies, by country, region, or economy Job openings on Monster.com, by AI skills required Venture capital investment in AI, by selected region, country, or economy AI companies and deals financed by venture capital in China and the United States Total AI funding by year
USPTO, 2020	US Patent and Trademark Office (USPTO) report "Inventing AI: Tracing the emergence of AI with U.S. patents	US patent applications for AI The volume and share of public AI patent applications The volume of public AI patent applications by AI component Diffusion of AI across patent technology subclasses, overall and by AI component Annual percentage of US inventor-patentees and patent owners with AI patent Granted AI patents by inventor-patentee location
Industrial Strategy Council, 2020	Sector Deals Success Metrics	Public attitudes towards the impact of increasing the use of AI in the UK, (%) Preparedness to use AI in the delivery of public services, G7 Countries, 2019 GVA per worker by sector with a Sector Deal Number of UK jobs in each sector covered by a Sector Deal Public sector adoption readiness Prevalence of open data
AIF, 2020 (a)	Enquête Nationale sur l' Intelligence Artificielle	Level of digital integration Horizon of AI utilization Annual investments for AI Competences for AI in a firm A level of AI -ecosystem in a firm
European Union, 2019	The AI Techno-Economic Segment Analysis. Selected Indicators	Number of AI players in selected types of activity (% over world total) – patent and frontier research Occurrence of AI topics (%) by geographical zone Higher presence of entities (firms or research organization) Number of project collaborations per region (in EU funded projects, Patenting and Frontier Research)
Statistic Canada, 2019	Survey of Digital Technology and Internet Use	Number of firms using AI Number of firms using AI technologies Number of firms using AI by reasons
Ministry of Science and ICT, 2017	The Innovation Growth Engine	Number of AI-specialized companies Technological competitiveness
RIETI, 2019	Digitalization of manufacturing process and open innovation: Survey results of small and medium sized firms in Japan	Use of IT such as AI/machine learning, IoT consortium, data communication with customer and/or supplier and provision of digital service related to product
Future of Humanity Institute, University of Oxford, 2019	China's Current Capabilities, Policies, and Industrial Ecosystem in AI	Patent filings and scientific publications related to AI R&D investment in AI Number of "AI practitioners" (AI talents)
China Institute for Science	China AI Development Report	AI Papers Clarivate Analytics' Web of Science database AI industry

and Technology Policy at Tsinghua University, 2018		AI patent applications Global distribution of AI patents Top assignees from the academia and from the business world International AI talent (Researchers) Global distribution of AI talent Distribution of Chinese AI talent Chinese AI talent Chinese AI talent by research area AI enterprises Average age of AI enterprises by province (unit: year)

Source: based on [NSF, 2020; USPTO, 2020; Industrial Strategy Council, 2020; Government of Canada, 2020; AIF, 2020; INSEE, 2019; Barometer CIRANO, 2018; Ministry of Science and ICT of the Republic of Korea, 2020; INSEE, 2019; European Union, 2019; Statistic Canada, 2019; Ministry of Science and ICT, 2017; RIETI, 2019; Future of Humanity Institute, 2018; China Institute for Science and Technology Policy at Tsinghua University, 2018].

Annex 5

Main Indicators of the Selected Global AI Indices

	I. DEVELOPMENT
Publications	**AI Index 2019 by Stanford's University Human-Centered AI Institute by the HAI** Number of AI journal papers per capita Number of AI journal papers Number of AI journal citations per capita Number of AI journal citations Number of AI journal references per capita Number of AI journal references Number of Deep Learning papers per capita Number of Deep Learning papers Comparative Advantage of Deep Learning Papers **Global AI Index 2019 by Tortoise** Number of Accepted Authors of Top Artificial Intelligence Journal papers Number of Paper Citations Average Number of Top Paper Citations Number of AI Publications Average Number of AI Articles Maximum Rank on H-Index (H-Index) Number of Artificial Intelligence 'Laboratories' or Equivalent Number of AI Societies
Patents	**AI Index 2019 by Stanford's University Human-Centered AI Institute by the HAI** Number of AI patents/patents per capita Number of AI patent citations/patent citations per capita Number of AI patent references/patent references per capita **Global AI Index 2019 by Tortoise** Average days taken for approval by patent office Number of filed AI patents by applicant Number of filed artificial intelligence patents by inventor Number of granted artificial intelligence patents by applicant Number of granted artificial intelligence patents by inventor Patent Acceptance Rate for Applicants Patent Acceptance Rate for Inventors
Conferences	**AI Index 2019 by Stanford's University Human-Centered AI Institute by the HAI** Number of AI conference papers/conference papers per capita Number of AI conference citations/conference citations per capita Number of AI conference references/conference references per capita **Global AI Index 2019 by Tortoise** Number of Accepted Authors to Artificial Intelligence Conferences Position on AI Model Leaderboards
Investments	**Government AI Readiness Index 2020 by Oxford Insights and IDRC** Company investment in emerging technologies **AI Index 2019 by Stanford's University Human-Centered AI Institute by the HAI** Total AI Private Investment AI Private Investment per capita **Global AI Index 2019 by Tortoise** Total Earmarked Spend on Artificial Intelligence Total Funding of Artificial Intelligence Companies
Human capital	**Government AI Readiness Index 2020 by Oxford Insights and IDRC** Graduates in STEM Quality of engineering and technology higher education Digital skills Knowledge-intensive employment

	AI Index 2019 by Stanford's University Human-Centered AI Institute by the HAI Percentile Rank of AI Skills on Coursera AI (% of total enrollment) Relative Skill Penetration Number of unique AI occupations (job titles) **Global AI Index 2019 by Tortoise** Number of IT/SCI Undergraduates/pop. Number of IT/SCI Graduates/pop. Number of STEM Graduates/pop. Number of 'Artificial Intelligence' MeetUp Users Number of Data scientists/Data engineers Number of Machine Learning engineers/Artificial Intelligence engineers Number of Researchers Average Data Scientist Wage Number of Universities offering 'Advanced Artificial Intelligence' courses Number of Universities in Top 100 Computer Science Number of Universities in Top 100 Physical Sciences
Ecosystem	**Government AI Readiness Index 2020 by Oxford Insights and IDRC** Number of technology unicorns Market value of public technology companies **Government AI Readiness Index 2020 by Oxford Insights and IDRC** Number of Startups Funded Number of funded startups per capita **Global AI Index 2019 by Tortoise** *Startups and venture capital* Average Artificial Intelligence Company Funding Funding of Artificial Intelligence Startups Number of Artificial Intelligence Startups/companies/companies on a nation's stock exchange /Unicorns *Technical* Cloud adoption of AI professionals Python Package Downloads R Package Downloads Alexa MOOC's Website Rank Percentage Contribution to the Training of Machine Number of Kaggle Grandmaster and Master contributors Number of GitHub Commits/"Stars" Number of Stack Overflow Questions/Answers Stack Overflow Ratio *Institutional* Open Data Barometer Score Cybersecurity Score Presence of right to explanation Commits on popular open source AI packages Collaborators on open AI platforms ISO AI Committee Participation
	II. ADOPTION AND USE
Adoption	**Government AI Readiness Index 2020 by Oxford Insights and IDRC** Value of trade in ICT services/goods (per capita) Computer software spending **Government AI Readiness Index 2020 by Oxford Insights and IDRC** Robot Installations (in thousands of units) AI hiring index

Source: based on [HAI, 2019; Tortoise, 2019; Oxford Insights, IDRC, 2020].

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