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Landscaping the Artificial Intelligence ecosystem

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Abstract. Artificial Intelligence (AI) is spreading throughout our economies and societies in multiple ways, but the absence of standardized classifications prevents us from obtaining a measure of its pervasiveness. AI is not a part of a specific sector, but rather a transversal technology because the fields in which it is applied do not have precise boundaries. In this work, we address the need for a deeper understanding of this complex phenomenon by investigating economic players' involvement in industrial activities aimed to supply AI-related goods and services, and AI-related R&D processes in the form of patents and publications. In order to conduct this extensive analysis, we use a complex systems approach, which identifies the core dimensions that should be considered. Therefore, by considering the geographic location of the involved players and their organisation types (i.e., firms, governmental institutions, and research institutes), we (i) provide an overview of the worldwide presence of AI players, (ii) analyze the demographic structure of AI firms (ii) investigate the patterns in which AI technological subdomains subsist and scatter in different parts of the system, and (iii) reveal the size, composition, and topology of the AI R&D collaboration network. Based on a unique data collection of multiple micro-based data sources and supported by a methodological framework for the analysis of techno-economic segments (TES), we capture the state of AI in the worldwide landscape in the period 2009–2018. As expected, we find that major roles are played by the US, China, and the EU28. Nevertheless, by measuring the system and describing different aspects of the AI landscape, we unveil elements that provide new, crucial information to support more conscious discussions in the process of policy design and implementation. This work contributes to AI Watch[2], the European Commission knowledge service to monitor the development, uptake and impact of AI for Europe.

1 INTRODUCTION

The general aim of this study is to map a techno-economic segment from a multidimensional perspective, providing an overview of the worldwide AI landscape in the last decade. To establish a comprehensive landscape, we target both industrial and R&D activities. This helps to capture economic players that participate in the landscape with a variety of foci, interests and impact capacity. Therefore, players' economic activities of interest for the analysis of the TES ecosystem include R&D processes (research and innovative developments), general economic processes (industrial production, trade, marketing and other services), firms funding (venture capital funds or other types of investment).

The analysis starts from a micro-based perspective that allows us to capture both pertinent activities (e.g. research projects, firm activities) in the AI technological domain and the involved players. The present work aims to provide statistical and quantitative answers on how to measure the AI ecosystem as a complex techno-economic segment.

The work aims to answer the following research questions: (i) Who are the players involved in the supply and evolution of AI worldwide? (ii) What type of firms are involved in the AI ecosystem? (iii) How do players interact and behave in the techno-economic space that is considered? (iv) Which types of artifacts are being developed in this field?

Section 2 briefly describes the methodology applied and reveals the sources of the unique and purpose built database. Section 3 describes the results in order of the research questions raised and Section 4 concludes and gives perspectives for future research paths.

2 METHODOLOGY AND DATA

The unit of the analysis is the player. This can be a company, university, research institution or governmental authority. A player has an active role in the AI segment, with the capability to influence its economic development and future evolution. The focus is set on the organizations, and not on individuals, namely the applicant organization owning the invention in the case of patents, authors' affiliation in conference proceedings, companies, governmental entities, etc.

To target the AI TES ecosystem and collect representative data about AI-related R&D and industrial activities, we target a list of vertical sources (AI-specific sources), and a list of horizontal databases (general, not-AI specific sources) containing information regarding any technology. The latter are queried in order to identify those activities relevant to the selected technological domain, AI, and their corresponding players. The sources cover a wide range of types of economic activities and geographic areas:

1. Vertical sources (AI specific sources):

1.1. For production and trade (companies' repositories including startups, firms financed by venture capital, etc.):

1.1.1. AI startups from AngelList, a platform joining about 27,500 companies and startups aiming at facilitating contacts with angel investors and job-seekers (angel.co/artificial-intelligence)

1.1.2. The Global Artificial Intelligence Landscape by Asgard and Roland Berger 2018, a set of data and information on the AI segment collected for investment purpose and targeting mainly software startups (asgard.vc/global-ai//)

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[2] https://ec.europa.eu/knowledge4policy/ai-watch

1.1.3. CB Insights, a platform collecting data on companies, venture capital, startups, etc., in new or dynamic markets (cbinsights.com)
1.1.4. Other sources: AAI Job Fair, AI & Big Data Expo Global 2018, Allianz Global Artificial Intelligence, AI Breakthrough Awards 2018
1.2. For research activity:
1.2.1. Frontier research: the articles and authorship information are collected from the top 10 AI international conferences. We consider fractional count to avoid double counting of publications submitted by several authors from different affiliations (more details are available in Samoili et al., 2020).

2. Horizontal sources (general sources):
2.1. For innovation activity:
2.1.1. EPO PATSTAT, a widely recognised database containing bibliographical data relating to more than 100 million patent documents from leading industrialised and developing countries (epo.org). The documents used in the study refer to priority patent applications. We consider fractional count to avoid double counting of patent applications submitted by several applicants.
2.2. For research activity:
2.2.1. CORDIS data repository collecting information on EU funded projects, from which projects from FP7 and H2020 have been selected (cordis.europa.eu/projects). This source is only considered for a deeper analysis in the European comparison, but is discarded in all worldwide comparisons to avoid a Eurocentric bias in this analysis. As with patent applications, fractional counting is applied to the EU-funded projects.
2.3. For production and trade:
2.3.1. BvD Orbis, the Bureau van Dijk (now a Moody's Analytics company) database collecting financial strength indicators, company reports and ownership information about around 300 million companies worldwide (bvdinfo.com)
2.3.2. Crunchbase, a platform listing business and investment information about private and public companies (crunchbase.com)
2.3.3. Venturesource by Dow Jones, a comprehensive global database on companies backed by venture capital and private equity, including information on venture capital transactions (dowjones.com/products/ venturesource-2)
2.3.4. VentureRadar, a data collection including information and interpreting innovation and growth signals of companies discovered by means of their digital presence (ventureradar.com).

Each document, collected from the described data sources, contains information about the activity (e.g. the description of the activity, date of the activity) to which they are associated and the player/s involved in it. In the initial part of the ETL (Extract, transform, load) process, database queries with terms relevant to the technology are performed to acquire activities and metadata of identified sources. The text-mining part is conducted with a scalable search for the technology in question, through a search engine based on the Lucene library (Elasticsearch engine version 2.4.6), and then results are evaluated based on a series of statistical indices. The objective is to detect and select the most representative R&D and industrial activities of an emerging technology.

The information finally considered for the analyses of the AI worldwide ecosystem from 2009 to 2018 presented in this report contains 57,722 documents by means of which 34,009 players are identified.

Based on this data the analyses of the AI techno-economic segment ecosystem consist of: (i) descriptive statistics allowing an overview of the ecosystem's landscape; (ii) demographic analysis of industrial players; (iii) network analysis allowing the investigation of players' R&D collaborations, and (iv) topic modelling techniques allowing the study of thematic and technological key areas of strength (for more extensive elaboration on the applied topic and network analysis see Righi et al., 2020).[3]

3 Results: The AI Ecosystem

This section presents the results in order to describe the landscape of AI.

3.1 Players Worldwide

The main leaders in the AI technological landscape during the last decade are the US, China and EU: three out of four worldwide players involved in AI techno-economic processes are located in these areas. These are followed by India, South Korea, Canada and Japan. The latter appears as a follower because of a slowdown in AI in the last ten years (WIPO, 2019). In order to account for the size of the countries' economies, the ratio of number of players over GDP in € billion is measured. Considering the ratio of number of player divided by GDP-PPS, Israel emerges with a considerable role in AI, a prominent position also reported by other studies (Statista, 2017; WIPO, 2019). Moreover, two groups of countries are identified among the top-10 areas per number of AI players: one with a medium ratio (Canada, South Korea, US, China and EU28), and another with a relatively low ratio (India, Japan and Russian Federation). The low ratio can be explained by the delay of AI uptake in their national economies, with the exception of Japan, whose modest position is caused by the stagnation of the sector during the last two decades (WIPO, 2019).

3.2 Industry Focus

The first group of firms of the AI ecosystem are firms with a core business related to AI, so mainly supplying AI-related goods or AI-services. The other group of firms of the AI eco-system are enterprises, which use AI -as evidenced by AI research or patenting activities of the firm. This can be either to offer goods or services with embedded AI (e.g. film streaming service with an AI powered recommendation systems) or developing AI to improve their management or production processes.

The AI industrial landscape is mainly dominated by the US, China and the EU28, hosting almost 75% of worldwide AI firms. Following the top three areas, India and Canada reveal to be relevant countries in the AI landscape, along with South Korea. The position of Japan, which in terms of number of firms involved in the supply of AI-related goods or services is modest, is very relevant regarding its patenting performance. The distribution of innovating firms, i.e. with at least one AI patent application filed during the observed period, shows China in a very strong leading position. Almost 60% of all AI patenting firms are from China. Only 6.5% are from the EU28, considerably less than the US and just behind South Korea.

3 For own exploration of this database a dashboard is available at

The set of firms involved in AI are discussed with reference to their age, size, sector of economic activity, and their role in the AI ecosystem for the most important areas (Canada, China, EU28, India, Japan, South Korea, USA).

3.2.1 Firm Age

India and the EU28 hold the largest share of youngest firms involved in AI (up to 5 years), which is around 40% and 30% respectively. The same age group, for all other areas, accounts for a much smaller percentage, and it is never higher than 15%. Also the percentage of EU28 firms between 5 and 10 years is remarkable (30%) and presents values similar to those presented by South Korea (34%) and India (26%). In conclusion, the involvement of EU28 firms in AI seems to be a relatively recent phenomenon that strongly took off only in the last ten years.

When moving the attention to the firms founded between 11 and 20 years ago, the areas presenting the largest percentages are (in decreasing order): China, South Korea and the US, which therefore appear to have started their involvement in AI in the first decade of the new millennium. While South Korea and the US present more balanced proportions among the percentages of firms born in different periods, China presents a massive number of AI firms (almost 50%) born approximatively in the first decade of the century.

Finally, the largest percentage of old firms (born at least 20 years ago) is held by Japan (50%), which seems to have had a pioneering role in the development of AI industry. Another interpretation is that already established firms may have successfully taken up AI in later stages. This suggests that while in Japan AI is significantly spread in the economy, this process didn't lead to a wave of new firms foundation, as testified by the small number of active firms detected in the period 2009-2018 and by the low share of Japanese firms detected to be born in the last 5 or even 10 years.

3.2.2 Firm Size

Regarding the size of firms, the analysis reveals the presence of larger firms in China and Japan. In particular, half of Chinese companies are large or very large. The EU28, South Korea, Canada and the US show a different size structure, with a higher involvement of small firms that accounts for about 75%, in each of these areas. This gives evidence of a different pattern regarding the manner in which AI techno-economic processes and industry are structured and developed in these economies.

3.2.3 Economics Sector

The consideration of the main economic sector in which AI TES firms are operating, reveals different patterns among major areas. First of all, the large percentage (50%) of AI Chinese firms belonging to the Manufacturing sector is substantially higher than in any other area. This result confirms the traditional strength of China in the ICT manufacturing sector in all macro-economic variables (Mas et al. 2019) and what observed on Chinese trade activity: the main involvement of China in AI is related to the production and development of hardware, not only in the form of complete computers but also chips, electronic components and sensors (Righi et al. 2017). This is also in line with what observed in topic analysis, where China reveals to have involved strong specialisation in Computer vision and Connected and automated vehicles (CAVs), which are technological subdomains strongly related to manufacturing processes.

On the other hand, the EU28, the US and India present a sensibly large percentage of firms belonging to the Information and Communication (ICT) sector and to the Professional, Scientific and Technical Activities. This is in line with what is observed in the analysis of the key areas of specialization, where the EU28, the US and India differ with respect to China especially because of their leading involvement in AI Services.

Regarding South Korea and Japan, they present a more balanced distribution between firms belonging to different sectors. In particular, South Korea presents more than 30% of firms in the Manufacturing sector, reflecting the strength of the ICT manufacturing sector in this country (Mas et al. 2019). South Korea, as well as the EU28, appears to have only a modest percentage of firms from the Wholesale and Retail Trade, a sector in which the US, Canada, Japan and China have a more prominent presence.

3.2.4 Developing Capacity and Use of AI

In this subsection we differentiate between firms according to their degree of developing capacity and use of AI. For this purpose, we have grouped AI firms into three categories based on their business description and patenting activity. This categorisation allows the distinction of different uses of the AI technology in the economic activities firms perform.

i. Firms having a core business related to AI and developing AI patents ("Big Tech", "AI firms with AI patents",). These are companies whose core business is strictly linked to AI, and which are producing technological developments in the field of AI. These are mainly large hi-tech companies that have placed AI at the core of their business. They make up 1% of all AI firms and more than 50% of them are active in the ICT sector. Examples of firms that qualify for this group are Alcatel and Deepmind in the EU; Tencent and Baidu in China; Google, Facebook, Microsoft or Salseforce in the US. While the US has the highest number of firms in this category, Japan and South Korea have the highest percentages of big AI tech firms.

ii. Firms having a core business related to AI and not developing patents ("AI Firms without AI patents", yellow in Figure 17). Firms which are mainly based on AI technologies and whose main economic activity deals with the supply of AI services, solutions and products, but that do not contribute with the innovative technological developments. They represent the majority of AI firms (67 %), they tend to be smaller and younger firms and are disproportionately active in the sector Professional, Scientific and Technical activities, though the majority (34%) belong to the Information and Communication sector.

iii. Firms whose core business is not related to AI but are developing AI-related patents ("Other Firms with AI patents",. These are firms that are integrating AI technologies in their products or production processes. Even though AI is not their main economic activity, the firms in this group have a crucial role in contributing to the implementation and development of AI throughout the whole economy. 31% of AI firms belong to this category, out of which more than 40% are active in the manufacturing sector. Examples are Dyson, Shazam, Hisense, China Petroleum, Netflix and Bank of America.

The data show a very varied distribution regarding business activity in AI across geographical areas. On the one hand, in the US and the EU28 the large majority of firms have a core business that is AI-related and they are not involved in the core development of the technology, as they do not patent. On the other hand, China and South Korea have a large quantity of firms that contribute to technological development without having a core business focused on AI, and much less firms that can be classified as core AI-firms. Considering the textual analysis presented in section 3.4 and the analysis of firms' economic sector, this evidence confirms that the EU28 and the US are characterized by having much more economic activities providing AI services and solutions (e.g. data processing, Machine learning (ML) platforms), both to private customers (B2C) and to other businesses (B2B). On the other hand, Chinese firms reveal to be much more focused on the technological development of the fundaments of AI, e.g. concerning the integration of processors and sensors in more complex machines (for instance in Natural language processing (NLP), Computer vision, CAVs) and the development of new algorithms (i.e. machine learning).

3.3 Research Focus and Networks

The R&D score proposed in this subsection is computed by considering the fractional count of the number of activities in which each player participated (both shared activities and individual activities). As several types of activity are considered (patents and publications), presenting distributions with different scale and variance, the number of activities is normalised by type to the interval [0,1]. Subsequently, for each player, the corresponding normalised values are summed. The sum and the average of the players' R&D scores are calculated based on the geographical area where the players are located.

When the sum of players' R&D score is considered, three geographical areas emerge: China, the US and the EU28, holding very different scores. The R&D score of China is approximatively twice the US' score and almost four times that of the EU28. This indicates that the volume of Chinese AI R&D activities is considerably higher than other countries'. On patenting Chinese AI patents prevail. Regarding publications, although the number of Chinese articles is closely followed by the US, the research impact is reversely proportional according to their H-index of research publications (Ding 2018), although the impact is not captured by the R&D score.

To further analyse the R&D performance, the average R&D score by area is computed. This reveals that players from the US are the most active, and that Canada has a considerable role. The Canadian presence can be explained mainly by the AI experts concentration in the region of Ontario (Toronto) with high ranking universities and innovation hubs. According to this indicator, China ranks second. The overall activity of European players is significant, but the individual propensity to develop patents and/or publications is modest. Not only the patenting players in the EU28 are less than those in the US and China, but on average they also tend to develop less patents (1.6 patent applications per player in the EU28, vs 3.3 patent applications per player in the US and 2.8 in China).

3.3.1 R&D Openness in the EU

This section discusses the structure of collaborations at a regional levelin the EU. For this purpose patenting, frontier research publications, and EU-funded projects are compared. The top 20 EU28 regions by number of players in AI-related R&D activities are studied regarding their peers' location and assess the openness and internationalisation of these regions. The location of the peers is considered in three categories, i.e. within the same region, in a different region of the same country, or in a different country.

The most common type of collaboration is with out-of-country players; however, each sub-network shows a different pattern of peers' location. The sub-network of EU-funded projects activates almost exclusively out-of-country collaborations. The distribution of the number of collaborations over the different regions is more uniform than the respective distributions for patenting and frontier research. This suggests that EU funded projects are able to foster a homogeneous and balanced involvement in AI.

Regarding the collaborations in patenting activities, the considered regions present a higher propensity to develop collaborations within the same region, in comparison with the other two subnetworks. This is the case of Västsverige (SE23) (85%), Karlsruhe (DE12) (80%), Comunidad de Madrid (ES30) (50%), Rhône-Alpes (FR71) (50%), and País Vasco (ES21) (86%). Regarding collaborations with other regions belonging to the same country, the regions with the highest propensity to develop this kind of collaborations are all located in Germany: Stuttgart (DE11) (57%), Köln (DEA2) (40%), Darmstadt (DE71) (38%), Berlin (DE30) (35%), and Oberbayern (DE21) (33%). This confirms the intense collaborative structure among German players.

Regarding the collaborations in publications, a relatively larger percentage of collaborations with players from the same country but not the same region (with respect to collaborations in other types of activities) is spotted. Therefore, academic research networks of the largest European regions are more structured within the country than other types of R&D collaborations. There are five regions with more than the 25% of collaborations with players from the same country but not the same region. These are Île de France (FR10) (27%), Oberbayern (DE21) (26%), Berlin (DE30) (28%), Zuid-Holland (NL33) (27%), and Rhône-Alpes (FR71) (32%). Given also the overall amount of activities developed by the players of these regions (namely 112, 31, 31, 15, and 44 respectively), these regions play a noticeable role within their country in terms of frontier research in AI.

3.4 Topics

Another layer of the comprehensive analysis of the AI landscape is the analysis of the textual content of worldwide R&D and industrial activities. By means of a machine learning approach (Latent Dirichlet Allocation) implemented on the collected corpus of documents, six non-mutually exclusive thematic key areas are identified.[4]

3.4.1 Key thematic areas

— Natural Language Processing: contains activities related to machine identification and generation of information from and

[4] For more details on the methodology see [4]

to written and spoken human communications. This information can be retrieved, analysed and also generated as speech signals by a functional unit, with applications varying from speech-to-text to speech synthesis, machine translation, text summarisation, etc.

— Computer Vision: refers to activities that identify human faces and objects in digital images, as part of object-class detection. In this task, the locations and sizes of the faces and objects are also identified (e.g. pedestrians, vehicles, etc.). Applications of this thematic topic are found in biometrics, human-computer interaction, surveillance, photography and other areas of the computer vision field.

— Machine Learning: as the basic algorithmic approach to achieve AI taking advantage from different learning paradigms: reinforcement, supervised, semi-supervised, unsupervised. It covers the theoretical concepts and libraries used in AI for production and research, e.g. convolutional neural networks, stochastic reinforcement learning, machine learning libraries (e.g. TensorFlow, Keras, PyTorch), etc.

— Robotics and Automation: gathers activities related to the application and research of the technological intelligent tools that aim to assist or substitute human activity, or to enable actions that are not humanly possible (e.g. medical robots), in order to optimize technical limitations, labour or production costs. This topic involves all the phases of design, construction and operation of robotic systems. Communication between digital systems, performance of remote and local operations in the medical, technical, industrial, teaching, agricultural fields and other applications are included (e.g. robotic arms, drones, commercial robots as customer assistants, domestic robots, etc.)

— Connected and Automated Vehicles (CAV): considers activities relative to the technologies of autonomous vehicles, connected vehicles and driver assistance systems, in all the phases from theoretical background, to design and construction and communication. All the automation levels (no driver assistance in driving, to no human assistance in driving) and the different communication technologies (V2V, V2C, V2I, V2P, V2X) are taken into account.

— AI Services: includes activities providing databases, software, visualisation and other services allowing the deployment and maintenance of applications. These applications cover a variety of needs in a cloud, the web, or in local machines (e.g. for financial advisers, travel planning, business decisions, cloud storage services, Virtual Private Network (VPN) clients, etc.). This area includes AI related activities covered by Infrastructure as a Service (IaaS), Platform as a Service (PaaS), and Software as a Service (SaaS).

3.4.2 Worldwide AI specialisation

The thematic Revealed Comparative Advantage (RCA) indicator is employed to explore and analyse the specialisation of geographic areas in the AI field. It measures a country's specialisation within the AI domain in comparison with the world average specialisation in that area.

The RCA index of the EU28 demonstrates a comparative advantage in the thematic areas of Robotics and Automation, and of AI Services with values of the indicator above world's benchmark. When considering all worldwide Robotics activities, also the US, Canada, Singapore and Israel have prominent roles, with revealed comparative advantage on this area. Regarding the AI Services thematic area, the EU's advantage may be explained by the growth of the software industry, which is five times the growth of the rest of the European economy (Atomico, 2018). Another strong area for EU28 is Machine learning, the "know-why"-oriented thematic area. Although the EU does not reach the world average, it is among the three top world leaders just below the benchmark and China. Connected and Automated vehicles is not among the EU28's specialisations in relative terms.

The US has a comparative advantage in three AI areas: AI Services, Robotics and Automation, and NLP. In these three areas, the US hosts between 30% and 45% of worldwide activities. The country has also a strong position in ML, hence establishing its interest and specialisation in the "know-why" of the AI technology. The country is relatively better positioned in the CAVs area than in Computer vision, but both with an important part in absolute terms, since this country ranks second in number of activities in this area. The US has strong presence, although not always leading, in almost all the identified AI key areas. As one of the two colossi in AI, such an extensive presence in all areas is expected.

China's areas of specialisation are Computer vision, CAVs, and the theoretical aspect of AI development, Machine learning. In particular in ML, China appears as the only country among the top having a RCA indicator above the world benchmark. China is not only specialised in these areas, but is also the world leader in number of AI activities in the three of them, hosting more than half of the worldwide activities in these thematic areas.

4 CONCLUSIONS AND PERSPECTIVES

This work studies the vast amount and great variety of activities in the landscape of AI in the last decade, 2009-2018. It presents a methodology to identify and analyse the firms, research institutes and governmental institutions playing an important role in the AI industrial and research landscape.

The quantitative evidence presented demonstrates the dominating positions of the US, China and the EU, but also describes the interesting roles of some emerging AI economies such as India, Singapore or Israel. Both China and the US are leaders in different aspects of the AI world. US is the leader in industrial activity and in the AI thematic areas of AI Services, Robotics and Automation, and to an extent in Natural language processing. China has a very strong governmental involvement and is the clear leader in Machine learning, Computer vision and Connected and Automated vehicles. Overall, the activity of both US and China indicates that they have an extensive presence in all AI areas.

The EU has a more targeted role in the AI landscape. The data presented in the report confirms EU's strong positioning in Robotics and Automation, and in AI Services, with a revealed comparative advantage in both areas. It additionally has an extensive, spread and collaborative research sector (sizeable even when EU-funded projects with AI content are not considered). However, the EU compares less favourably regarding AI firms presence. A look into the EU firm structure reveals the comparatively lower propensity of AI firms to perform innovative activities in the AI field, submitting less AI related patents, and a large proportion of AI firms active in services sectors like Information and Communication or Professional, Scientific and Technical activities. These findings suggest a slower AI penetration in the remaining sectors relative to the US and China. The AI firm demographics of the EU show a young firm population, which on the one hand points to AI entrepreneurial activity, but on the other hand may mean limited activities of established firms in developing AI for their businesses. In the analysed period, UK played an undisputed role in the EU landscape. It is home to the highest number of AI players and takes the leadership in most AI thematic areas within the EU.

Other countries that outstand both in relative and absolute terms in one or more thematic areas are South Korea and Japan, which excel in Natural language processing, Computer vision and Connected and Automated vehicles, and India in AI Services and to an extent in Robotics and Automation.

Talent is a fundamental piece for the development of disruptive technologies and their subsequent adoption by the business world. Top world regions have the capacity to attract talent from all over the world, leading to a certain level of AI brain drain in other world regions. The EU's framework programmes have proven effective in building a research network of excellence throughout the Union. In order to keep and attract talent and reduce the risk of becoming mainly a consumer of AI services, the EU needs to play an active role to foster industrial capacity and research excellence and reinforce the academy-industry links. All of this in view of keeping to the fundaments of the European Union, following ethical rules, respecting human rights and striving for an inclusive society. Many challenges rest ahead in the AI landscape. It remains to be monitored how these different roles in the AI landscape will develop in the future.

Possible extensions of this project include the consideration of the ownership structure of the identified economic players, in order to analyze the internationalization of AI enterprises. This additional information on. e.g. the location of the ultimate owner may offer an interesting alternative view of the global AI ecosystem. Furthermore, the analysis of the R&D excellence might benefit from additional indicators of R&D excellence that account for influential capacity, such as citation-related indices. This may also cause notable shifts in the research landscape. The investigation of the way governments support the development of AI could provide additional insights of the AI landscape. Future potential advancements could lie in the broadening of the AI conceptual framework, in order to acknowledge dimensions not explored in the current version of the landscape project. This could be to incorporate questions of ethics in AI, which covers concepts such as trust, fairness and accountability, and have become the focus of interest for academic and policy bodies.

REFERENCES

Atomico. State of European Tech, (2018).

Ding, J. Deciphering China's AI dream. Future of Humanity Institute Technical Report, (2018).

Mas, M., Fernández De Guevara, J., Robledo, J.C., Righi, R., Cardona, M., Samoili, S., López Cobo, M. and De Prato, G. The 2019 PREDICT Key Facts Report. An Analysis of ICT R&D in the EU and Beyond, EUR 29770 EN, Publications Office of the European Union, Luxembourg, (2019):

Righi, R., Samoili S., Lopez-Cobo, M., De Prato G. International ICT Trade Dynamics 2004-2014: an explorative network analysis, DigiWorld Economic Journal, 107(3), pp 69-94, (2017).

Righi, Riccardo, et al. "The AI techno-economic complex System: Worldwide landscape, thematic subdomains and technological collaborations." *Telecommunications Policy*, (2020).

Samoili S., Righi R., Cardona M., López Cobo M., Vázquez-Prada Baillet M., and De Prato G., TES analysis of AI Worldwide Ecosystem in 2009-2018, EUR 30109 EN, Publications Office of the European Union, Luxembourg, (2020).

Statista, Artificial Intelligence, (2017).

WIPO. WIPO Technology Trends 2019: Artificial Intelligence. Geneva: World Intellectual Property Organization, (2019).